

ENVIRONMENTAL ENGINEERING, SIXTH EDITION

ENVIRONMENTAL ENGINEERING, SIXTH EDITION

Environmental Health and Safety for
Municipal Infrastructure, Land Use
and Planning, and Industry

EDITED BY NELSON L. NEMEROW, FRANKLIN J. AGARDY,
PATRICK SULLIVAN, JOSEPH A. SALVATO



WILEY

John Wiley & Sons, Inc.

This book is printed on acid-free paper. 

Copyright © 2009 by John Wiley & Sons, Inc. All rights reserved.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.

Published simultaneously in Canada

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 646-8600, or on the web at www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at www.wiley.com/go/permission.

Limit of Liability/Disclaimer of Warranty: While the publisher and the author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Neither the publisher nor the author shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

For general information about our other products and services, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books. For more information about Wiley products, visit our web site at www.wiley.com.

Library of Congress Cataloging-in-Publication Data:

Environmental engineering. Environmental health and safety for municipal infrastructure, land use and planning, and industry / edited by Franklin J. Agardy, Patrick Sullivan.—6th ed.
p. cm.

Selected and revised from earlier work: Environmental engineering / [edited by] Joseph A. Salvato, Nelson L. Nemerow, Franklin J. Agardy. 5th ed. 2005.

Includes bibliographical references and index.

ISBN 978-0-470-08305-5 (cloth)

1. Municipal engineering. 2. Environmental engineering. 3. City planning.
4. Environmental protection. 5. Factory and trade waste. I. Agardy, Franklin J. II. Sullivan, Patrick J., Ph.D. III. Title: Environmental health and safety for municipal infrastructure, land use & planning, and industry.

TD159.E56 2009

628—dc22

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Doctors Agardy and Sullivan would like to dedicate this sixth edition of *Environmental Engineering* to Nelson L. Nemerow who passed away in December of 2006. Dr. Nemerow was born on April 16, 1923 and spent most of his productive years as an educator and prolific author. He spent many years teaching at Syracuse University, the University of Miami, North Carolina State, Florida International, and Florida Atlantic University. He authored some 25 books dedicated to advancing the art of waste disposal and utilization. His passion was waste minimization and the title of one of his most recent publications, *Zero Pollution for Industry*, summed up more than fifty years of teaching and consulting. A devoted husband and father, he divided his time between residences in Florida and Southern California. Nelson served in the United States Merchant Marine during World War II. His commitment to excellence was second to none.



CONTENTS

PREFACE	xvii
CONTRIBUTORS	xix
CHAPTER 1 INDUSTRIAL SOLID WASTES UTILIZATION AND DISPOSAL	1
<i>Salah M. El-Haggar</i>	
Introduction / 1	
Life Cycle Assessment and Cradle-To-Cradle Concept / 4	
Industrial Waste / 7	
Plastics Industry / 7	
Thermo Plastics / 9	
Thermosets / 12	
Mixed Plastic Wastes / 13	
Plastic and Cork Industry / 22	
Food Industry / 25	
Aerobic Fermentation Process / 25	
Anaerobic Fermentation Process / 29	
Cement Industry / 31	
Utilization through Cleaner Production Techniques / 33	
Industrial Ecology Approach / 34	
Recycling Opportunities / 36	
Final Remarks / 39	
Marble and Granite Industry / 40	
Marble and Granite Waste / 42	
Physical and Chemical Properties of Slurry / 43	

Scrapes / 44
Environmental Impacts and Mitigation / 44
Metal Foundry Industry / 51
Foundry Sand / 53
Uses of Foundry Sand / 54
Iron and Steel Industry / 55
Environmental Impacts / 56
The Problem in Egypt / 58
Potential Utilization of Slag / 58
Final Remarks / 64
Waste Industry / 65
Direct Waste Recycling Industry / 66
Multiple Waste Recycling Industry / 66
Waste Exchange Network Recycling Industry / 67
Environmentally Balanced Industrial Complexes / 69
Multiple Waste Recycling Industry / 70
Mechanical Tests / 71
Environmental Tests / 73
Final Remarks / 75
Disposal of Industrial Wastes / 76
References / 77
Bibliography / 80

CHAPTER 2 RESIDENTIAL AND INSTITUTIONAL ENVIRONMENT

83

<i>Xudong Yang</i>
Substandard Housing and Its effects / 84
Growth of the Problem / 84
Critical Period / 86
Health, Economic, and Social Effects / 88
Appraisal of Quality of Living / 91
APHA Appraisal Method / 91
Census Data / 96
Health, Economic, and Social Factors / 96
Planning / 96
Environmental Sanitation and Hygiene Indices / 97
Other Survey Methods / 97
Health Principles / 99
Minimum Standards Housing Ordinance / 103

Housing Program /	104
Approach /	104
Components of a Good Housing Program /	105
Outline of a Housing Program /	107
Solutions to the Problem /	108
Selection of Work Areas /	110
Enforcement Program /	111
Enforcement Procedures /	114
Housing Form Paragraphs for Letters /	118
Structural Safety /	119
Incomplete Bathroom /	119
No Hot Water /	119
Leaking Water Closet /	121
Floors Not Water Repellent /	121
Exterior Paint Needed /	123
Rotted and Missing Siding /	123
Sagging Wall /	123
Loose Plaster /	124
Leaking Roof /	124
No Gutters or Rain Leaders /	124
No Handrails /	125
Lead Paint /	125
Refuse in Attic /	125
Water-Closet Flush Tank Not Operating Correctly /	125
Garbage Stored in Paper Box or Bag /	125
Dilapidated Garbage Shed /	125
Debris in Yard or Vacant Lot /	126
Dirty Apartment /	126
Overcrowded Sleeping Room /	126
No Window in Habitable Room /	127
Unlawful Third-Floor Occupancy /	127
Unlawful Cellar Occupancy /	127
Clogged Sewer /	127
Unvented Heater /	127
Furnace Flue Defective /	128
Rubber-Hose Gas Connection /	128
Rat Infestation /	128
Roach Infestation /	128
Overflowing Sewage Disposal System /	128

Improperly Protected Well-Water Supply /	129
Major Repairs /	129
Minor Repairs /	129
Obtain at Least Three Estimates /	129
Plumbing /	129
Plumbing Code /	129
Backflow Prevention /	134
Indirect Waste Piping /	137
Plumbing Details /	137
Indoor Air Quality /	137
Causes and Sources of Indoor Air Pollution /	137
Biological Contaminants and Health Effects /	140
Other Contaminants /	141
Ventilation /	147
Respiratory Illness Control /	150
Venting of Heating Units /	151
Mobile Home Parks /	154
Institution Sanitation /	155
Institutions as Small Communities /	155
Hospitals and Nursing Homes /	156
Hospital and Related Wastes /	160
Schools, Colleges, and Universities /	163
Correctional Institutions /	163
Environment Inspection and Report Outline /	167
Day-Care Centers /	169
References /	169
Bibliography /	174

CHAPTER 3	SOLID WASTE MANAGEMENT	177

<i>George Tchobanoglous</i>	
Definition of Terms /	178
Integrated Waste Management /	180
Source Reduction /	180
Recycling and Composting /	182
Combustion (Waste-to-Energy) /	183
Landfills /	183
Implementing Integrated Solid Waste Management /	184
Sources, Characteristics, and Quantities of Solid Waste /	185
Sources of Solid Waste /	185

Characteristics of Solid Waste /	185
Commercial and Household Hazardous Waste /	189
Construction and Demolition Debris /	192
Special Wastes Collected Separately /	193
On-Site Handling and Storage /	195
Low-Rise Residential Areas /	196
Low- and Medium-Rise Apartments /	198
High-Rise Apartments /	198
Commercial and Institution /	199
Solid Waste Collection /	199
Type of Service /	199
Collection Frequency /	199
Types of Collection Systems /	202
Personnel Requirements /	204
Health Issues /	207
Transfer and Transport /	209
Economic Analysis of Transfer Operations /	209
Types of Transfer Stations /	210
Vehicles for Uncompacted Wastes /	211
Transfer Station Siting Issues /	213
Waste Reduction and Materials Recovery /	213
Waste Reduction /	214
Materials Recovery and Recycling /	217
Processing Technologies for the Recovery of Materials /	218
Implementation of Materials Recovery Facilities /	218
Technical Considerations in the Planning and Design of MRFs /	224
Composting /	225
Uses of Compost and Constraints to Its Use /	229
Composting Process /	230
Composting Technologies /	232
Compost Process Design and Operational Considerations /	236
Issues in the Implementation of Composting Facilities /	239
Health Hazards /	240
Sanitary Landfill Planning, Design, and Operation /	242
Sanitary Landfill Planning /	242
Sanitary Landfill Methods /	246
General Landfill Design Issues /	251

- Leachate Generation, Control, and Treatment / 252
- Landfill Gas Generation, Control, and Recovery and Utilization / 258
- Management of Surface Waters / 263
- Landfill Mining / 267
- Landfill Facilities and Equipment for Disposal by Sanitary Landfill / 268
- Landfill Operation and Supervision / 274
- Summary of Recommended Operating Practices / 276
- Site Closure or Conversion / 278
- Incineration / 279
 - Description of Operation of MSW Incinerator / 279
 - Combustion Products and Residues / 281
 - Types of Incinerators (Combustors) / 283
 - Control of the Incineration Process / 286
 - Residue Management / 287
 - Site Selection, Plant Layout, and Building Design / 289
 - Issues in the Implementation of Incineration Facilities / 290
- Hazardous Wastes / 292
 - Definition of Hazardous Waste / 292
 - Legislation / 293
 - Generation of Hazardous Waste / 296
 - Hazardous Waste Management / 300
- References / 305
- Bibliography / 307

CHAPTER 4 AIR POLLUTION AND NOISE CONTROL 309

Robert Jacko and Timothy La Breche

- Air Pollution / 309
 - Health Effects / 310
 - Economic Effects / 311
 - Effects on Plants / 314
 - Effects on Animals / 315
 - Aesthetic, Climatic, and Related Effects / 315
- Sources and Types of Air Pollution / 320
 - Manmade Sources / 321
 - Natural Sources / 321
 - Types of Air Pollutants / 325
- Sampling and Measurement / 326

Particulate Sampling—Ambient Air /	327
Gas Sampling /	329
Smoke and Soiling Measurement /	331
Stack Sampling /	332
Measurement of Materials' Degradation /	333
Environmental Factors /	333
Meteorology /	334
Topography /	338
Air Pollution Surveys /	340
Inventory /	340
Air Sampling /	341
Basic Studies and Analyses /	341
Ambient Air Quality Standards /	342
Federal Standards /	342
Clean Air Act of 1990 /	345
Clean Air Act Amendments of 1997 /	346
Pollutant Standards Index (PSI) /	347
Controls /	347
Source Control /	347
Emission Control Equipment /	351
Particulate Collectors and Separators /	351
Gaseous Collectors and Treatment Devices /	357
Dilution by Stack Height /	358
Planning and Zoning /	360
Air Quality Modeling /	361
Program and Enforcement /	363
General /	363
Organization and Staffing /	365
Regulation and Administration /	365
Noise Control /	367
Definitions and Explanation of Selected Terms and Properties of Sound /	367
Effects of Noise—A Health Hazard /	375
Sources of Noise /	376
Measurement of Noise /	377
Methods for Noise Control /	378
Control of Industrial Noise /	380
Control of Transport Noise /	381
Noise Reduction /	381

Federal Regulations /	384
State and Local Regulations /	387
References /	388
Bibliography /	391
Air Pollution /	391
Noise Control /	393

CHAPTER 5	SURVEYING AND MAPPING FOR ENVIRONMENTAL ENGINEERING	395

<i>Kurt W. Bauer</i>	
Introduction /	395
Importance of Maps /	396
Basic Definitions and Concepts /	396
Foundational Elements for Creation of Maps /	396
Map Projections /	398
Tangent Plane Projection /	398
Lambert Projection /	399
Mercator Projection /	401
Transverse Mercator Projection /	401
Other Projections /	401
The State Plane Coordinate System /	402
Survey Control Networks /	402
The National Geodetic Survey Control System /	403
U.S. Public Land Survey System /	405
Map Requirements for Planning and Environmental Engineering /	407
Desirable Control Survey and Mapping System /	409
Applications of Mapping System /	410
Flood Hazard Area Mapping /	416
Wetland Area Mapping /	416
Public Works Management Information System /	419
Sanitary Sewerage System Attribute Data /	421
Survey Methods /	426
Bibliography /	428

CHAPTER 6	PLANNING AND ENVIRONMENTAL ASSESSMENT	429

<i>Kurt W. Bauer</i>	
Introduction /	429
Definition of Terminology /	430

Criteria for Good Planning /	431
Institutional Structure for Urban Planning /	432
The Comprehensive Plan /	433
The Planning Process /	437
Definition of Planning Area /	438
Inventory and Analysis /	438
Formulation of Objectives and Standards /	443
Identification of Development Requirements /	443
Development and Evaluation of Alternative Plans /	444
Plan Selection and Adoption /	444
Plan Implementation and Policy Development /	445
Public Works Development Process /	447
Outline for a Sewerage Facilities Planning Report /	447
Outline for a Stormwater Management Facilities Planning Report /	453
Outline for a Water Supply Facilities Planning Report /	460
Public Participation /	465
Continuing Nature of Comprehensive Planning Process /	466
Project Planning /	467
Site Planning /	469
Introduction /	469
Site Selection /	470
Site Assessment /	471
Generally Desirable Site Features /	472
Site Inventory /	473
Improvements Needed /	478
Site Design /	478
Land Subdivision /	480
Subdivision Design /	482
Site Selection and Assessment /	484
Alternative Subdivision Design Types /	486
Utility Services /	492
Fiscal Analysis /	494
Program Planning /	494
Operational Planning /	496
Public Health Element of Comprehensive Plan /	497
Role of Engineering /	502
Environmental Assessment and Impact Statements /	503
Environmental Impact Analysis /	505

National Environmental Policy Act (NEPA) /	505
Terminology /	506
Scoping /	508
Recommended Format for Environmental Impact Statement /	509
Content of an Environmental Impact Statement /	510
Selection and Analysis of Alternatives /	514
Comprehensive Assessment /	515
Bibliography /	524
INDEX	525

PREFACE

Today's scientists, engineers, public health workers and physicians face challenges which were predicted, but certainly not expected to emerge this soon and to the magnitude presently occurring. The problems and proposed solutions in this volume cover a broad spectrum of issues including industrial and domestic solid wastes, air pollution and associated global warming, noise pollution and housing.

Many engineering elements go into developing solutions to these problems including the need for more detailed mapping and surveying, developing improved housing codes, including the development of more eco-friendly building materials and greater emphasis on conservation. Issues such as site planning and associated environmental assessments now play a major role in virtually all proposed developments.

New technologies and approaches are constantly evolving and are being implemented in greater scale than ever before. Old landfills are being mined for fuel (gasses), new landfills are designed to prevent waste materials from migrating to groundwater, and new approaches to waste incineration focus on energy recovery and conversion of waste materials into usable materials.

In many developed communities, noise pollution has been identified as a major problem and one sees more and more barriers constructed to suppress noise. Going a step further, home construction codes have led to the development of materials for construction which are not only more eco-friendly but act as a much improved barrier to both noise and heat transfer.

As the earth's population grows, problems of food, water, land, housing, sanitation, medical care and global warming, to name a few, continue to place new challenges on the engineering community. The question always uppermost in our minds is "Are we able to cope?" The answer lies in the knowledge of engineers and the resources necessary to not only meet these challenges, but to address them head on and develop appropriate solutions. This text should help engineers and scientists meet these challenges.

FRANKLIN J. AGARDY
PATRICK SULLIVAN
NELSON NEMEROW

CONTRIBUTORS

KURT BAUER, PE, RLS, AICP Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin, kwbauer@sewrpc.org

SALAH M. EL-HAGGAR Professor of Energy and Environment, Mechanical Engineering Department, The American University of Cairo, Cairo, Egypt, elhaggar@aucegypt.edu

ROBERT JACKO Department of Civil Engineering, Purdue University, West Lafayette, Indiana, jacko@ecn.purdue.edu

TIMOTHY LA BRECHE Department of Civil Engineering, Purdue University, West Lafayette, Indiana

GEORGE TCHOBANOGLOUS, Ph.D. Professor Emeritus of Civil and Environmental Engineering, University of California at Davis, Davis, California, gtchobanoglous@ucdavis.edu

XUDONG YANG Chang-Jiang Professor, Department of Building Science, Tsinghua University, Beijing, China, xudongy@miami.edu

CHAPTER 1

INDUSTRIAL SOLID WASTES UTILIZATION AND DISPOSAL

SALAH M. EL-HAGGAR

Mechanical Engineering Department, The American University in Cairo,
Cairo, Egypt

INTRODUCTION

There are a lot of definitions for the word *industry*. The most generic definition is, “An organized manmade activity that provides goods and services essential for maintaining and developing human life.” As much as there is diversity in human needs and activities, there is also a great diversity in industry. North America Industrial Classification System (NAICS) has classified industries into the following industrial sectors according to their activities:

- Agriculture, forestry, fishing, and hunting
- Mining
- Utilities
- Construction
- Manufacturing
- Wholesale trade
- Retail trade
- Transportation and warehousing
- Information
- Finance and insurance
- Real estate and rental and leasing
- Professional, scientific, and technical services
- Management of companies and enterprises

- Administrative and support and waste management and remediation Services
- Educational services
- Health care and social assistance
- Arts, entertainment, and recreation
- Accommodation and food services
- Other services (except public administration)
- Public administration

Another approach to classifying industries in different Asian and African countries is by their potential environmental impact according to three different categories. The three main categories are white-list industries, “category A,” gray-list industries, “category B,” and black-list industries, “category C.”

White-list industries/projects/establishments have minor environmental impacts. They include the following:

- Textile factories, excluding dying unit and located in approved industrial sites
- Leather and shoe factories situated in approved industrial sites without tanneries
- Rubber and plastic factories situated in approved industrial sites
- Smokehouses producing small quantities (500 Kg or less) of foodstuff per day
- Very small wastewater treatment plants with a capacity of 1,000 person equivalent or less
- The expansion or modification of an existing road that would be immediately carried out to lengthen the road or widen it by 15 percent or less
- Breweries, malt houses, and mineral-water factories situated in approved industrial sites

Gray-list projects or industries for establishments might result in substantial environmental impacts. They include the following:

- Iron foundries and nonferrous metal foundries
- Engine works and machine shops
- Manufacture and assembly of motor vehicles
- Cleaning establishments and commercial operated laundries
- Tanneries with a production of 1 million square feet/year or less
- Pharmaceutical and chemical factories
- Small wastewater treatment plants with a capacity ranging from 1,000 person equivalent to 1 million person equivalent, etc.

Black-list projects or industries for establishments have severe potential impacts. These include the following:

- Iron and steel works with production greater than 150 metric tons/day
- Cement works using dry process and lime works with high capacity (100 metric tons/hour and above)
- Mining minerals in new areas where the mining exceeds a total area of 1,500 acre land
- Pesticide manufacturing plants
- Pulp and paper production
- Lead smelters
- Oil and gas fields development, production, and exploration

A third approach to classify industries into two major sectors: the primary sector and the secondary sector. The primary sector of industry is responsible for converting the natural resources into primary products. The major types of industries that are considered to be primary industry are agricultural industry, mining, fishing, and forestry. Those types of industry prepare the raw material for other industries. The secondary industries take the output of the primary industries and, through processing, manufacturing, and construction provide a finished product ready to be used by the consumer. The secondary sector can be further classified into heavy industries and light industries. Heavy industries include iron and steel industries, marble and granite industries, petroleum and petrochemical industries, industrial equipments, and cement industry. Light industries include textile, clothing, food (including sugar and dairy), oil and soap, chemical and pharmaceutical, pulp and paper, metal finishing, furniture, fertilizers, tanning, electronics, and telecommunication industries.

Whatever the methodology utilized to classify industries within the industrial sector, the most important concern here is that these classifications are usually done to assemble companies into common groups that reflect shared markets and products or to reflect their degree of impact on the environment so that more control or waste utilization could be achieved.

Industry has been an open system of materials flow. People transformed natural materials such as plants, animals, and minerals into tools, clothing, and other products. When these materials were worn out, they were dumped or discarded, and when the refuse buildup bothered the habitants, they simply relocated it, which was easy to do at the time due to the small number of habitants and the vast areas of land.

An open industrial system—one that takes in materials, energy and water, creates products and waste materials and then throws most of these—will probably not continue indefinitely and will have to be replaced by a different system. This system would involve, among other things, paying more attention to where materials end up, and choosing materials and manufacturing processes that generate a more circular flow through recycling concept. Until today, industrial societies have attempted to deal with pollution and other forms of waste largely through pollution control, treatment, or disposal regulations according to life cycle assessment (LCA), following the concept of cradle-to-grave shown

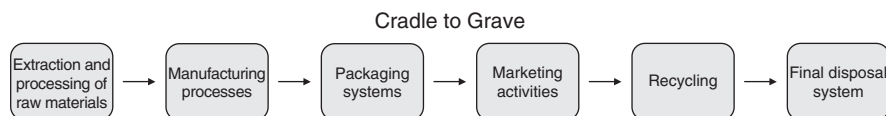


FIGURE 1.1 Traditional life cycle assessment.

in Figure 1.1. Although the “depletion of natural resources” strategy has been partially successful, the high capital and running costs, as well as the depletion of natural resources, cause it to be “unsustainable.” Consequently, LCA should be based on the cradle-to-cradle concept, not cradle-to-grave concept, for industrial activities for conservation of natural resources.¹ The goals of any industry must include the preservation and improvement of the environment, as well as the conservation of natural resources. With industrial activities increasing all over the world today, new ways must be developed to make large improvements in our industrial interactions with the environment.

Industrial development/modernization is characterized by two main trends. The first is the establishment of new technologically competitive industries, and the second is the expansion and renovation of existing industries to increase their productivity. Industrial modernization is characterized by implementing cleaner production techniques to approach industrial ecology and reach cradle-to-cradle concept.¹ Industrial development and industrial modernization require establishing a good management system within an existing establishment such as an environmental management system or ISO 14001 to be able to approach cradle-to-cradle.

The new strategy for conservation of natural resources according to the cradle-to-cradle concept discussed in this chapter will help the developing countries to develop new job opportunities and reduce the cost of products as well as protecting the environment without any further burden to the investors. As for developed countries, this will help them conserve the natural resources so they can stop searching for more and more suitable sites for landfills. According to the Japan Environmental Agency, Japan currently consumes 1,950 million metric tons/year of natural resources and imports 700 million metric tons/year from overseas.² A total of 450 million metric tons of waste (industrial and municipal) are generated per year. Over 60 percent of this waste is either incinerated or landfilled. Current estimates predict that remaining landfill capacity will be exhausted by 2007. As a result, Japan’s government has created a comprehensive program for achieving a *recycling economy* through a series of laws such as the Basic Law for Promoting the Creation of a Recycling Oriented Society and the law for the Promotion of Effective Utilization of Recycled Resources.

LIFE CYCLE ASSESSMENT AND CRADLE-TO-CRADLE CONCEPT

Life cycle assessment (LCA) is one of the very important tools to evaluate the environmental impacts associated with any given industrial activity, from

the initial gathering of raw materials from the earth to the point at which all residuals are returned back to the earth, or cradle-to-grave. LCA results will not be promising for industrial activities that are based on a cradle-to-grave flow of materials. Unfortunately, most manufacturing processes since the Industrial Revolution began are based on a one way, cradle-to-grave flow of materials—starting with the extraction of raw materials, followed by processing, producing, and marketing of the goods, then utilization by consumers, and finally, disposal of waste generation, as shown in Figure 1.1.³ The technological advancements in manufacturing processes and the constantly increasing variety of materials and products have led to a continuous rise in the amounts of waste generated. The cradle-to-grave flow of materials has proven to be just enough to protect the environment if proper and efficient disposal facilities are used. In developing countries, however, improper environmental design and operation of the disposal facility usually cause severe ecological impact as well as depletion of natural resources.

LCA helps identify the impact of the product on the environment throughout its life cycle. The main components of LCA should include the identification and quantification of not only the waste generated through the entire life cycle but also the raw materials and energy requirements throughout the entire life cycle and their environmental impacts.

A lot of work has been done to develop methodologies, guidelines, and benefits for LCA according to the cradle-to-grave concept to protect the environment throughout the life cycle of the product. The International Organization for Standardization (ISO) has developed a series of international standards to cover LCA in a more global sense, such as ISO14040 (LCA—Principles and Guidelines), ISO14041 (LCA—Life Inventory Analysis), ISO14042 (LCA—Impact Assessment), and ISO14043 (LCA—Interpretation). All ISO 1404Xs that are related to LCA are based on cradle-to-grave approach for environmental protection. It is time now to change the LCA-ISO standard from cradle-to-grave to cradle-to-cradle to protect not only the environment but also the natural resources.

LCA is a very important tool to guarantee that there are no harmful impacts on the environment, starting from extracting the raw material (cradle) all the way to the final disposal in a landfill (grave). In other words, the product's design should be selected, in part, according to safe disposal process. This process protects the environment but will deplete the natural resources. By contrast, under a cradle-to-cradle concept, the product's design would be such that materials could be reused or recycled, no wastes would get produced or would be recycled, and accordingly, no negative impacts on the environment would get generated within the closed loop of life cycle of the product, as shown in Figure 1.2. This can be achieved by having industries change their products from a cradle-to-grave design, where the product will eventually get disposed of in a landfill at the end of its life, to a cradle-to-cradle design, where the materials are circulated in a closed loop without losing any natural resources. The environmental and health impacts—as well as the consequences of depleting the natural resources as a result of using traditional treatment, incineration and/or final disposal through

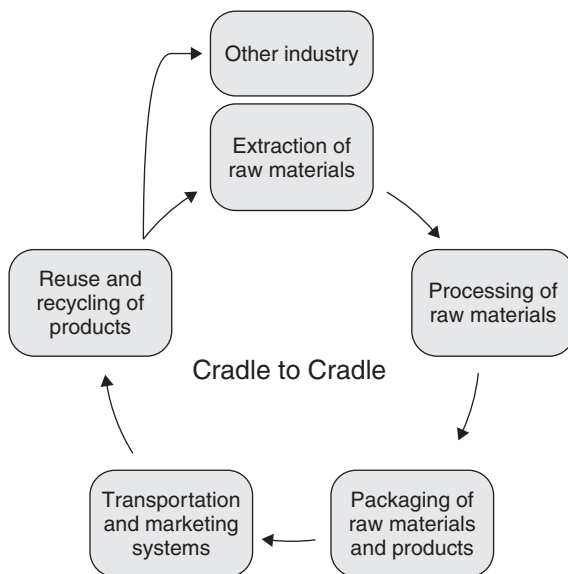


FIGURE 1.2 New life cycle analysis based on the cradle-to-cradle concept.

landfill—are becoming more dangerous, and making sustainable development a more urgent need. Establishing or approaching a new LCA based on the concept of cradle to cradle instead of cradle to grave by a full utilization of raw material, water, and energy is a must for sustainable development.⁴

Braungart and McDonough [2002] proposed a shift from a cradle-to-grave approach where waste products are disposed of in a landfill to a cradle-to-cradle approach, where waste can be used for the production of other products. They recommended the “eco-effective” recycling approach to enable material reuse with high quality. They added that combining different materials in one product prevents the products from being fully recycled. Accordingly, product designers need to plan for the reuse of their products in order to prevent waste generation. This shift in a product’s design approach will require an added responsibility to the producer—extended producer responsibility, or EPR—to be able to recycle the products after its lifetime.

The cradle-to-cradle concept promotes sustainable development in a practical approach, as will be discussed throughout this chapter. It is a system of thinking based on the belief that human endeavors can emulate nature’s elegant system of safe and regenerative productivity, by transforming industries to sustainable enterprises and eliminating the concept of waste.

Natural ecosystems are based on principles that can be adopted by humans in industry. For example, no waste generation—in natural ecosystems, an organism’s waste is consumed by others. This can be applied in industry such that one industry’s wastes are another’s raw material. *Industrial ecology* will be discussed later in this chapter. This is the fundamental concept of eco-industrial parks,

where industries are grouped together to have a continuous flow of material and no waste generation, as in the case of eco-industrial park in Kalundborg, Denmark, and other places worldwide.

Adopting cradle-to-cradle principles creates a cyclical flow of materials, as opposed to the one-way cradle-to-grave concept. The materials consumed in industry resemble the nutrients that flow cyclically in natural ecosystems and can circulate in one of two metabolisms, biological or technical.

According to the cradle-to-cradle concept, products would be made of materials that can be safely manufactured, used, recovered, and reused, while still maintaining their high value throughout their life cycle. This way, valuable used material can be continuously cycled in closed loops and transformed for reuse as other products. By applying the principle of cradle-to-cradle design and transforming industrial systems to a closed-loop system of material flow, not only will this design save the environment from waste generation and negative impacts, but industries can even benefit from the continuous availability of products made of high-value material even after the end of the product's lifetime.

INDUSTRIAL WASTE

The most common industrial wastes generated from industrial sectors are packaging materials using plastic and paper from almost all industrial sectors, organic wastes from food and other industries, dust from the cement industry and the marble and granite industries, glass culets from almost all industries, slag and foundry sand wastes from smelters or foundries, and waste from iron and steel industries.

Closing the loop for sustainable industrial waste management (SIWM) is very important for national development. SIWM means all components within the industrial wastes should be recycled in order to reach the cradle-to-cradle ideal for industrial waste management. This might require development of innovative recycling techniques through universities or research centers or added regulations on producers, such as extended producer responsibility (EPR) to design the products for recyclability. The cradle-to-cradle approach is new worldwide but has been implemented with success at The American University in Cairo (AUC) for most types of wastes, as will be discussed in this chapter.¹

PLASTICS INDUSTRY

Plastics have played a very significant role in industrial development since their invention. If we take a look around us, we will discover that most tools, accessories, packaging, and equipment are made out of plastic, as shown in Figure 1.3. Some of these products have a very short life cycle and are highly consumable. Others might have longer life cycle. These products are used frequently and, in most cases, are then discarded and turned to wastes. Recycling of plastics has become a great industry throughout the world because of its effectiveness and high profits.

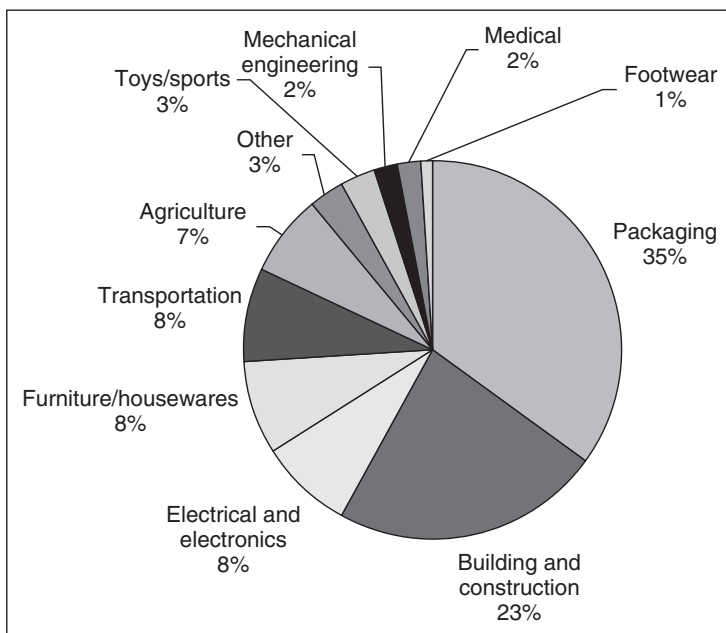


FIGURE 1.3 Uses of plastics by industry. (Source: R. J. Crawford, *Plastics Engineering*, 3rd ed. (Oxford: Butterworth–Heinemann, 1998).)

Even though plastics have a variety of benefits, they are detrimental to the environment. Many of the environmental impacts associated with the production and manufacturing of plastics include the fact that plastic production consumes a large amount of energy and materials, primarily fossil fuel, which, when combusted, emits toxins into the air. It is estimated that 4 percent of the world's annual oil production is used as a feedstock for plastics production and an additional 3-4 percent is used during manufacture.⁵ Plastics production also involves the use of potentially harmful chemicals, which are added as stabilizers or colorants. Many of these have not undergone environmental risk assessment, and their impact on human health and the environment is currently uncertain.⁵ An example of this is phthalates, which are used in the manufacture of polyvinylchloride (PVC). PVC has in the past been used in toys for young children, and there has been concern that phthalates may be released when these toys come into contact with saliva, if the toy is placed in the child's mouth or chewed by the child. Risk assessments of the effects of phthalates on the environment are currently being carried out.⁵ Other environmental impacts of plastics include the extensive amount of water that is needed in manufacturing. Also, the numerous plastic bags that are dispersed as litter in urban areas have also become a plaguing concern. Due to the magnitude of the problem associated with plastic waste, this section focuses on methods and mechanisms to reduce this problem for the betterment of the environment and our lifestyles. A different study concluded that 1.8 metric

tons of oil are saved for every metric ton of recycled polythene produced.⁵ The benefits of recycling plastics are numerous, and thus should be investigated and utilized to the fullest extent.

There are numerous benefits to the recycling of plastics:

- Reduce water usage by 90 percent.
- Reduce CO₂ emissions by two and a half times.
- Reduce energy consumption by two-thirds.⁵

Plastic is divided mainly into two types: thermo plastics and thermo sets. Each type has its own manufacturing processes and its own characteristics. Most of the plastics are considered thermo plastics and can be recycled easily without any problems such as polypropylene (PP), Polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), and polyvinyl chloride (PVC). The other type of plastics is called thermo sets. This type is difficult to recycle due to its chemical composition. As a result, products from this type of plastics are discarded. These include melamine, epoxy, phenolics, and alkyds. It is worth mentioning that most thermo sets have excellent mechanical properties rather than thermo plastics. Thus, it is considered a total loss and waste of energy if these wastes are not recycled.

Thermo Plastics

Most thermo plastics can be recycled; however, there are four types of thermo plastics that are commonly recycled due to their high percentage of usage. Figure 1.4 shows the distribution and the amount of the plastic materials to be

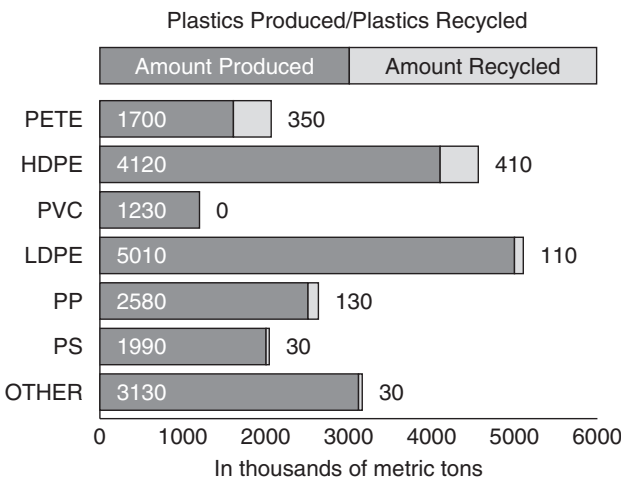


FIGURE 1.4 Amount of thermo plastics produced and recycled in the United States.

recycled every year in the United States. These recyclable materials are arranged from the most frequently used to the least frequently used as follows:

- Polyethylene (PE): it includes high and low density polyethylene
- Polypropylene (PP)
- Polystyrene (PS)
- Polyvinyl chloride (PVC)

Plastic recycling is still a relatively new and developing field of recycling. The postconsumer items made from PET and HDPE resins have found reliable markets within the United States, Asia, and Africa. Applications for recycled plastics are growing every day. Plastic waste can be blended with a certain percentage to virgin plastic to reduce cost without sacrificing properties. Recycled plastics are used to make polymeric timbers for use in picnic tables, fences, and outdoor toys, thus saving natural resources.

About 35 to 50 percent of the total volume of plastic wastes is in the form of packaging wastes, as shown in Figure 1.3. Once rejected, plastics packages gets contaminated and reuse creates a more serious problem, which is the so-called commingled plastics, affecting, in return, the properties of the new recycled products.⁶

The recycling of thermoplastics, or plastics, can be accomplished easily with high revenue. Each type of plastic must go through a different process before being recycled. Hundreds of different types of plastics exist, but 80 to 90 percent of the plastics used in consumer products are (1) PET (polyethylene terephthalate), (2) HDPE (high-density polyethylene), (3) PVC (polyvinyl chloride), (4) LDPE (low-density polyethylene), (5) PP (polypropylene), (6) PS (polystyrene), and (7) others (such as vinyl), as shown in Figure 1.5.

Plastics can be recycled mechanically or chemically. Chemical recycling can solve the problem of composites better than mechanical recycling.⁷ Each one has its own pros and cons for recycling plastics. So, it is very important to decide which techniques will be selected according to the type of waste and the product(s) produced. Mechanical recycling is the most famous recycling technique because of its simplicity to use and ability to be handled by anyone. Mechanical recycling involve a number of processes such as cleaning, sorting, cutting, shredding, agglomeration, pelletizing, and finally reprocessing by injection molding, blowing, or extrusion according to the required products. A simplified schematic diagram for plastic recycling process is shown in Figure 1.6.

Recycled PET has many uses, and there are well-established markets for this useful resin. By far, the largest usage is in textiles. Carpet manufacturing companies can often use 100 percent recycled resin to manufacture polyester carpets in a variety of colors and textures. PET is also spun like cotton candy to make fiber filling for pillows, quilts, and jackets. PET can also be rolled into clear sheets or ribbon for audiocassettes. In addition, a substantial quantity goes back into the bottle market. China is currently using it in the manufacturing process of fiberoptics.

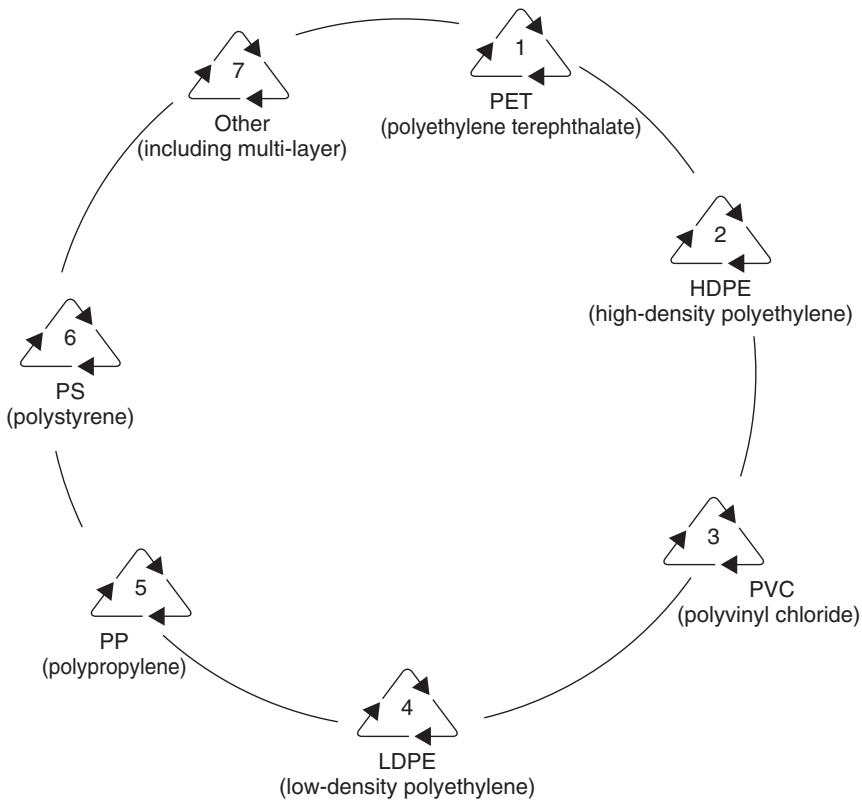


FIGURE 1.5 Coding of thermoplastics.

Some common end uses for recycled HDPE are plastic pipes, lumber, flow-erpots, trashcans, or nonfood application bottles. Some end uses for recycled LDPE are plastic trash bags and grocery sacks, plastic tubing, agricultural film, and plastic lumber.

There are mainly three stages needed to recycle plastics. The initial stage, where the wastes are collected, sorted, separated, and cleaned, is labor intensive, requiring little capital investment and relatively no technical skills. Automating this stage requires high capital and might not be economically visible to be able to continue with recycling. Careful attention of this process is very important to guarantee the economics of recycling. It is always recommended to use plastic coding system shown in Figure 1.5 to sort plastic easily and to enhance the properties of recycled plastic. The second-stage, preprocessing, is where the collected wastes are being prepared for processing. In this stage, the wastes are reduced in size by undergoing cutting, shredding, and agglomeration. The final stage is the processing stage, where mixing, extrusion, blowing, injection, and product manufacturing takes place. All types of thermo plastics can be recycled if they are sorted and properly cleaned, as shown in Figure 1.6.⁸

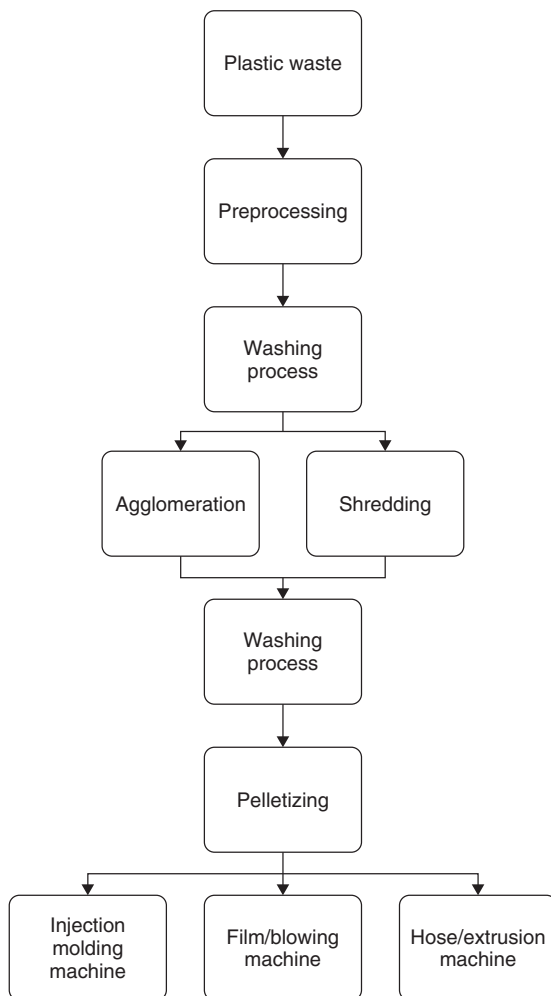


FIGURE 1.6 Process flow diagram for plastic recycling.

Thermosets

Thermosets are the second type of plastic products. Thermosets are formed by aid of the thermo plastics polymers when they covalently bonded to form chains that are interconnected and cross-linked to each other, and they differ from thermo plastics in that once they are formed with the aid of heat or pressure, they cannot be shaped or remelted again. The chain or the cross-link that forms the thermo sets occurs by the aid of some chemical reactions or due to heating or adding of a catalyst. The chemical reactions that are involved in producing the product are not reversible, and that's why it is so hard to reform it again. Once the product is converted from a liquid state to a solid state, it will be referred to as *cure*.

TABLE 1.1 Mechanical Properties for Thermosetting Plastics

Material	Tensile Strength 10 ³ PSI	Tensile Modulus 10 ⁵ PSI	Compressive Strength 10 ³ PSI	Yield Strength 10 ³ PSI
Epoxy	1–3	30–35	25–40	10–60
Unsaturated Polyester	4–50	7–9	15–50	10–80
Phenolics	4–9	16–20	10–40	5–12
Urea formaldehyde	5–13	10–15	25–40	10–18
Melamine	5–13	11–24	20–45	9–23
Alkyds	3–9	5–30	12–38	6–20

It is considered the last step in polymerization. The structure of all thermo sets looks like a network. All the molecules are permanently cross-linked together in a 3D network. This structure makes all thermo sets products maintain their high strength and hardness in relatively high temperatures. In addition, they have high chemical and creep resistance. Table 1.1 shows some of the mechanical properties of thermo sets materials.

Mixed Plastic Wastes

The unrecyclable mixed “different types” plastic waste “plastic rejects” can be collected and sorted into three groups (according to the technology used for size reduction): rigid thermoplastics, thin film thermoplastics, and thermo sets, as shown in Figure 1.7. The plastic rejects can be produced as a result of sorting and screening of mixed solid waste to separate organics from inorganic waste.

**FIGURE 1.7** Mixed plastic waste.

The rejects might have some nonplastic waste, such as glass culets. The first step to recycle plastic rejects is to reduce the size so it can be mixed with other additives and produce a homogeneous mixture.

The size of rigid plastic can be reduced using horizontal axis shredders shown in Figure 1.8, while thin film plastics such as black plastic bags used for trash can be agglomerated using a vertical axis agglomerator machine shown in Figure 1.9 to reduce their sizes. Thermo sets can be crushed using a ball mill, shown in Figure 1.10.

Melamine, the most common type of thermo sets, will be used as an example of thermo set. It is usually found in a form of plates, cups, and other products. In order to recycle Melamine, it must be changed from the rigid forms into a powder form as to be mixed with the thermo plastics. Changing the Melamine into powder can be done through the ball mill machine shown in Figure 1.10.

The rigid thermo plastic waste is fed into a shredder shown in Figure 1.8 for size reduction and then cleaning with caustic soda in a warm-water bath after shredding. The shredder consists of a horizontal drum with four rotating blades opposite to stationary blades shown in Figure 1.8. The shredded plastics pass through a grid into a collecting tray. The sizes of shredded plastics range between 5 to 10 mm in size according to the grid used. The shredded plastics are collected in bags or containers to be further reprocessed or sold. The end products of shredding are irregularly shaped pieces of plastic, depending on the required final product and the type of industry that will use it.



FIGURE 1.8 Shredding “crushing” machine.

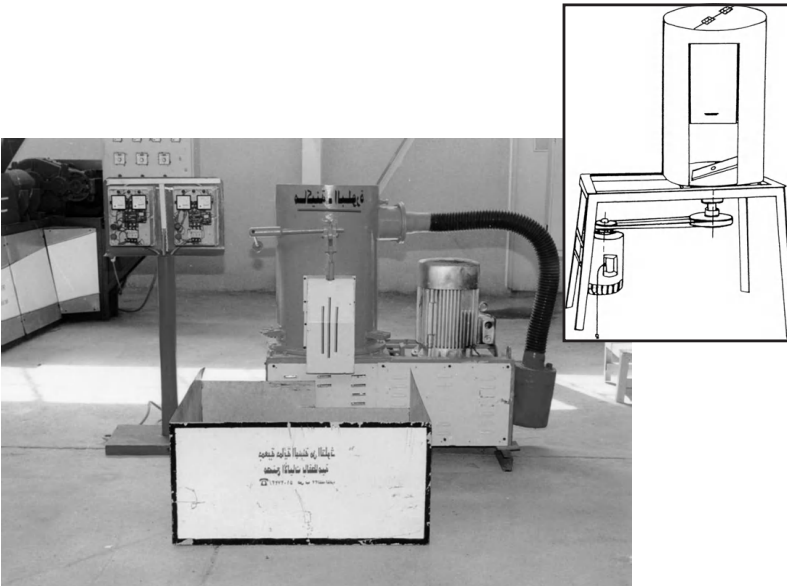


FIGURE 1.9 Agglomeration machine.

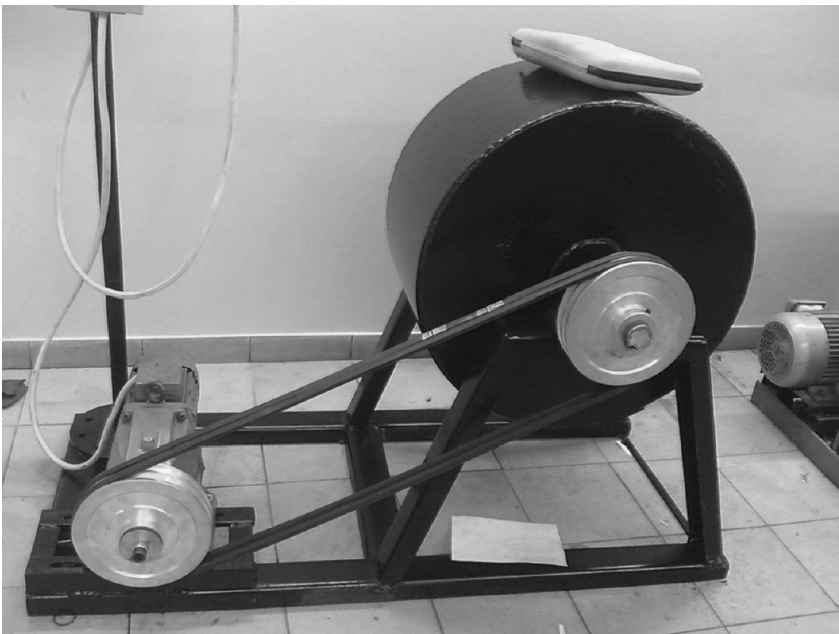


FIGURE 1.10 Ball mill machine.

Shredders can also be used for plastics films, bags, and sheets to be shredded into small pieces, but the energy consumption is more and the produced capacity is less. So, it is recommended to use an agglomerator that cuts, preheat, and dry the plastics into granules. The agglomerator will increase the material's density and quality, which will end up with a continuous flow in the extruder and hence better efficiency. In the process of agglomeration, heat is added indirectly through friction between plastic film and the rotating blade located at the bottom of the agglomerator, shown in Figure 1.9. It is therefore important to rapidly cool the plastic film to obtain the crumb shape desired. This is achieved through adding a small cup of water.

The ball mill machine used to crush thermo sets consists of an electric motor with a gearbox to make speed reduction down to 40 revolutions per minute. The motor is connected with a pulley to translate the motion through a belt to another pulley, which is connected to the shaft. The shaft carries a cylindrical drum in which the melamine or other form of thermo sets is inserted. The drum is welded to the shaft and the shaft is carried by two bearings at both ends of the shaft as shown in Figure 1.10. The balls within the ball mill machine will convert the thermo sets into powder by the gravitational force of the balls. Therefore, the particle size of the powder can be controlled through the number of balls, ball shape, and the time the machine will operate.

The recycling system for mixing plastic wastes as shown in Figure 1.11 consists of a volume-reduction step to reduce the size using agglomerator to cut the plastic bags into small pieces (granules), shredder to cut the rigid plastic into small pieces, and/or ball mill to crush the thermo sets. After the volume-reduction step, a mixture of the three with a certain percentage will be used with some additives to adjust the properties and appearance and heated indirectly to 140° to 240°C depends on the mixture and required applications. The indirect heating process occurs in an indirect heating furnace shown in Figures 1.12 and 1.13. Figure 1.12 demonstrates the vertical axis mixing and heating furnace. Figure 1.13 illustrates the horizontal axis mixing and heating furnace. Both designs guarantee a good mixing of the wastes and additives with indirect heating to produce a homogeneous hot paste for further processing.

The hot paste is then transferred to the mold according to the required shapes and applications. The mold will be placed in a hydraulic press to be pressed into the required shape shown in Figure 1.14. The mold will be cooled for 20 to 30 minutes according to the product.

Product development from mix plastic waste recycling, in general, is a must to maximize the benefits. This leads to a number of economic opportunities to remanufacture products with the recovered material. Just as market forces cannot be ignored when introducing a new product, they must also be taken into account when introducing remanufactured products. The product development from recycling mix plastic waste is more important and challenging than the product development of recycling of one type of plastic because the properties of products from mix plastic waste might change according to the product and required properties. Therefore, continual checking is a must for appropriate

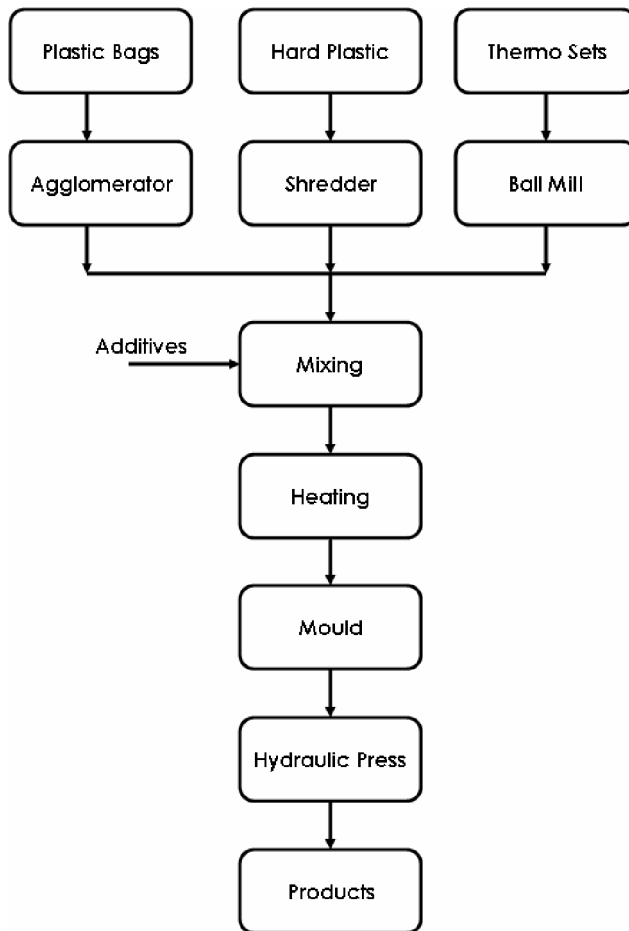


FIGURE 1.11 Process flow diagram for recycling plastic mix.

quality control and quality assurance. A number of products were produced with very good success according to the standard, such as bricks, interlocks, table toppings, wheels, manholes, road ramps, and sheets.

Figure 1.15 show the development of bricks from the solid brick (left) to bricks with holes to facilitate the assembly and disassembly of walls because bricks were made out of plastics with additives and cannot accept mortar to adhere bricks together. Any adhesive materials other than mortar are very expensive, which adds to the cost of the brick. Therefore, it is much more cheaper to bind them together using pins fitted in holes, as shown in Figure 1.15, for easy assembly and disassembly. Another problem of bricks made out of plastic rejects is the weight or density of the brick. The weight of the brick from plastic rejects is heavy compared with ordinary bricks. Thus, the bricks are not economically

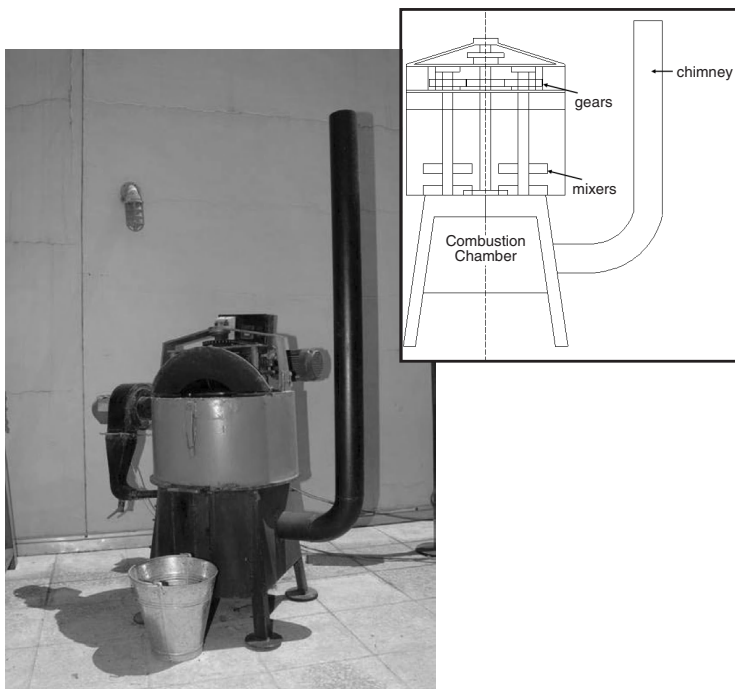


FIGURE 1.12 Vertical axis mixing and heating furnace.



FIGURE 1.13 Horizontal axis mixing and heating furnace.



FIGURE 1.14 Hydraulic press.



FIGURE 1.15 Development of bricks.

profitable when compared to the ordinary bricks, including the cost of adhesives. This type of bricks might have special application other than ordinary walls for construction applications.

Figures 1.16a and 1.16b show another application for plastic rejects that is much more profitable than bricks because it doesn't need adhesives. This new product is interlocks that can be used in pavements of roads, pedestrian gardens,



FIGURE 1.16a Development of interlock.



FIGURE 1.16b Application of interlocks.



FIGURE 1.17 Manhole cover and base.

factory floors, backyards, and so on. The interlocks made out of plastic rejects with additives proved to have higher strength according to ASTM standard than the normal interlock made out of cement, aggregate, and sand.⁹ Figure 1.17 shows another very important application (manhole cover and base) that is much more profitable than interlock. A manhole or maintenance hole (sometimes called an inspection cover) is the top opening to an underground vault used to house an access point for making connections or performing maintenance on underground and buried public utility and other services including sewers, telephone, electricity, storm drains, and gas. The manhole cover is designed to prevent accidental or unauthorized access to the manhole. Manhole bases and covers are usually made out of case iron or reinforced fiber plastic (RFP), or can be produced out of plastic rejects. The main advantages of manholes made out of plastic rejects are less cost, less energy consumption, durability, and being acid proof. The weight can be adjusted by adding sand to the mix. Sand will increase the required specific weight up to a certain percentage (28 percent) to avoid any strength impact. The carrying load for 40 cm manhole is 1.8 metric tons, which is slightly higher than fiber-reinforced plastic (FRP) manholes and can be increased by adding steel bars.

Manhole covers are round because manholes are round; they could also designed with any geometry according to the required dimensions. Round tubes are the strongest and most material-efficient shape against the compression of the earth around them. A circle is the simplest shape whereby the lid cannot fall into the hole. Circular covers can be moved around by rolling. And they need not be aligned to be replaced.

Manholes are one of the very important applications to be produced from rejects. They can be used instead of ordinary cast-iron manholes and can be



FIGURE 1.18 Partitions made out of rejects.

made with different geometry and dimensions. Manhole bases and covers proved to be an excellent product out of rejects from social, economical and technical points of view.

Another application made out of rejects is sheets with any dimension and thickness, according to demand and needs. The partition shown in Figure 1.18 is 120 cm by 120 cm with 10 mm thickness to replace corrugated sheets or plywood. The sheets made out of rejects are much cheaper and more durable than corrugated sheets or plywood. These sheets can replace MDF (medium fiber boards) as well in many applications. Also, they can handle all weather conditions such as high/low temperatures, wind speed, and humidity.

PLASTIC AND CORK INDUSTRY

The objective of this case study is to recycle the PVC plastic offcuts from slippers production to produce new slippers from scrap PVC plastics and approach cradle-to-cradle design. This case study was implemented in a company located in Sohag, Egypt (upper Egypt), which produces around 1,500 metric tons/year of PVC sheets, cut to make footwear. The cutting and printing process used around 70 percent of the PVC sheet with the remaining 30 percent being discarded as scrap. In total, 450 metric tons of scrap PVC were sent to the local landfill each year.

This case study was prepared and implemented in cooperation between El-Ameer for plastic and Cork Company and Egyptian Environmental Affairs Agency (EEAA) SEAM project. The company produces 1,050 metric tons of

products every year from 1,500 metric tons of raw material. This case study led to the recycling of 450 metric tons of scrap plastic to produce slippers. Capital investment was \$100,000 and resulted in annual savings of \$560,000, providing a payback in two months.

The process flow diagram to produce final product from raw material, as well as final product from recycled waste, is shown in Figure 1.19. A number of trials were undertaken to develop the optimum recipe, as shown in Table 1.2. Table 1.2 shows the recipes used for producing PVC sheets using new PVC and that for recycling scrap PVC.

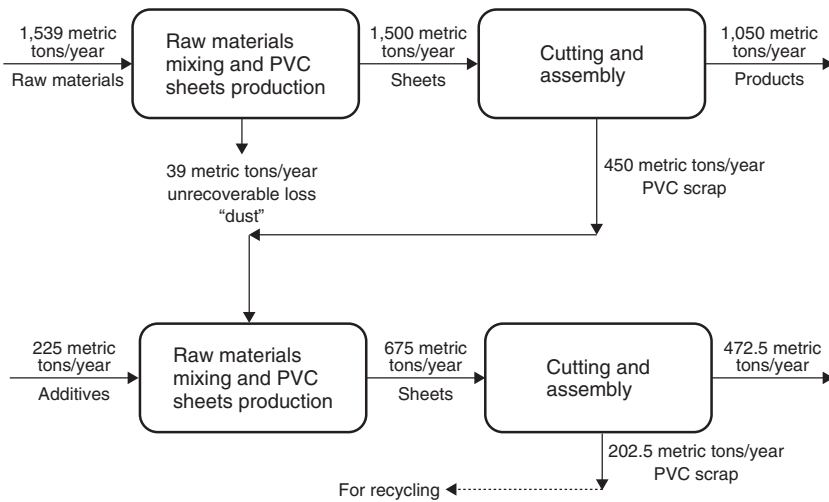


FIGURE 1.19 Process flow diagram for plastic and cork industry according to cradle-to-cradle concept.

TABLE 1.2 Raw Material Recipes Using Raw Material and Scrap PVC

No.	Raw Material	Using New PVC kg/batch	Using Scrap PVC kg/batch
1	PVC	45	—
2	Scrap PVC	—	50
3	Calcium carbonate	45	10
4	Rubber (NBR)	10	12
5	Zinc stearate	2.5	1.5
6	Fillers	1	—
7	Polyzar	1.5	—
8	Compom (azodicarbonamide)	1.5	1.5
9	DOP oil	2	—
10	Color	1	0.6
11	Sulfur, agriculture grade	0.35	0.05

The sheet-making process had to be modified to account for use of scrap plastic. In the case of new plastic, sheets formed are required to be cooled before imprinting and cutting. When scrap plastic is used in the recipe, the viscosity of sheets requires that hot sheets are directly subjected to imprinting and cutting. To cater for this, a new mechanical press was installed that could imprint and cut directly on the hot sheet.

A comparison of the costs of batch processing for raw PVC and recycled plastic scrap is given in Table 1.3. Average costs using new PVC is \$0.95 per Kg against \$0.46 per Kg using the scrap plastic. Figure 1.20 shows two slippers, one made from raw PVC and another one made from recycled PVC.

TABLE 1.3 Cost Comparison between Production with New and Scrap PVC

No.	Raw Material	Using New PVC		Using Scrap PVC	
		kg/batch	\$/batch	kg/batch	\$/batch
1	PVC	45	63	—	—
2	Scrap PVC	—	—	50	—
3	Calcium carbonate	45	2	10	0.4
4	Rubber (NBR)	10	17.5	12	21
5	Zinc stearate	2.5	3.5	1.5	2.1
6	Fillers	1	0.35	—	—
7	Polyzar	1.5	0.66	—	—
8	Compom (azodicarbonamide)	1.5	5	1.5	5
9	DOP oil	2.0	3.2	—	—
10	Color	1	6.32	0.6	3.8
11	Sulfur, agriculture grade	0.35	0.37	0.05	0.05
12	Electricity		0.1		0.1
13	Water		0.1		0.1
14	Labour		1.75		1.75
15	Fuel		1		1
Total Cost / Batch		110 Kg	104.85	76 Kg	35.3

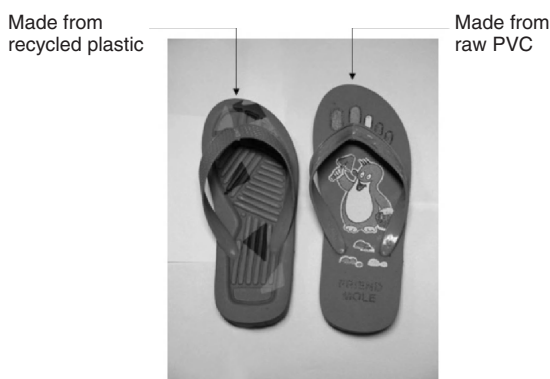


FIGURE 1.20 Slippers made from raw PVC and recycled plastic.

FOOD INDUSTRY

Food industry can be classified into a number of industries such as fruit and vegetable industry, vegetable oil industry, dairy industry, canning industry, beverage industry, meat industry, and so on. Most of these industries typically generate large volumes of effluents and solid waste. The main solid wastes generated from food industry are organic wastes, including discarded seeds, fruits, and vegetables. Odor problems can occur with poor management of solid wastes and effluents, when onions are processed, and when ready-to-serve meals are prepared, for example. So, it is very important to deal with such organic waste with full understanding of the processes, requirements, and hygiene.

Food waste recycling can take place through aerobic fermentation (composting) or anaerobic fermentation (biogas) processing. Composting is a process that involves biological decomposition of organic matter, under controlled conditions, into soil conditioner or organic fertilizer through aerobic fermentation.¹⁰ While anaerobic fermentation process involves biological decomposition of organic waste under controlled conditions to produce fertilizer and biogas.¹¹

Aerobic Fermentation Process

Aerobic fermentation is the decomposition of organic material in the presence of air. During the composting process, microorganisms consume oxygen, while CO_2 , water, and heat are released as result of microbial activity, as shown in Figure 1.21. Four main factors control the composting process: moisture content, nutrition (carbon: nitrogen ratio), temperature, and oxygen (aeration).

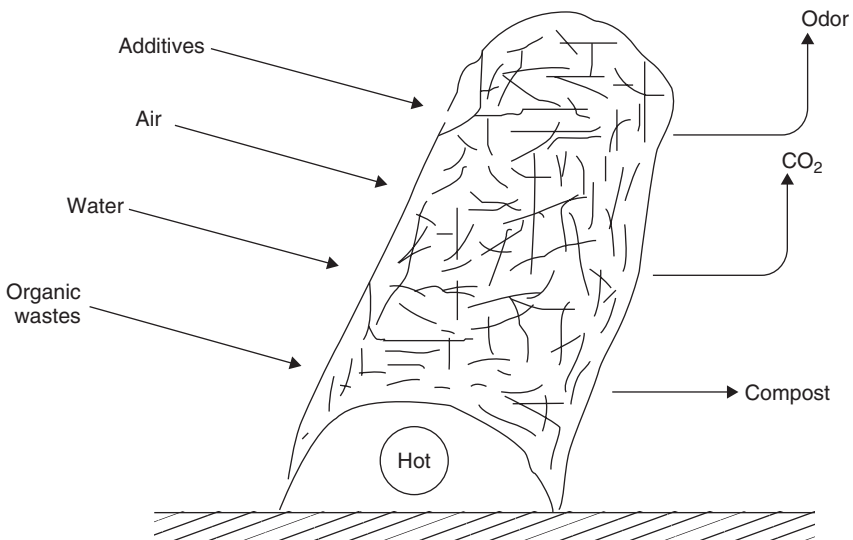


FIGURE 1.21 Composting process.

1. *Moisture content.* The ideal percentage of the moisture content is 60 percent.¹⁰ The initial moisture content should range from 40 to 60 percent, depending on the components of the mixture. If the moisture content decreases less than 40 percent, microbial activity slows down and became dormant. If the moisture content increases above 60 percent, decomposition slows down and odor from anaerobic decomposition is emitted.
2. *Carbon to nitrogen ratio.* Microorganisms responsible for the decomposition of organic matter require carbon and nitrogen as a nutrient to grow and reproduce. Microbes work actively if carbon to nitrogen ratio is 30:1. If the carbon to nitrogen ratio exceeds 30, the rate of composting decreases. Decomposition of the organic waste material will slow down if C:N ratios are as low as 10:1 or as high as 50:1.

However, in order to compensate the low nitrogen content of organic waste, nitrogen should be added to obtain more effective compost. To increase the C:N ratio in rice straw as an agricultural waste, for example, these techniques may be implemented:

- *Chemical additives:* This method could be done by the addition of either uric acid, or urea or ammonia.
 - *Natural additives (manure):* In this technique, nitrogen is obtained from animal or poultry manure.
3. *Temperature.* The activity of bacteria and other microorganisms produce heat while decomposing (oxidize) organic material. The ideal temperature range within the compost to be efficient varies from 32°C to 60°C. If the temperature is outside this range, the activity of the microorganisms slows down, or might be destroyed. A temperature above 55°C while composting kills the weeds, ailing microbes, and diseases, including shengella and salmonella; this help to reduce the risk of diseases' transmission from infected and contaminated organic wastes.
 4. *Oxygen (aeration).* A continuous supply of oxygen through aeration is a must to guarantee aerobic fermentation (decomposition). Proper aeration is needed to control the environment required for biological reactions and to achieve the optimum efficiency. Different techniques can be used to perform the required aeration according to the composting techniques. The most common types of composting techniques are natural composting, passive composting, forced composting, and vermi composting.

Natural Composting Piles of compost are formed along parallel rows, as shown in Figure 1.22 and are continuously moisturized and turned. The distance between rows can be determined according to the type and dimension of the turning machine.¹² Piles should be turned about three times a week at summer and once a week at winter to aerate the pile and achieve homogenous temperature and aeration throughout the pile. This method needs large surfaces of lands, many workers, and running cost.

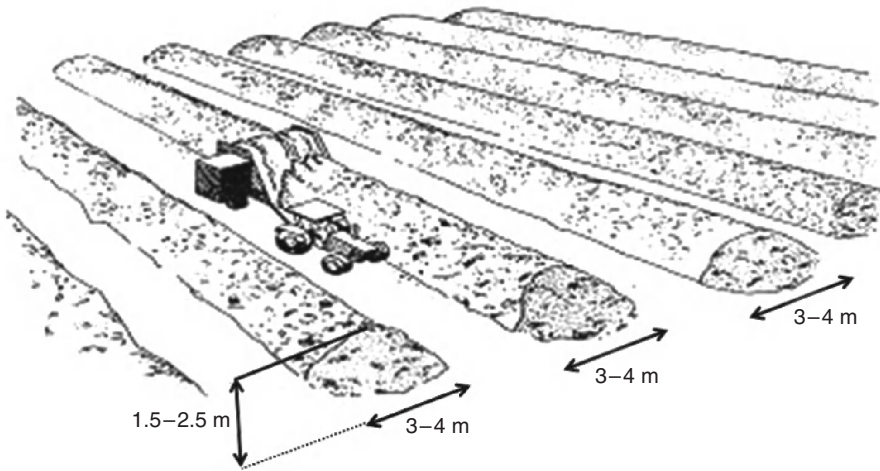


FIGURE 1.22 Natural composting process. (Source: F.R. Gouin et al., “On-Farm Composting,” Northeast Regional Agricultural Engineering Services, NRAES-54, Cooperative Extension, 1993.)

Passive Composting Parallel rows of perforated high-pressure PVC piping are placed at the bottom, on which compost is added above it. The pipes are perforated with 10 cm holes to allow air to enter the composting piles, as shown in Figure 1.23. The pipe manifold helps in distributing the air uniformly. Air flows through the ends of the pipes to the compost. This system is better than the natural system because of the limited flow rates induced by the natural ventilation. This method needs limited surfaces of lands, less running cost, and does not need skilled workers. This method is recommended for cost effectiveness; it is the most economic aeration method. Therefore, it is the most suitable method for developing communities that want to achieve maximum benefit from the food recycling with the minimum capital investment and a good-quality soil conditioner. The soil conditioner can be converted into organic fertilizer by adjusting the NPK ratio (nitrogen: phosphorous: potassium) through additives.^{13,14}

Forced Aeration Forced aeration works like the previous system except that the ends of plastic pipes are connected to blowers that force (or suck) the air through the compost with a specific rate and velocity. Otherwise, if the air rate exceeded a certain limit, the temperature inside the compost pile would decrease, affecting the microbial activity. Also, the air velocity during the day should always be higher than at night. This system needs higher technology with air velocity control and more energy consumption. That is why it is less economic compared to the other two systems and it is not recommended for rural or developing countries that want to make profit out of all recycling processes. This method needs capital investment, skilled workers, and running cost.

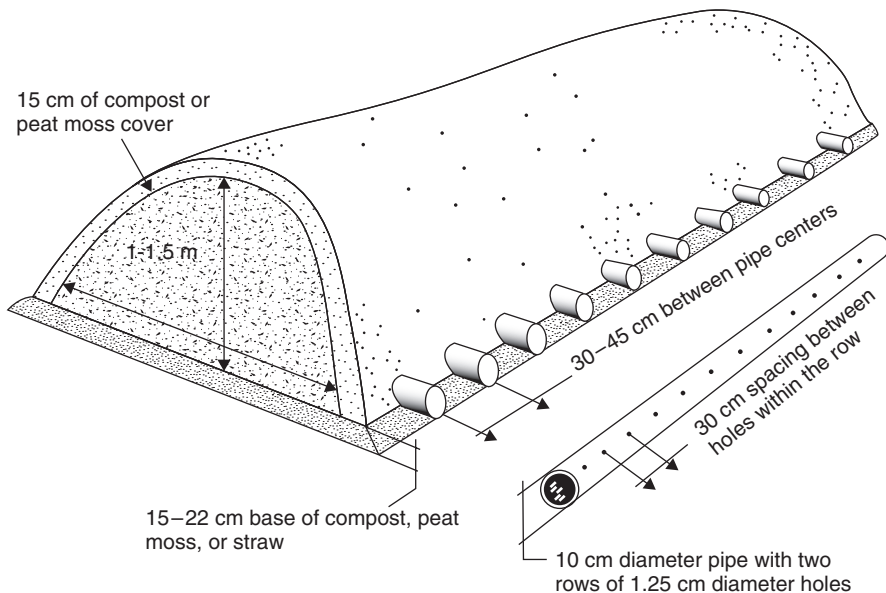


FIGURE 1.23 Passive aeration process. (Source: F.R. Gouin et al., "On-Farm Composting," Northeast Regional Agricultural Engineering Services, NRAES-54, Cooperative Extension, 1993.)

Vermi Composting It is an ecologically safe and economic method that depends on the worms' characteristic of transforming the organic wastes to fertilizers that are extremely beneficial to earth. There are two types of earthworms that are used due to their insensitivity to environmental changes:

1. The red wiggler (*Eisensia Foetida*)
2. The red worm (*Lumbricus Rebellus*)

Under suitable aeration, humidity, and temperature, worms feed on organic wastes and expel their manure (worm castings) that breaks up the soil, providing it with aeration and drainage. It also creates an organic soil conditioner as well as a natural fertilizer. Worm castings have more nutrients than soil conditioner in terms of nitrogen and phosphorous.

A mature worm will produce a cocoon every 8 to 10 days that contains an average of eight baby worms that mature in approximately 70 days, and in one year each 1,000 worms produce 1,000,000 worms.¹⁵

Vermi composting can be used in houses easily by using a special container (worm bin) that can be placed anywhere that is not subjected to light such as kitchen, garage, and basement. The organic waste is put in this container, and the worms with them. The worms are odorless and free from disease.

Anaerobic Fermentation Process

Biogas conversion is the anaerobic fermentation of organic matter (organic waste) by microbiological organisms under controlled conditions. The aim of fermentation is to produce methane (biogas) that can be used as an energy source. The fermentation process is done anaerobically—that is, without the presence of air—to allow the bacteria to perform the breakdown. The byproduct of fermentation consists of about 60 percent CH_4 and 40 percent CO_2 , along with traces of H_2 , N_2 , and H_2S . Biogas is produced by means of a digester, which is a device used to process organic waste and produce methane. There are many types of digesters available; however, the two most famous designs are the Chinese fixed dome (constant volume) and the Indian floating cover (constant pressure). A combination of both could also be designed.

Chinese Fixed Dome The Chinese fixed-dome design is one of the oldest digester designs dating back to the 1930s. It consists of an underground fermentation chamber made of bricks and a dome-shaped tank on top of the chamber. The biomass mixture is entered through the inlet and fermentation occurs, with the gas rising to fill the tank and the slurry exiting through the outlet. This design combines the digester with the holding tank where the gas is stored. The gas then passes through an outlet pipe at the top, as shown in Figure 1.24.

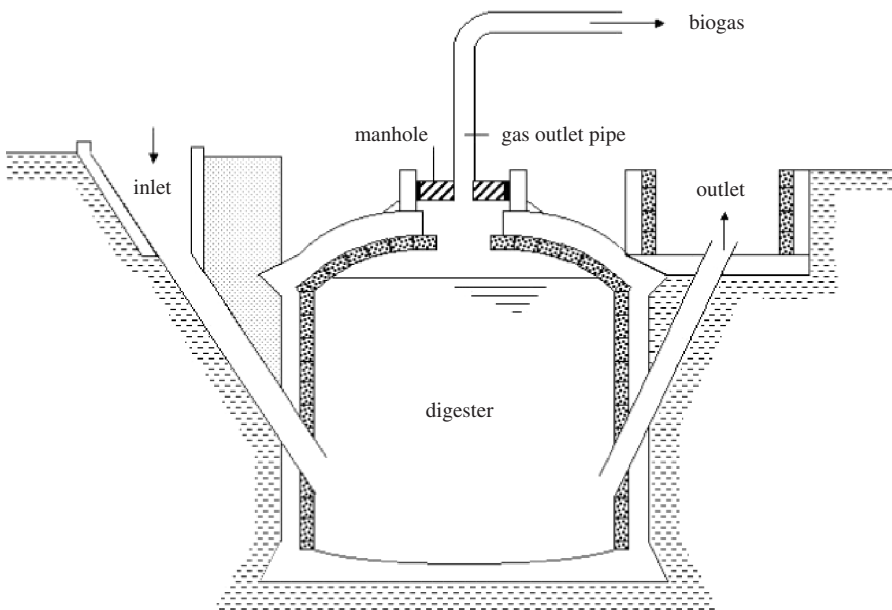


FIGURE 1.24 Chinese fixed-dome digester. (Source: Matthias Plöchl and Monika Heiermann, “Biogas Farming in Central and Northern Europe: A Strategy for Developing Countries?” 2006, cigr-ejournal.tamu.edu/submissions/volume8/Invited27Feb2006.pdf.)

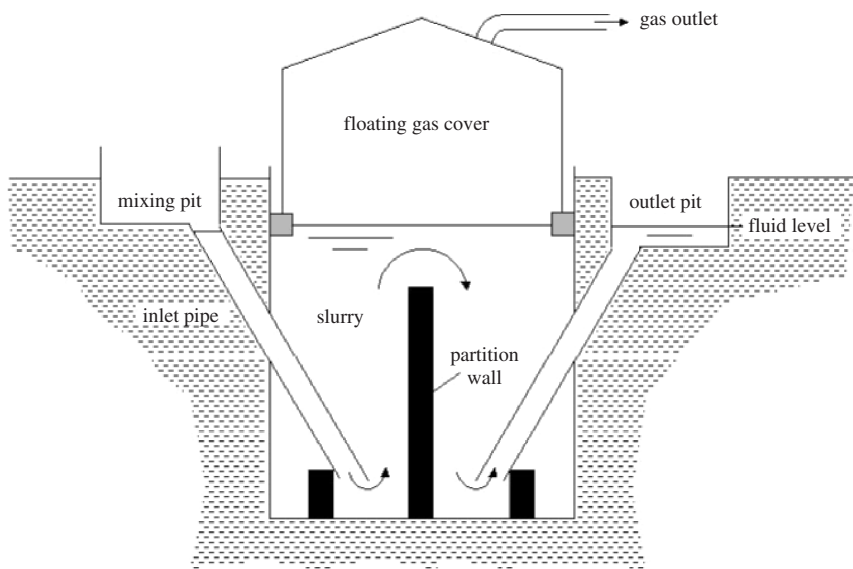


FIGURE 1.25 Indian floating cover. (Source: Matthias Plöchl and Monika Heiermann, “Biogas Farming in Central and Northern Europe: A Strategy for Developing Countries?” 2006, <http://cigr-ejournal.tamu.edu/submissions/volume8/Invited27Feb2006.pdf>.)

Indian Floating Cover The Indian floating-cover design is shown in Figure 1.25. This design was first presented as the Janata design but was further developed in 1984 to the Deenbandhu model, with both models based on the Chinese dome design. This model employs the same principles as the Chinese fixed-dome digester, with the biomass mix entering through the inlet and decomposed in the underground brick chamber. However, in this design the cylindrical gas tank is a floating cover that is separate from the mixing tank. The slurry left from the fermentation process is used as a fertilizer. The mixing process should occur at a high temperature range (30° to 40° or 50° to 60°C), and could take up to two months, depending on the quantity of biomass processed.¹⁶

TABLE 1.4 Uses of Biogas as Energy Sources

Applications	1 m ³ Biogas Equivalent
Lighting	Equal to 60 to 100 W bulb for 6 hours
Cooking	Can cook 3 meals for a family of 5 to 6
Fuel replacement	0.7 kg of petrol
Shaft power	Can run a 1 horsepower motor for 2 hours
Electricity generation	Can generate 1.25 kilowatt hours of electricity

Source: Practical Action, “Biogas And Liquid Biofuels,” 2006, www.itdg.org/docs/technical_information_service/biogas_liquid_fuels.pdf.

Biogas can be used in several applications as an energy source, ranging from light bulbs to internal combustion engines. It has an energy content of about 5,000 Kcal/m³. Some of the uses of biogas as an energy source are shown in Table 1.4.

CEMENT INDUSTRY

The cement industry is an important resource for development, and it is an intensive energy-consuming industry. It produces significant releases to the environment, primarily as airborne emissions such as dust emissions (cement bypass dust) and gaseous emissions of NO_x, SO_x, CO_x. It plays an essential role in the international market because cement, which is the most important ingredient of concrete, is one of the most dynamic products that directly contribute to the construction industry. Therefore, the cement industry is necessary for sustainable development in any country and can be considered the backbone for development.

Cement is a controlled chemical combination of calcium, silicon, aluminum, iron, and small amounts of other ingredients.¹⁷ Lime, which can be extracted from limestone, shells, or chalk, constitutes 60 to 67 percent, and silica constitutes 17 to 25 percent, while alumina and iron oxide constitute the remaining small percentage.¹⁷ According to Van Oss and Padovani, the chemical composition of a typical Portland cement clinker is mainly four oxides: calcium oxide or lime (CaO), about 65 percent; silica (SiO₂), about 22 percent; alumina (Al₂O₃), about 6 percent; and iron oxide (Fe₂O₃), about 3 percent.¹⁸

These elements are found in a wide variety of raw materials, and they are also found in byproducts of different industries such as blast-furnace slag from the iron and steel industry and fly ash from the electric power industry. From 115 operating plants reporting in the Portland Cement Association, 45 plants used blast furnace or iron slag as a raw material and over 40 plants used fly ash or bottom ash from electric power plants as an alternative raw material.¹⁷

Input materials for the cement industry are natural resources that are extracted from earth and have no negative effects on the environment. These materials are limestone, clay, and sand. Meanwhile, the final product is also an environmentally friendly product that is composed primarily of calcium silicate.¹⁷ This means that the environmental impacts of the cement industry is associated with the process rather than with the materials themselves.

A closer look into the production process of cement will provide us with an insight of how the production system works; further, this will enable us to determine and identify potential sources of emissions and wastes. There are four main process routes in the manufacturing of cement: the dry, semi-dry, semi-wet, and wet process.¹⁹ According to World Business Council for Sustainable development, common to all four processes are the following subprocesses:²⁰

- Substances containing lime are quarried or shipped in.
- The raw materials are crushed into a fine powder to facilitate mixing and blending.

- The fine mixture is heated up to a temperature of 1430° to 1650°C in large rotating cylinders known as *cement kilns* to produce clinker.
- Then the clinker is cooled down and gypsum is added to it. The mixture is then ground into fine powder to form Portland cement.
- A large percentage of the final powder cement is stored in silos to be further transported or shipped, while a small percentage is packaged in 50 kg sacks.

Within the production process of cement, there are two different types of process methods, referred to as *wet* and *dry*. The major difference between the two types is the medium used to mix the powdered raw materials prior to heating, and the amount of moisture content in the materials entering the kiln. Karstensen added that between these two ends of the spectrum, there are semi-wet and semi-dry processes.¹⁹ In the wet method, water is added to the raw materials after milling to facilitate thorough mixing, and the mixture is added to the kiln as slurry containing 30 to 40 percent water.¹⁷ In the dry method, the powders are generally blended in a silo using compressed air. If the material entering the kiln is wet or has a high moisture content, this will require more energy and more time for driving off water. The wet process was the dominant older technology, because, in the age of abundant cheap energy, it was cheaper to burn more fuel and add length to the kiln than to add extra devices.¹⁷

Nowadays, kilns use the dry method. The dry method provides substantial energy savings, as well as a higher throughput. However, the energy advantages of the dry process were more fully realized with the addition of pretreatment equipment to condition the powdered raw materials before their introduction into the kiln.^{17,20} A further development, called a *precalciner*, pumps more heat into the pretreatment phase, often combining some additional fuel with air from the clinker cooling stage, which has thus been preheated. The precalciner system is the most energy-efficient arrangement, and also has the highest throughput, with the shortest kiln (PCA).

Emissions may come from different stages during cement production processes, depending on the raw materials, preparation procedures, kiln type, and emissions control systems used.²⁰ The largest volume substances emitted during the production of cement are carbon dioxide, particulate matter (dust), oxides of nitrogen, and sulfur dioxide.

Dust and particulate matter include emissions of coarse dust, fine dust, soot, particles, and aerosols.¹⁷ The emission of dust, particularly from kiln stacks, has been the main environmental concern in cement manufacture.¹⁹ During the manufacturing steps of cement, exhaust gas passes through the fine material, resulting in a dispersed mixture of gas and particulates. According to PCA, the product is a fine powder, and various process steps involving grinding, both of the input materials and the final product, have the tendency to emit fugitive dust. Therefore, particulate control systems on exhaust air from the clinker cooling and grinding processes produce a waste material known as *cement kiln dust* (CKD).

Reduction and control of dust emissions in a modern cement plant requires investments and adequate management practices. Dust emissions from cement kilns have been reduced dramatically over the last two to three decades due to regular improvements in design and operation, including increased use of modern dedusting equipment such as electrostatic precipitators or bag filters.

Kiln dust collected from the gas cleaning devices is highly alkaline and may contain trace elements such as heavy metals corresponding to the contents in the source materials.^{19,20} Usually, kiln dust is completely returned to the process either to the kiln system or to the cement mill, only in rare cases, it is not possible to recycle kiln dust or bypass dust completely in the process.¹⁹ This residual dust is disposed of on a controlled landfills or is treated and sold to other industries as additive for waste stabilization or as fertilizer.²⁰

The most popular way of disposal of the cement bypass dust is landfilling, which—to be done properly with all the required lining and covering—costs a lot of money and still pollutes the environment and depletes the natural resources. That is why proper and effective disposal or reuse of cement bypass dust is always one of the main concerns for both the cement industry and environmental protection. The chemical analysis for the bypass dust is shown in Table 1.5.

Utilization through Cleaner Production Techniques

Treatment or proper disposal of wastes to be able to comply with environmental protection regulations has always been considered as an additional cost that has no return to industry or community, which will also have a bad effect on the environment one way or another—its cost sometimes represents a significant portion of the total cost of the produced product, which is passed on to consumers or deduced from the profits of the industry resulting—either way—in an indirect waste of money.

The core element of cleaner production techniques is prevention versus clean-up or end-of-pipe solutions to environmental problems. In other words, its core element is the establishment of a safe sustainable environment yet doing

TABLE 1.5 Chemical Analysis of Cement Bypass Dust

Chemical Formula	Percentage
SiO ₂	9.0–13.0
Al ₂ O ₃	3.0–4.0
Fe ₂ O ₃	2.0–2.5
CaO	45.0–48.0
MgO	1.7–1.9
SO ₃	4.0–11.0
Na ₂ O	3.0–8.0
K ₂ O	2.0–6.0
Cl	4.0–13.0

it the most efficient way to avoid any unnecessary cost. It is considered a new and creative approach toward products and production processes.

Cleaner production focuses on reducing the use of natural resources, thus minimizing the waste generated from the process. It also stresses preventing these wastes at the source by the use of cleaner production techniques, which does not mean changing processes, as a process may be made “cleaner” without necessarily replacing process equipment with cleaner components. It can simply be done by changing the way a process is operated. Some people might suggest changing the technology or process from dry technology to wet technology to reduce the amount of cement bypass dust as one of the cleaner production techniques. This is true from the bypass dust point of view only, but wet process will increase the energy consumption and the amount of fuel consumed. This will lead to more consumption of natural resources, more air pollutant emitted to the atmosphere, more air pollution control devices installed, and more money spent in terms of capital cost and running cost. Others might think of recycling the bypass dust as one of the cleaner production technique options. This option might be cost effective if the product from the recycling process is competitive with similar product in the market from the quality and price point of views.

Therefore, cleaner production has many benefits if managed properly; it can reduce waste disposal cost, raw material cost, and the environmental impact of the business, and improve profitability and worker safety. It can also improve the public relations and image, thus also improving the local and international market competitiveness. It is simply a win–win concept, and the challenge that rises here is how to achieve cleaner production in an appropriate manner. The proper approach to tackle this challenge is: (1) source inventory (Where are wastes and emissions generated?), (2) cause evaluation (Why are wastes and emissions generated?), (3) option generation (How can these causes be eliminated?). Knowing the answer of these questions and achieving a proper cleaner production can be made using the six-step organized approach:

1. Simply getting started and taking action toward the issue
2. Analyzing process steps, inputs, outputs (flows and emissions)
3. Generating cleaner production opportunities
4. Selecting cleaner production solutions that fit your environment and that you're capable of doing
5. Implementing cleaner production solutions
6. Sustaining cleaner productions

Following this simple, logical approach, one can simply help alleviate the problems of environmental pollution with significant economical benefits.

Industrial Ecology Approach

Under what we may call the same umbrella of cleaner production, a philosophy/strategy/framework of industrial ecology came to life.²¹ However,

most definitions of industrial ecology include similar attributes with different emphases, and these attributes include the following:

- A systems view of the interactions between industrial and ecological systems
- The study of material and energy flows and transformations
- A multidisciplinary approach
- An orientation toward the future
- An effort to reduce the industrial systems' environmental impacts on ecological systems
- An emphasis on harmoniously integrating industrial activity into ecological systems
- The idea of making industrial systems emulate more efficient and sustainable natural systems

The concept of industrial ecology beyond already existing practices is to reduce negative impacts of industrial using a systems-oriented approach and linking with natural ecosystems in a twofold manner:

1. *Analogy*: Natural systems are seen as a "... model of highly efficient use of resources, energy, and waste," which industrial systems should try to adopt.²² This is the same idea that had been introduced and discussed in the cleaner production approach.
2. *Integration*: Industrial systems are viewed as only one part of the surrounding systems, with which they must be in concert,²³ which is—to a limit—a new point that can be further studied.

Using the industrial ecology concept, many benefits would be provided, other than the same gains that are provided by the cleaner production, which are reduction in the use of virgin materials, reduction in pollution, increased energy efficiency, and reduction in the volume of waste products requiring disposal, many other benefits of great importance are to be gained such as increase in the amount and types of process outputs that have market value,²⁴ and the birth of new industries which means more work chances and high economic benefits, also like hidden resource productivity gains, synergies between production and distribution beyond production chain: closed loop, and the creation of eco-industrial parks and interfirm relations.

This takes us to the recognition of what eco-industrial parks are all about. Eco-industrial parks actually represent the form that every industrial community should be according to industrial ecology. In these parks, every single waste is either reused or retreated in a certain way that sustainability of resources and environment is assured. Most industrial ecologists believe that Kalundborg, a small city on the island of Seeland, 75 miles west of Copenhagen, is the first recycling network in history.²⁵ The four main Industries and a few smaller businesses feed on each other's wastes in transforming them into useful inputs.

As Gertler explains, the basis for the Kalundborg system is “creative business sense and deep-seated environmental awareness,” and “while the participating companies herald the environmental benefits of the symbiosis, it is economics that drives or thwarts its development.”²⁴

The same idea and approach to reaching a sustainable environment is what the—cradle-to-cradle concept calls for compared with the—cradle-to-grave approach. The cradle-to-grave concept means that the raw materials of a certain industry are being used only once and then are dumped in a landfill, which is a one-way stream of materials. As explained earlier, this has been happening all over the world one way or another since the Industrial Revolution. But now to realize environmental reform in the cement industry, the cradle-to-cradle concept has to get into place, where every material is considered as a nutrient either to the environment or to the product itself. In order to form a community to cope with such concept and action, according to Braungart and McDonough, there are four steps to be made:²⁶

“Phase 1—Creating Community: identification of willing industrial partners with a common interest in replacing hazardous chemicals with natural one or less hazardous, targeting of toxic chemicals for replacement;

Phase 2—Utilizing Market Strength: sharing list of materials targeted for elimination, development of a positive purchasing and procurement list of preferred intelligent chemicals;

Phase 3—Defining Material Flows: development of specifications and designs for preferred materials, creation of a common materials bank, design of a technical metabolism for preferred materials;

Phase 4—Ongoing Support: preferred business partner agreements amongst community members, sharing of information gained from research and material use, co-branding strategies.”

Recycling Opportunities

According to cleaner production techniques and industrial ecology concept, a number of alternatives can be demonstrated to utilize the cement bypass dust as a raw material in another industry or another process or within the same process, such as the following:

- Recycling within the cement production process (most efficient in wet process) and requiring more research to optimize the percentage of bypass dust to be recycled without affecting the cement properties
- Production of tiles/bricks/interlocks blended cements
- Production of glass and ceramic glass
- Production of safe organic compost (soil conditioner) by stabilizing municipal wastewater sludge
- Enhancing the production of road pavement layers

Recycling through Tiles/Bricks/Interlocks By pressing the cement bypass dust in molds under a certain pressure force, bricks/interlock/tiles can be formed with a breaking strength directly proportional to the pressure used to form it, and sometimes the breaking strength is even higher than the pressure used to form it. In Cement Turah factory in Egypt, experiments were conducted on the following:

- Using 100 percent cement bypass dust with pressure force of 200 kg to form a cylindrical cross-section bricks of 50 cm² area where the breaking pressure of these bricks reached 120 kg/cm². In addition, chemical treatment of these bricks during the hydraulic molding can achieve a breaking pressure of 360 to 460 kg/cm² for the 100 percent cement dust bricks.
- Using 15 to 20 percent cement dust with clay and sand along with pressure thermal treatment to reach breaking pressure of 530 to 940 kg/cm².
- Using 50 percent cement dust with sand along with thermal treatment only to reach breaking pressure of 1,300 kg/cm²

Using cement bypass dust with clay to produce bricks has proven to reduce the weight of the bricks along with reducing the total linear drying shrinkage. In addition, this opportunity can utilize very high percentages of the bypass dust. However, this will still depend on the market needs and the availability of easily transported bypass dust.

Recycling through Glass and Ceramic Glass Using bypass dust as a main raw material (45 to 50 percent) along with silica and sand stone and melting the mix at temperatures ranging 1,250° to 1,450°C, glass materials were obtained. The glass product has a dark green color with high durability due to the high calcium oxide (CaO) content in cement bypass dust. It can be used for bottle production for chemicals containers. This step was then followed by treatment for 15 to 30 minutes at temperatures ranging from 750° to 900°C to form what is known as ceramic glass. This new product, unlike glass, has a very high strength, is unbrittle, is untransparent, and looks like marble. The produced ceramic glass is highly durable and can resist chemical and atmospheric effects. Consequently, this new product opens the way for utilizing huge quantities of bypass dust in producing architectural fronts buildings, prefabricated walls, interlocks for sidewalks and many other engineering applications.

Recycling through Composting of Sewage Sludge Because of the high alkalinity and pH value of cement kiln dust (11–12), it can be used in stabilizing municipal sewage sludge. Municipal sludge contains bacteria and parasites. Therefore, if used directly as a soil conditioner, it will cause severe contamination to the soil and the environment and may be very hazardous to health.

Two types of sludge from sewage treatment plants can be used. The first one is from a rural area where no heavy metals were included and the second is

from an urban area where heavy metals might exist, depending on the level of awareness and industrial compliance.

Due to the high alkalinity of cement bypass dust, when it is mixed with municipal sludge, it enhances the quality of sludge by killing the bacteria and viruses.²⁷ Also, it will fix the heavy metals (if they exist) in the compost and convert them into insoluble metal hydroxides, thus reducing flowing of metals in the leachate. Agricultural waste such as rice straw, corn stalk, and so on, which is considered a major environmental problem in most countries, can be added to the sludge for composting process to adjust the carbon to nitrogen ratio and enhance the fermentation process. Agricultural waste will also act as a bulking agent to improve the chemical and physical characteristics of the compost and help reduce the heavy metals from the sludge.

The uniqueness of this process is related to the treatment of municipal solid waste sludge, which is heavily polluted with ascaris eggs (most persistent species of parasites) using passive composting technique. This technique is very powerful and very efficient, with much less cost (capital cost and running cost) than other techniques, as explained before. First, primary sludge will be mixed with 5 percent cement dust for 24 hours. Second, agricultural waste as a bulking agent will be mixed for passive composting treatment. Passive composting piles will be formed from sludge mixed with agricultural waste (bulking agent) and cement dust with continuous monitoring of the temperatures and CO₂ generated within the pile. Both parameters are good indicators of the performance and digestion process undertaken within the pile.

Passive composting technique explained before have shown very promising results, especially by adding cement dust and agricultural wastes. Results show that ascaris has not been detected after 24 hours of composting, mainly due to the high temperature elevations reaching 70° to 75°C for prolonged periods, as well as the high pH from cement dust. Also, the heavy metal contents were way beyond the allowable limits for both urban sludge, as well as rural sludge.²⁷

As a result of previous discussion, three major wastes (cement bypass dust, municipal wastewater sludge MWWS from sewage treatment plants, and agricultural waste) can be used as byproducts to produce a valuable material instead of dumping them in the landfill or burning them in the field. This technique will protect the environment and establish a new business where cement bypass dust exists. If cement bypass dust does not exist, quick lime can be used to treat the MWW sludge. Sludge has a very high nutritional value but is heavily polluted with ascaris and other pollutants, depending on location. Direct application of sludge for land reclamation has negative environmental impacts and is health hazardous. Cement bypass dust is always considered a hazardous waste because of high alkalinity. The safe disposal of cement dust costs a lot of money and still pollutes the environment because it is very fine dust with high pH (above 11) and has no cementing action. Agricultural waste has no heavy metals and contains some nutrients, which will be used as a bulking agent. The bulking agent can influence the physical and chemical characteristics of the final product.

It will also reduce the heavy metal content of the sludge and control C/N ratio for composting.

Recycling through Road Pavement Layers Cement bypass dust can be used in three ways in road pavement layers. The first application deals with subgrade layer. The second application deals with base layer, while the third application deals with asphalt mixtures.

Subgrade Layer Adding 5 to 10 percent of cement bypass dust to the soil improves its characteristics and makes it more homogenous and stiff to maintain loads.

Base Layer Limestone is used in the base layer for road paving in general. Also, good binding and absence of voids in this layer are crucial to maintain strength and to prevent settlement and cracking of this layer, which is located right below the asphalt layer. Therefore, adding cement bypass dust as filler material to the base layer eliminates the voids formed between rocks and each other due to its softness. Consequently, it increases the density (weight/volume) of this layer due to increase of weight and fixation of volume, which improves the overall characteristics of binding, especially if base layers of thickness more than 25 cm is required in the design using the same paving equipment. Also, the absence of voids in the base layer provides protection against the negative impact of acidic sewage water and underground water, which work on cracking and settling the base layer.

Asphalt Mixtures The asphalt mixture is a mix of sand, gravel, broken stones, and soft materials, along with the asphalt. In Marshal's standard test for designing asphalt mixtures, it has been found that the percentage of asphalt required can be reduced as the density of the mixture increases. Therefore, adding cement bypass dust, which has very fine and soft particles, improves the mixture efficiency by filling the voids. Also, the bypass dust contains high percentages of dry limestone powder and some basic salts that, in nature, decrease the creeping percent of the asphalt concrete, enhance the binding process, and reduce the asphalt material required, which is very desired in hot climates.

This process was implemented in the road joining the stone mill of Helwan Portland Cement Company and the company's factory in Egypt. The results from binding the base and subgrade layers assured that adding the cement bypass dust to the layers improved the overall characteristics of the road. The road is still operating in perfect condition, after 12 years of trucks using the road with a load capacity not less than 100 metric tons.

Final Remarks

The environmental and socioeconomic benefits as a result of utilizing cement bypass dust can be summarized as follows:

- Reducing air pollution problems
- Utilizing high percent of bypass dust, if not all
- Improving the pavement layer characteristics with very low cost
- Reducing the asphalt percent required in the design for the same performance asphalt mixture
- Providing more job opportunities
- Using low-price product with high quality and strength
- Developing new business opportunities
- Preventing biomass field burning to get rid of the agricultural waste in sludge treatment process
- Reducing greenhouse gas emissions
- Killing microbes and parasites in sludge, forming a high-quality soil conditioner, as well as improving land reclamation and public health

MARBLE AND GRANITE INDUSTRY

Marble and granite industry is considered one of the oldest and largest industries in the world. Marble and granite have been used in Egypt since the time of the ancient Egyptians. Historically, the industry moved from labor-intensive to capital-intensive with the advent of technological advancement, including development of automated production tools such as cranes and diamond-cutting wires. Marble consists mainly of calcite or dolomite, or a combination of these carbonate minerals. Marble is a type of metamorphic rock formed from limestone. It is formed from limestone by heat and pressure in the earth's crust that causes the limestone to change in texture and makeup (recrystallization process). Impurities present in the limestone during recrystallization affect the mineral composition of the marble that forms. The minerals that result from impurities give marble wide variety of colors. The purest calcite marble is white. Marble containing hematite has a reddish color. Marble that has limonite is yellow, and marble with serpentine is green.²⁸ The specific gravity of marble usually ranges from 2.5 to 3, while granite has a very high specific gravity and can go up to 9.

Marble consists of soluble residue (0.89 percent), Fe_2O_3 (0.28 percent), CaCO_3 (97.74 percent), MgCO_3 (1.22 percent), phosphoric acid – (0.04 percent), along with the impurities: SiO_2 , Fe_2O_3 , limonite, manganese, Al_2O_3 , and FeS_2 (pyrite).²⁹ Granite, the hard natural igneous rock having visible crystalline texture, is formed essentially of quartz and orthoclase or microcline. It is formed from volcanic lava. The principal constituents of granite are feldspar, quartz, and biotite. However, the percentage composition of each varies and accordingly imparts different color and texture to the final product. The percentage composition of feldspar varies between 65 and 90 percent, of quartz can extend from 10 to 60 percent and that of biotite lies between 10 and 15 percent.³⁰ Granite consists of silica (SiO_2), 70 to 77 percent; alumina (Al_2O_3), 11 to 14 percent; potassium oxide (P_2O_5), 3 to 5 percent; soda (Na_2O), 3 to 5

percent; lime, 1 percent; iron (Fe_2O_3), 1 to 2 percent; iron (FeO), 1 to 3 percent; magnesia (MgO), 0.5 to 1 percent; titina, less than 1 percent (.38 percent); and water (H_2O), 0.03 percent.³⁰

Nature has gifted Egypt with large deposits of high-quality marble and granite. Since 2700 B.C., the Ancient Egyptians used granite to build their important temples and buildings. Ancient Romans, as early as the third century B.C., acquired the Egyptian knowledge in quarrying and cutting the ornamental stones, especially granite. This technology was transferred back to Italy and, due to the natural endowment of Italy coupled with the acquired technical knowledge, the marble industry flourished and the Italians became world leaders in the production of marble. The production of marble passes through several stages.³¹ The main stages are demonstrated in Figure 1.26:

1. *Exploration and identification of a quarry location.* The locations are identified, followed by testing and verification of characteristics of the marble quarry.
2. *Extraction of marble from the quarries.* Extraction of the marble stone happens in several ways, depending on the technology owned by the quarrymen. Marble does not split easily into sheets of equal size and must be mined carefully.

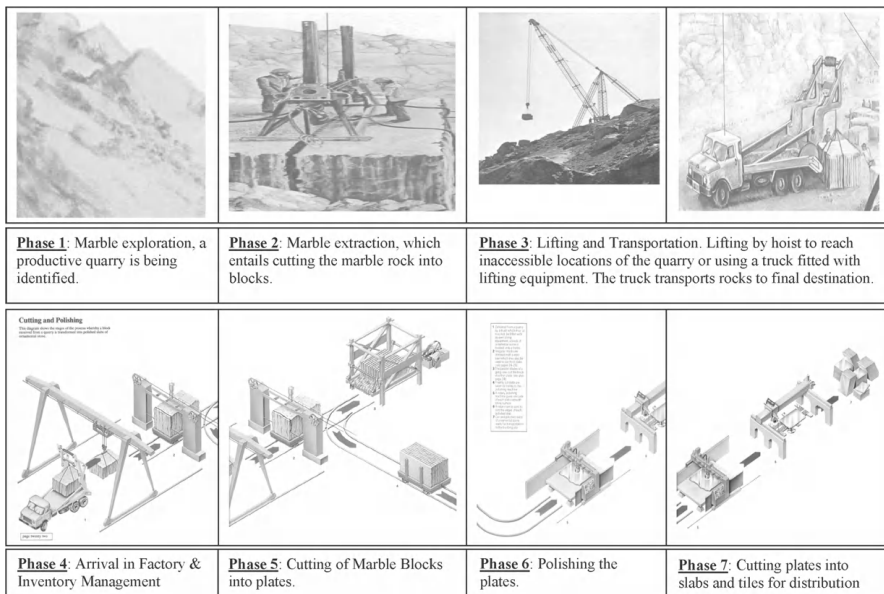


FIGURE 1.26 Marble production process (Source: Azza Kandil and Tarek Selim, “Characteristics of the Marble Industry in Egypt,” www.aucegypt.edu/academic/economics/papers/wk6.pdf, Accessed July 5, 2007.)

3. *Lifting and transportation.* After cutting the rocks of marble, marble blocks need to be lifted to a truck for transportation to the factories.
4. *Inventory management.* The inventory of raw stone blocks is very bulky and requires a very spacious area.
5. *Cutting the stone into slabs and tiles.* When a certain order is placed, the raw stone block is transported to the factory to be cut as demanded, either into tiles or slabs of various thicknesses (usually 2 cm or 4 cm). Stone cutting is a lengthy process that can take more than a continuous 12 to 16 hours of operation, depending on the model of the cutting machine, as well as the status of its diamond wire or diamond blades.
6. *Polishing.* After the stone has been cut to the specific dimensions, there are different techniques towards reaching a “finished” product. The most known of these techniques is polishing. The polishing operation is fully automated, with the use of powdered abrasives that keeps on scrubbing the surface of the marble until it becomes smooth and shiny. The smoother the abrasive used, the shinier and smoother is the surface of the marble. Here, water showers are essential to prevent overheating.
7. *Distribution to end users.* The distribution channels depend very much on the end product produced by the factory. If the factory produces finished tiles and slabs, then this is a finished order, processed according to the customer requirements, and a customer delivery takes place. Distribution often goes to workshops that are usually the middleman between the supplier and the end user. These workshops receive the cut plates of marble and store them in their shops for the end user to choose from.

Marble and Granite Waste

Nearly 70 percent of this precious mineral resource gets wasted due to mining, processing, and polishing, as shown in Table 1.6. The processing waste being dumped on the riverbeds is threatening the porosity of aquifer zones.³² However, for each marble or granite slab of 20 mm produced, a minimum of 5 mm is crushed into powder during the cutting process. This powder flows along with the water, forming marble slurry. In other words, a minimum of 20 percent marble/granite produced results in powder in the form of slurry. This slurry has approximately 35 to 40 percent water content. In India, about 30 percent weight

TABLE 1.6 Waste Distribution among Different Phases

Process	Marble Production	Mine Waste	Processing Waste	Polishing Waste	Total Waste	Mine Out Reserve
Quantity	30 percent	50 percent	15 percent	5 percent	70 percent	100 percent

Source: Siddharth Pareek, “Gainful Utilization of Marble Waste: An Effort towards Protection of Ecology and Environment,” 2007, www.cdos-india.com/papers/18%20-%20Gainful%20Utilization%20of%20Marble%20Wast%20-%20Siddharth%20Pareek.doc.

of marble blocks are converted into powder, and it is about 1.5 million metric tons per annum. Requirement of water in the processing plants is about 2,750,000 liters per hour.³²

Therefore, there are mainly two types of wastes solid wastes and semisolid or slurry that can be produced from marble and granite processing. Solid waste consists of stone rubble with inadequate dimension for use in any application. This rubble is of low commercial value and is usually disposed of in landfills. Natural stone slurry occurs during physical processes such as extraction, sawing, and polishing. The equipments used in these activities necessitate the use of large amounts of water, for cooling, lubrication and cleaning. This mixture of water and very small particles produces a semiliquid substance that is generally known as '*natural stone slurry*', due to its appearance.³³ Thus, a "filter press" is a key component in the eco-friendly technology for marble processing. The amount of water saved can be recirculated as a coolant from the settling tank to the saw nozzle after collecting the slurry for possible utilization as tiles or bricks, or to be used in cement industry or paving roads.

Another type of waste can be generated during quarrying. The quarrying waste disposal practices are as follows:³²

- The waste generated during the quarrying operations is mainly in the form of rock fragments.
- The generated waste by the quarries are usually dumped in empty pits in the nearby area, thereby creating huge mounds of waste.
- The waste and overburden is dumped on roads, riverbeds, and agriculture fields, leading to widespread environmental degradation.
- The quarry operators express their inability in proper segregated and disposal of waste due to the small sizes of the quarry.

Physical and Chemical Properties of Slurry

The dimension of slurry particles was therefore compatible with the filling and densing of the transition zone (measuring between 10 and 50 μm) and of the capillary pores (which range from 50 nm to 10 μm of diameter), thus acting as a microfiller. According to parallel specific testing, it was concluded that the used slurry had no hydraulic or pozzolanic activity.

The average dimension of the slurry particles was inferior to 74 μm (which would exclude its use as an aggregate for concrete production, according to the conventional concrete technology approach). Their chemical nature was exclusively dependent on the original material (without clay or other deleterious materials), and the test results showed that the slurry was fit to be used in concrete mixtures.

The chemical analysis of marble slurry is shown in Table 1.7. The high content of CaO confirmed that the original stones were marble and limestone. It was also verified that the slurry did not contain any organic matter, thus confirming that it could be used in concrete mixtures.

TABLE 1.7 Chemical Analysis of Marble Slurry

Test Carried Out	Test Value (in percent)
Loss on ignition	43.46
Silica	1.69
Alumina	1.04
Iron oxide	0.21
Lime	49.07
Magnesia	4.46
Soda	Less than 0.01
Potash	Less than 0.01

Source: Sanjay Singh and V. Vijayalakshmi, "Marble Slurry—A New Building Material," *Technology Information, Forecasting, and Assessment Council*, 2006, <http://www.tifac.org.in/news/marble.htm>

The tested slurry had a specific density of 2.72 g/cm^3 . Furthermore, by using an easy particle sizer M6.10 equipment, it was possible to compare both grading curves of cement and slurry particles. The specific surface area of the slurry particles was $7128 \text{ cm}^2/\text{g}$ and its average size was $5.0 \text{ }\mu\text{m}$ (smaller than cement particles).

Scrapes

Another waste is marble/granite scrapes (small pieces), which represent nearly 10 to 15 percent. These are usually dumped into landfills without any precaution. There are two types of scrapes: bulk stone and polished scrapes. Bulk stone scrapes are the huge masses produced at the mine when large blocks are cut out of their natural environment. These masses are usually crushed to small aggregates with a crusher, and ultimately used in tiles. Polished scrapes are normally 2 to 4 cm thick. Both types of scrapes have the following in common:

- They consume space.
- When piled up, they form hills of scrape that can house harmful animals like snakes and rats.
- They are not self-degrading materials.

Environmental Impacts and Mitigation

The environmental impacts and mitigation of both marble slurry and scrapes will be discussed in this section. As a result of disposal of the marble slurry generated during the processing of marble and granite, the following environmental damage might occur:

- The porosity and permeability for the topsoil is reduced tremendously, and in due course of time it results in waterlogging problems at the surface, which does not allow the water to percolate down.

- The fine marble particles with high pH reduce the fertility of the soil by increasing its alkalinity. The high pH of the dry slurry makes it corrosive material that is harmful to the lungs, and may cause eyesores.
- Dry slurry diffuses in the atmosphere, causing air pollution to human and possible pollution to nearby water. It settles down on crops and vegetation, thus severely threatening the ecology of the marble clusters.
- It may corrode nearby machinery.
- It depletes natural resources in terms of wastewater, marble, and granite powder, small pieces of marble, and granite.

The solid larger pieces can be easily incorporated in concrete or in sculptures, as in bonded marble. As for the slurry, it has much potential—from pavement filler material to agricultural fertilizers. Almedia et al. produced a paper that briefly describes many of the applications of marble and stone waste:³³

- Cement industry
- Tiles
- Red ceramic bricks and tiles
- Mortars and concrete
- Polymer concrete
- Other cement-based products
- Pavement
- Embankment
- Agglomerate marble

Cement Industry Recent research studies concluded that there is technical viability to incorporate massive quantities of natural stone slurry as “raw material” in the production of clinker, without any previous complex treatments.

As an example, the Portuguese cement industry is responsible for the consumption of 12 million metric tons of raw materials each year, about 10 million metric tons of which is limestone. The Portuguese natural stone slurry produced annually represents 3.5 percent of the total limestone raw material needed by the national cement industry.

Tiles India also presents successful cases related to the production of tiles containing 90 percent of stone slurry bonded by 10 percent of resin.

Red Ceramic Bricks and Tiles A European research project concluded that it is possible to incorporate large amounts of natural stone slurry by substituting conventional calcium carbonate used in the production of red ceramic bricks, without compromising the behavior of the obtained final product.

The presence of this slurry in a 2 to 3 percent ratio solved the expansion problems usually associated with structural ceramic materials. Furthermore, depending on the kind of basic raw material used, it is possible to use up to 25 percent of slurry.

Confirmation on the behavior of this kind of recycled material was also obtained from similar research done in Brazil and India, where red ceramic tiles are produced with 20 percent of stone slurry input.³³

Generally speaking, the bricks and floor tiles are heterogeneous because they consist of natural clays with a very wide-ranging overall composition. Consequently, they can tolerate the presence of different types of wastes, even in considerable percentages.

The raw materials that will be used in brick type compositions are plastic red clay (PRC) and low-grade clay (LGC). While in floor tile formulations, in addition to the PRC, shale clay (SC) is added and the granite sludge is added to both. Regarding the chemical composition of these three types of clay, (the PRC is based on illite, kaolinite, montmorillonite and some quartz and feldspar, while the LGC clay is mainly based on quartz and illite. The SC consists essentially of a mixture of quartz, mica (muscovite), kaolinite, illite, and montmorillonite.³⁴

The sludge in general has relatively fine particle size distribution, and this means that it doesn't require any further grinding step and can replace the low-grade clay components used in the fabrication of brick type products or the feldspar in floor tiles compositions.

There were tests conducted regarding adding the sludge to the bricks and floor tiles as in the case of incorporating the cutting sludge in industrial porcelain tiles. The tests were conducted on granite sludge as a trial. The clay materials, together with the sludge, were mixed at different weight percentages regarding both the brick type and the floor tiles type, as shown in Table 1.8.

Regarding both compositions, the brick type were fired at 950°C in an industrial furnace and then followed by a long cycle of about 9 hours. The floor tile type were fired at 1100°C in an electrical laboratory furnace with a holding time of 1 hour at the maximum temperature.³⁴ The results were satisfactory concerning the tests, but focused more on the linear shrinkage, the water absorption, and the flexural strength. The results are shown in Table 1.9.

TABLE 1.8 Tested Brick and Floor Tiles Compositions

	Brick-type composition (wt percent)				
	1	2	3	4	5
PRC	30	35	35	40	45
LGC	70	30	15	0	5
Granite sludge	0	35	50	60	50
	Floor tile-type compositions (wt percent)				
	6	4	7	8	9
PRC	30	40	50	0	0
SC	0	0	0	40	50
Granite sludge	70	60	50	60	50

Source: J. M. F. Ferreira et al. "Recycling of Granite Sludges in Brick-Type and Floor Tile-Type Ceramic Formulations," University of Aveiro, 2007.

TABLE 1.9 The Properties of the Fired Products

Temperature Composition		Fired Properties		
		Linear Shrinkage (percent)	Water absorption (percent)	Flexural Strength (Mpa)
950°C (BT)	1	0.15	13.02	13.4
	2	0.18	12.97	12.3
	3	0.16	12.92	10.3
	4	0.21	13.00	11.8
	5	0.29	13.01	11.7
1100°C (FTT)	6	0.17	6.04	39.8
	4	0.19	1.60	53.8
	7	0.28	0.43	57.4
	8	0.26	0.10	68.2
	9	0.30	0.00	74.6

* BT = Brick type

* FTT = Floor tiles type

Source: J. M. F. Ferreira et al. "Recycling of Granite Sludges in Brick-Type and Floor Tile-Type Ceramic Formulations," University of Aveiro, 2007.

Focusing on the results that were achieved after conducting the tests, it was found that the granite sludge that is derived from the cutting processes of this natural stone can be considered and reused to be an interesting raw material for the brick type and floor tile formulations. The results shown above clarify that there is a wide range of results regarding all the tests. For instance, focusing on the results of samples 4 and 5, the granite sludge represents approximately 50 percent of the total weight and the results of these samples regarding the linear shrinkage, water absorption, and the flexural strength are acceptable. Also from the results, it is obvious that PRC is beneficial because it enhances the overall performance and its absence will negatively affect the properties of the end product.

In the final analysis, "the granite sludge in brick type compositions can be as high as 60 percent. For floor tile type products, the incorporation of the sludge can be used in the range of 50 to 60 percent when combined with the SC, or it can be limited to a maximum of 50 percent in the case of PRC."³⁴ Therefore, since the brick type and floor tile type industry requires several tons of raw materials, it will be economical and environmental to consume the marble and granite sludge.

Mortars and Concrete Technical possibilities of producing concretes and mortars containing stone slurry have been studied with positive results in several countries. Research works in Portugal led to similar conclusions, demonstrating improvements in several properties. Tests were performed by Almeida et al. in order to investigate the maximum percentage of marble slurry that can be incorporated in concrete.³³ The mixes used for the tests are shown in Table 1.10.

TABLE 1.10 Concrete Mix Properties

Mixture	Sand Substitution	Compressive Strength 7 days (MPa)	Compressive Strength 28 days (MPa)	Spitting Tensile Strength (MPa)	Modulus of Elasticity (GPa)
CMSS0	0	60.3	85.1	4.2	40.5
CMSS5	5	66.5	91.1	4.8	43
CMSS10	10	55.3	79.4	4.2	41.4
CMSS15	15	58.1	79.5	4.3	38.8
CMSS20	20	53.9	77.5	4	36.9
CMSS34	34	41.1	60.8	3.3	33.5
CMSS67	67	36.4	58.2	3.2	30.7
CMSS100	100	30.1	50.3	3	26.7

Source: Nuno Almeida, Fernando Branco, and José Roberto Santos "Recycling of Stone Slurry in Industrial Activities: Application to Concrete Mixtures," (2005), <http://www.sciencedirect.com/science>.

Different concrete mix proportions were tested for compressive strength, tensile strength and modulus of elasticity as shown in Table 1.10.

Compressive Strength When 5 percent of the initial sand content was replaced by stone slurry (CMSS5), 10.3 percent higher compressive strength after 7 days, and 7.1 percent higher compressive strength after 28 days were detected, when compared with CMSS0. This increase can be related to the higher concentration of hydrated cement compounds within the available space for them to occupy. Furthermore, by acting as micro filler, the stone slurry promoted an accelerated formation of hydrated compounds, thus resulting in a significant improvement of compressive strength at earlier ages (7 days).³³

In fact, the amount of slurry present in CMSS5 enabled the very fine particles of it to act as nucleation points. This is related to an effect of physical nature that ensures effective packing and larger dispersion of cement particles, thus fomenting better hydration conditions. Moreover, the slurry particles completed the matrix interstices (transition zone and capillary pores) and reduced space-free water. The combination of these phenomena resulted in a better bonding among the concrete components.³³

CMSS10, CMSS15, and CMSS20 presented a reduction of compressive strength ranging from 3.6 percent to 10.6 percent at 7 days of age, and from 6.7 percent to 8.9 percent at 28 days of age (when compared to CMSS0). Lower performance of CMSS10 could seem improbable, taking into account its water/cement ratio. However, for this extremely low water/cement ratio, the available space for accommodating hydrated products was insufficient, thus inhibiting chemical reactions.³³

Regarding higher contents of stone slurry (substitution of more than 20 percent of sand), the decrease of compressive strength values was significant. The

incorporation of such amounts of very fine material did not permit the microfiller effect to prevail, which, in addition to a rather inappropriate grading, caused lower results.³³

When substituting all the sand for stone slurry (CMSS100), test results showed 50.3 MPa at 28 days and 30.1 MPa at 7 days. Although these results were acceptable by comparison with conventional concrete, the relative reduction amounted to 40.9 percent for 28 days and 50.1 percent for 7 days. Therefore, it is possible to conclude that full substitution of fine aggregate for stone slurry is not reliable when compressive strength is a critical aspect to take in consideration.³³

Tensile Strength The benefits obtained in compressive strength property due to the microfiller effect induced by stone-slurry particles was even further important regarding the splitting tensile strength tests (relative increase of 14.3 percent detected for CMSS5). These are coherent results, in light of the explanation advanced regarding the compressive strength variation of CMSS5.³³

As for the compressive strength, when the substitution level of sand surpassed 20 percent, the tensile splitting strength was significantly reduced. Nevertheless, test results show that tensile splitting strength is less sensitive to high content of very fine particles than compressive strength. CMSS100 presented a result of 3 MPa, correspondent to a quite acceptable reduction of 28.6 percent relatively to CMSS0.³³

Modulus of Elasticity In accordance with the analysis made concerning the other mechanical properties, CMSS5 test results determined that this was the concrete mixture with better behavior in terms of modulus of elasticity (6.2 percent higher than CMSS0) and that all mixtures containing less than 20 percent of stone slurry obtained acceptable results. CMSS10 also presented a slight improvement of 2.2 percent in behavior. In the extreme case of slurry incorporation (CMSS100), the average of test results for the modulus of elasticity was 26.7 GPa (34.1 percent less than the reference concrete mixture CMSS0).³³

It is known that cement paste modulus of elasticity is generally half the modulus of elasticity of aggregates. Therefore, when introducing stone slurry (very fine particles, with slightly inferior size than cement particles), the paste could be considered as increased, thus promoting a negative effect on the modulus of elasticity of the hardened concretes. This fact, in addition to the higher water/cement ratio, could explain the lower modulus of elasticity attained for more than 15 percent substitution (inclusively).³³

Another reason that might explain the negative behavior detected for more than 15 percent of aggregate replacement for slurry, apart from the higher water/cement ratio, might be associated with a possible volumetric expansion occurring among the different materials, withdrawing aggregates (which better contributes to a higher modulus of elasticity) from one another, thus losing some ability to restrain deformations (further dependent on the paste).³³ In light of this, better behavior of CMSS5 and CMSS10 can be explained by better grading and packing of hardened concrete mixture, attained by reduced space among the different particles.³³

The results showed that the substitution of 5 percent of the sand content by stone slurry induced higher compressive strength, higher splitting tensile strength, and higher modulus of elasticity. The feasibility of incorporating up to 20 percent stone slurry in detriment of the respective amount of fine aggregate without prejudicing mechanical properties in a serious manner was also determined.

Polymer Concrete (PC) Marble and granite waste, in addition to organic binders, can be utilized in many different applications. Less-expensive recycled polymer binders have been used with marble, basalt, and quartz, as well as rice straw, bagasse, and cotton stalk fibers in polymer concrete (PC) production. Reasonable cost, durability under anticipated exposure conditions, adhesion to aggregate, handling properties, and ease of curing are the most important considerations in the choice of the resin used. The high cost of the traditional resins used in the preparation of PC makes it relatively expensive compared to the cement-based materials and is limiting the growth of PC-based products. Therefore, recycling of plastic polymers has received a great deal of attention to reduce the cost of resin production; in addition, it is an acceptable, convenient solution to some ecological problems resulting from the accumulation of these wastes.

Other Cement-based Products Applications include cement-based products such as structural blocks, lightweight blocks, soil–cement bricks, pavement coatings, and even acoustic panels developed at an experimental level that contained granite slurry, limestone aggregates, cement, and cork industry waste.³³

Pavement Stone slurry was not considered as suitable for pavement use, but some laboratory tests demonstrated that it is possible to incorporate this byproduct in asphalt mixtures as a commercial filler substitute. The use of slurry in road works is not common. In fact, some researchers attest that it is possible to use marble slurry in roadwork layers that account for 25 to 35 percent of the total pavement thickness.

In Turkey, limestone dust was generally used in asphalt mixtures as filler material. However, in recent years, many quarries were closed off because of the environmental protection rules put into use. Therefore, highway authorities and municipalities have difficulties for finding suitable filler material. As a result, using the waste material as filler should be investigated for road construction. For this reason, Almeida et al. has investigated using marble dust in asphalt mixtures as filler material.³³

Embankment As with pavements, opinions about the use of stone slurry in embankments are not unanimous. Despite the existence of bibliography referring to the possibility of using stone slurry in embankments (taking advantage of the insulation capability of the slurry) or mixed in a 25 percent ratio with soil, there are also several studies referring to environmental impacts related with the presence of this industrial waste in soil.³³

Agglomerate Marble Agglomerate marble is the designation for products that bind pieces of natural marble together with specially formulated polyester resin. This process allows the reconstruction of large recycled “marble” blocks, similar to the ones extracted from quarries, both in quality and visual aspects, which can be submitted to the same processing activities as natural stone. Research concerning the reutilization of marble slurry as a substitute of calcium carbonate was developed for agglomerate marble fabrication. For a total amount of slurry that reached up to 6 percent of the total compounds, it was technically possible to adopt this procedure.³³

This is sometimes called *cast marble*. It is a manmade product consisting of marble dust (calcium carbonate) and polyester resin. The type of resin used in bonded marble products is crystal clear and sometimes referred to as *casting resin*. This type of resin is costly to produce, thus adding more to the cost of the finished product. The calcium carbonate in the bonded marble creates a semiporous surface that has a very unique look and feel. The calcium carbonate also makes the piece pure white and allows for a very high degree of detail. Most bonded marble products are made in Italy, which has the whitest marble in the world. Other names for bonded marble are cast marble, cultured marble, and bonded Carrara marble.³⁵

Natural Carrara marble powder is mixed with a resin. The mixture is then poured into a mold of the statue design. The resin gives the marble powder an added strength superior to the natural stone. The finished product bears a near identical resemblance to the original hand-carved statue. The texture and features are duplicated and the color is a consistent ivory white. Because of the characteristics of the resin material, these bonded marble statues shown in Figures 1.27 are waterproof, and can be washed and cleaned with most agents. Water and weather will not harm the material, and it is very strong. It will not yellow over time, can handle high detail, doesn’t have bubbles, and will not crack.³⁶

METAL FOUNDRY INDUSTRY

The metal foundry industry can be divided into two sectors: ferrous and nonferrous. Ferrous foundries cast iron and steel products, while nonferrous foundries cast a variety of other metals such as aluminum, copper, zinc, lead, tin, and nickel. More than 75 percent of products by volume are ferrous. Although nonferrous industries use the same basic molding and casting techniques, byproducts can be different from those produced from ferrous industries.

The casting of metal in foundries is one of the oldest and largest recycling industries in the world. Metal foundries exist everywhere worldwide to produce different products such as valves, pipe fittings, pipe accessories used in water, and wastewater networks made out of cast iron, copper, or aluminum through metal foundry using sand-molding technology. Many other components in engines, pumps, blowers, compressors, and so on can also be produced in metal foundries. The sand molding technology consists of the following processes:



FIGURE 1.27 Bonded marble with antique stone finish 10 inches H (25 cm) (Source: www.goddessgift.net/page20.html.)

1. *Sand and mold preparation.* The sand is first mixed with a hardening material, like bentonite slurry for example, inside the sand preparation mixers. After that the sand molds are formed and are placed on the production line
2. *Melting.* The main types of metals are used in metal foundry: iron, aluminum, and copper. Other metal can also be used according to requests, such as zinc, aluminum alloy, copper alloy, and so on. A large quantity of slag, which is about 20 to 25 percent of the melted material, comes out from the melting process. The utilization of slag will be discussed with details in the next section.

3. *Pouring.* The end metal product is then poured into the moulds and left to cool and gain its strength. Then the moulds are untied to get the product from.
4. *Cleaning and Inspection.* All the products are gathered for inspection and quality assurance. Some of those are rejected and sent back to the furnace for remelting, and others are approved and cleaned. However, there is a huge quantity of wasted sand that creates a disaster to the company and surrounding environment, if it is left without use.
5. *Product final preparation phase.* The products are sent to workshops for cutting, making holes, and trimming. This process results in many metal wastes that are then delivered again to the furnaces for remelting.
6. *Assembly and examination phase.* After all the products are prepared, they are assembled according to the specifications, and then their mechanical properties are tested.
7. *Finishing and storage phase.* The final product is then painted by spraying it either with bitumen or epoxy in a controlled outdoor area. After the product is painted, it is stored in its final shape.

Foundry Sand

Foundry sand is a byproduct waste sand from a foundry or factory that produces castings of metal. Iron is the most common element used in foundries, but other heavy metals have been known to be used, including aluminum, copper, lead, and zinc.³⁷ Foundry sand is essentially uniformly sized sand with high-quality silica content. It is used as a mold to cast the metals into the desired product. The sand mold is bonded together using organic binders. The sand-casting system is the most commonly found system in the metal-molding industry. The foundry sand is generally clean before it is used in the casting process, but once it has been used, it may be hazardous.³⁸ The used or spent material often contains residues of the heavy metals and binder that may act as leachable contaminants. The residual sand is routinely screened and returned to the system for reuse. As the sands are repeatedly used, the particles eventually become too fine for the molding process and, combined with heat degradation from repeated pourings, requires periodic replacement of “spent” foundry sand with fresh foundry sand. This *spent sand* is black in color and contains a large amount of fines (particles of 100 sieve size or less).³⁹ Most of the sand-cast molds used for iron castings are of a type of foundry sand called *green sand*, which consists of high-quality silica, bentonite clay, sea coal, and water. The green sand is not actually green in color, but refers to the fact that it is used in the wet state. In the past, once the casting has been done, the spent foundry sand was often no longer used due to fears of environmental concerns and contamination. However, an article in *Civil Engineering* magazine stated, “Fears of environmental contamination have recently been laid to rest with new studies indicating that certain types of waste foundry sand are not only ecologically safe but literally cheaper than dirt in some cases.”⁴⁰ According to a study done by the U.S. National Transportation Board,

“the annual generation of foundry waste, including dust and spent foundry sand, in the United States is believed to range from 9 to 13.6 million tons. Typically, about 1 ton of foundry sand is required for each ton of iron or steel casting produced.”⁴¹ Most of this waste is landfilled, sometimes even being a cover material at landfill sites. It has been shown that spent foundry sand may be used in a multitude of applications without environmental considerations. A study done by Oakland–Berkeley Recycling Market Development Zone shows that spent foundry sand may be used as an addition to asphalt mixes and in the design of decorative tiles with the sand.⁴² The physical and chemical properties of spent foundry sand are shown in Tables 1.11 and 1.12, respectively.

Uses of Foundry Sand

According to a technology brief done by the Clean Washington Center in Seattle, the uses for spent foundry sand in different applications include the following.⁴³

Agricultural Products

- Amendments
- Commercial soil blends
- Compost
- Top dressing

Geotechnical Applications

- Barriers
- Embankments
- Highway construction
- Landfills
- Road bases
- Structural fills

TABLE 1.11 Physical Properties of Spent Green Foundry Sand

Property	Results	Test Method
Specific Gravity	2.39–2.55	ASTM D854
Bulk Relative Density, kg/m ³ (lb/ft ³)	2590 (160)	ASTM C48/AASHTO T84
Absorption, percent	0.45	ASTM C128
Moisture Content, percent	0.1–10.1	ASTM D2216
Clay Lumps and Friable Particles	1–44	ASTM C142/AASHTO T112
Coefficient of Permeability (cm/sec)	10 ⁻³ –10 ⁻⁶	AASHTO T215/ASTM D2434
Plastic limit/plastic index	Nonplastic	AASHTO T90/ASTM D4318

Source: Highway Research Center, U.S Department of Transportation: Federal Highway Administration, “Foundry Sand,” American Foundrymen’s Society, Inc., <http://www.tfhrcc.gov/hnr20/recycle/waste/fs1.htm>, Oct. 2, 2006.

TABLE 1.12 Chemical Composition of Foundry Sand

Constituent	Value (in percent)
SiO ₂	87.91
Al ₂ O ₃	4.70
Fe ₂ O ₃	0.94
CaO	0.14
MgO	0.30
SO ₃	0.09
Na ₂ O	0.19
K ₂ O	0.25
TiO ₂	0.15
P ₂ O ₅	0.00
Mn ₂ O ₃	0.02
SrO	0.03
LOI	5.15
TOTAL	99.87

Source: Highway Research Center, U.S Department of Transportation: Federal Highway Administration, “Foundry Sand,” American Foundrymen’s Society, Inc., <http://www.tfhrc.gov/hnr20/recycle/waste/fs1.htm>, Oct. 2, 2006.

Manufactured Products

- Asphalt
- Concrete products
- Flowable fill
- Portland cement

A detailed case study to utilize spent foundry sand as a reinforcement material to mixed polymeric waste will be discussed later in this chapter.

IRON AND STEEL INDUSTRY

The iron and steel industry is considered one of the most important industries for the sustainable development. It is considered the base for numerous industries that could not have been established without the steel industry, such as construction, automotive, and steel structure industries. There are three basic routes to obtain finished steel products:

1. Integrated steel production
2. Secondary processing
3. Direct reduction

Integrated steel production involves transforming coal to coke in coke ovens, while iron ore is sintered or pelletized prior to being fed into the blast furnace (BF). The ore is reduced in the blast furnace to obtain hot metal containing some 4 percent carbon and smaller quantities of other alloying elements. Next the hot metal is converted to steel in the basic oxygen furnace (BOF). Then, it is continuously cast to obtain semifinished products, such as blooms, bars or slabs. These semifinished products are rolled to the finished shapes of bars, sheet, rail, and H or I beams.

The secondary processing, often called minimills, starts with steel scrap that is melted in an electrical arc furnace (EAF). The molten steel produced is possibly treated in a ladle furnace and then continuously cast and finished in a rolling operation. Originally, minimills provided only lower grade products, especially reinforcing bars. But, they recently have been able to capture a growing segment of the steel market.

In the direct reduction method, production starts with high-grade iron ore pellets that are reduced with natural gas to sponge pellets. Then, the sponge iron pellets are fed into an electrical arc furnace. The resulting steel is continuously cast and rolled into a final shape.

There is a huge amount of solid waste “slag” generated from the iron and steel industry as a result of the impurities. Usually, slag is collected from the process and left in a nearby area occupying millions of square meters of land. Slag is not only hindering the use of millions of square meters of land for more useful purposes but also contaminating it with heavy metals such as barium, titanium, and lead. Also, it is well known that toxic substances tend to concentrate in slag that floats at the top of the furnace. Health hazards of heavy metals and toxic substances are well known. Based on the concentration levels of heavy metals, slags may be classified as hazardous waste materials. Furthermore, groundwater, as well as surface water, is susceptible to serious pollution problems due to the likely leaching of these waste materials.

Another type of solid waste generated from the secondary processing is the iron dust produced at the beginning of the process during feeding the scrap to the electrical arc furnace (EAF) for melting. Small quantity of sludge might also be produced during the process of iron in blast furnace.

This section describes the different types of solid waste materials generated from the iron and steel industry and the associated environmental problems. Different techniques of managing these waste materials are presented with a focus on utilizing slag, dust, and sludge in construction engineering applications. Test results of many research efforts in this area are summarized. In addition, numerous ideas to mitigate the environmental impacts of this problem are suggested.

Environmental Impacts

Iron making in the BF produces a slag that amounts to 20 to 40 percent of hot metal production. BF slag is considered environmentally unfriendly when fresh because it gives off sulfur dioxide and, in the presence of water, hydrogen

sulfide and sulphuric acid are generated. These are at least a nuisance and, at worst, are potentially dangerous. Fortunately, the material stabilizes rapidly when cooled and the potential for obnoxious leachate diminishes rapidly. However, the generation of sulphuric acid causes considerable corrosion damage in the vicinity of blast furnaces. In Western Europe and Japan, virtually all slag produced is utilized either in cement production or as road filling. In Egypt, almost two-thirds of the BF slag generated is utilized in cement production. Some 50 to 220 kg of BOF slag is produced for every metric ton of steel made in the basic oxygen furnace, with an average value of 120 kg/metric ton. At present, about 50 percent of BOF slag is being utilized worldwide, particularly for road construction and as an addition to cement kilns.⁴⁴

Recycling of slags has become common only since the early 1900s. The first documented use of BF slag was in England in 1903;⁴⁵ slag aggregates were used in making asphalt concrete. Today, almost all BF slag is used either as aggregate or in cement production. Steel for making slag is generally considered unstable for use in concrete but has been commercially used as road aggregates for over 90 years and as asphalt aggregates since 1937. Steel-making slag can contain valuable metal and typical processing plants are designed to recover this metal electromagnetically. These plants often include crushing units that can increase the metal recovery yield and also produce materials suitable as construction aggregates. Although BF slag is known to be widely used in different civil engineering purposes, the use of steel slag has been given much less encouragement.

BF dust and sludge are generated from the processing and cleaning, either by wet or dry means. The dust and sludge typically are 1 to 4 percent of hot metal production.⁴⁶ These materials are less effectively utilized than BF slag. In some cases, they are recycled through the sinter plant, but, in most cases, they are dumped and landfilled. Finding better solutions for the effective utilization of BF dust and sludge is an important problem. BOF dust and sludge are generated during the cleaning of gases emitted from the basic oxygen furnace. The actual production rate depends on the operation circumstances. It may range from about 4 to 31 kg/metric ton of steel produced, and has a mean value of about 18 kg/metric ton.⁴⁴ The disposal or utilization of BOF dust and sludge is one of the critical environmental problems in some countries.

Electrical arc furnace produces about 116 kg of slag for every metric ton of molten steel. Worldwide, about 77 percent of the slag produced in EAFs is reused or recycled.⁴⁴ The remainder is landfilled or dumped. Due to the relatively high iron content in EAF slag, screens, and electromagnetic conveyors are used to separate the iron to be reused as raw material. The EAF slag remaining is normally aged for at least six months before being reused or recycled in different applications such as road building. All efforts in Egypt have focused on separating the iron from EAF slag without paying enough attention to the slag itself. However, pilot research work conducted at Alexandria University in Egypt has investigated the possibility of utilizing such slag.⁴⁷ The test results proved that slag asphalt concrete could, in general, fulfill the requirements of the road-paving design criteria.

EAF dust contains appreciable quantities of zinc, typically 10 to 36 percent. In addition, EAF dust holds much smaller quantities of lead, cadmium, and chromium. EAF dust has been classified as a hazardous waste (K061) by the U.S. Environmental Protection Agency, and therefore its safe disposal represents a major problem. Although there are several technologies available for processing this dust, they are all quite expensive, on the order of US\$150 to US\$250 per ton of dust.

The Problem in Egypt

Apart from the granulated BF slag used in producing slag cement, all types of waste from any steel plant in Egypt were simply dumped in the neighboring desert. Based on the production figures of the major steel plants in Egypt and the generation rates of different waste materials per each metric ton of steel produced, the annual waste materials generated in Egypt was estimated and summarized in Table 1.13 over and above the accumulated stock pile in the near by area. There are stockpiles of 10 million metric tons of air-cooled BF slag and another 10 million metric tons of BOF slag laying in the near by area.

Obviously, waste generators will be required to pay a certain fee per metric ton disposed. In 1993, the cost of disposing one ton of steel plant wastes in the United States was \$15.⁴⁸ Today, it goes up to \$100. Large tonnage of iron and steel slags are increasingly produced in Egypt, and the huge space needed to dump them has become a real challenge. To have an idea about the considerable area needed for disposal, it is quite enough to know that the 20 million metric tons of BF and BOF slags currently available are estimated to occupy 2.5 million square meters.

Potential Utilization of Slag

Many of the environmental problems of solid waste materials generated from the iron and steel industry have been known for some time, and attempts have been made to tackle them with varying degrees of success. During the past few years, the iron and steel industry has been able to produce some creative

TABLE 1.13 Waste Materials Generated from Iron and Steel Industry in Egypt

Type of Waste	Annual Amount Generated (metric tons)
Blast furnace slag	600,000
Basic oxygen furnace slag	200,000
Electrical arc furnace slag	300,000
Blast furnace dust	20,000
Electrical arc furnace dust	15,000
Rolling mill scales and sludge	25,000

solutions to some of these environmental problems. It is highly probable that many other creative solutions also could emerge as a result of well-thought-out and well-supported research programs.

Processing of slag is a very important step in managing such waste material. Proper processing can provide slag with high market value and open new fields of application. Cooper et al. discussed the recent technologies of slag granulation.⁴⁹ The main steps of the granulation process were addressed with schematic drawings, including verification, filtering, and denaturing systems. The most recent continuous granulation technology at that time was introduced in detail with the help of many illustrative figures, as shown in Figure 1.28.

Foster addressed the high cost of disposing wastes generated from the steel industry and discusses an innovative idea from South Africa to manage BOF slag, which has a limited usage.⁴⁸ He came up with a new idea for processing BOF slag. This process starts with preparing the slag by grinding it, mixing it with a reductant such as sawdust or charcoal, and feeding it into a modified cyclone-type preheater. This reduction process removes iron oxide from iron. The slag is then passed over a magnet, which removes the iron particles. The low-iron slag is then mixed with other materials, such as clay, to produce an acceptable type of cement kiln feed.

Featherstone and Holliday introduced the idea of dry slag granulation shown in Figure 1.29.⁴⁵ The existing slag treatment methods, the new dry granulation method, and the value of granulated slag products were reviewed. The development, application, and advantages of the dry method of granulating molten slags were described. The dry granulated slag was proved to have many environmental

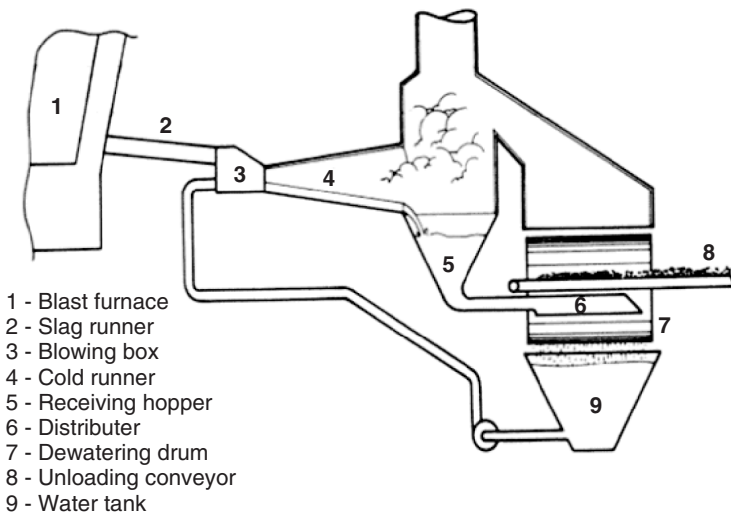


FIGURE 1.28 Continuous slag granulation system. (Source: A.W. Cooper, M. Solvi, and M. Calmes, "Blast Furnace Slag Granulation," *Iron and Steel Engineer*, 63, (July 1986): 46–52.)

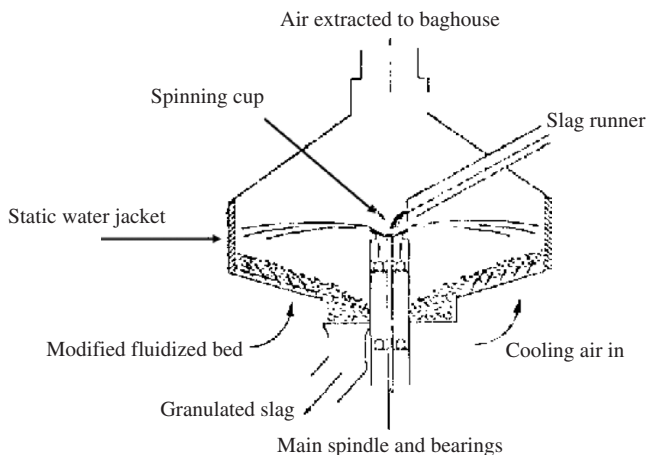


FIGURE 1.29 Dry slag granulation. (Source: W. B. Featherstone and K.A. Holliday, "Slag Treatment Improvement by Dry Granulation," *Iron and Steel Engineer* (July 1998): 42–46.)

advantages over conventional processes, while generating a product of equal quality in addition to its low cost and simplicity.

Swamy presented an extensive and critical examination of the use of ground granulated BF slag in concrete.⁵⁰ It was shown that the use of BF slag as aggregate in concrete can lead to high strength concrete with excellent durability. Apart from its ability to reduce the temperature rise due to hydration, test results showed that BF slag has a hidden potential to contribute high early age strength, excellent durability and very good chemical resistance. A mix proportioning method was advanced that assured the development of early strength for slags of normal surface area of 350 to 450 m²/kg. Table 1.14 summarizes the compressive strength development up to 180 days age for mixes with 50 percent (A) and 65 percent (B) slag replacement of coarse aggregates. Curing was shown to be a critical factor that affects early age strength, continued strength development, and fine pore structure responsible for durability. It was also shown that with a well-defined curing period, the mineralogy and chemistry of slag could be mobilized to develop a very fine pore structure that is far superior to that of Portland cement concrete. Such a fine pore structure can impart a very high resistance to concrete to the transport of sulfate and chloride ions and water.

Nagao et al. proposed a new composite pavement base material made of steel-making slag and BF slag. When the new composite base material was prepared by mixing steel-making slag, air-cooled slag, and granulated blast furnace slag in proportions of 65 percent, 20 percent and 15 percent, respectively, it was found to have material properties and placeability similar to those of conventional hydraulic and mechanically stabilized slags.⁵¹ Also, it was found feasible to quickly and economically suppress the swelling of steel-making slag by the hot water immersion that involves hydration reaction at 70° to 90°C, under which

TABLE 1.14 Compressive Strength Development of Slag Concrete

Mix	Age, Days	Compressive Strength, (MPa)
A	1	7.20
B	1	4.10
A	3	28.90
B	3	19.00
A	7	39.00
B	7	27.40
A	28	46.80
B	28	34.20
A	90	54.90
B	90	38.20
A	180	57.10
B	180	36.47

Source: R. N. Swamy, "Concrete with Slag: High Performance and Durability without Tears," 4th International Conference on Structural Failure Durability and Retrofitting, Singapore (1993), pp. 206–236.

slag can be stabilized in 24 hours at an expansion coefficient of 1.5 percent or less, as proposed by Japan Iron and Steel Federation.

One of the interesting research efforts in Egypt to find fields of application for iron and steel slags among other waste materials is the project carried out by Morsy and Saleh from 1994 to 1996.⁵² This project was funded by the Scientific Research and Technology Academy to investigate the technically sound and feasible utilization of two solid-waste materials, iron and steel slags, and cement dust, in addition to some other different liquid wastes. The study dealt with BF slag, both air-cooled and water-cooled, and BOF slag. The use of such slags in road paving as a base, subbase, and surface layers was examined through laboratory and pilot field tests. The results proved that these slags are suitable for use in all paving layers. Better performance and higher California bearing ratio were obtained for slags compared to conventional stones. The Egyptian standards for ballast require that the weight of cubic meter of ballast not be less than 1.1 metric tons, and that Los Angeles abrasion ratio does not exceed 30 percent. Test results showed that the properties of iron and steel slags surpassed the requirements of these standards and can be used as ballast provided that suitable grading is maintained.

Another study performed in Egypt in 1997,⁴⁷ by the Institute of Graduate Studies and Research at Alexandria University in conjunction with Alexandria National Iron and Steel Company, was aimed at investigating the use of EAF slag as road-paving base material and as coarse aggregate for producing concrete suitable for applications such as wave breakers, sidewalk blocks and profiles, and manhole covers. The physical and chemical properties of EAF slags

TABLE 1.15 Marshall Test for Asphalt Concrete Containing Slag

Asphalt Content, percent	Unit Weight (lb/ft ³)	Stability (lb)	Flow/ inch	Voids in Agg., percent	Voids in Total Mix
3.5	2.62	2279	10.2	14.8	9.2
4.5	2.72	2726	11.7	14.3	5.9
5.5	2.77	2550	12.4	14.5	3.5
6.5	2.73	2100	15.9	15.6	1.5
Design criteria	—	>1800	8–18	>13	3–8

Source: M. El-Raey, "Utilization of Slag Produced by Electric Arc Furnace at Alexandria National Iron and Steel Company," Institute of Graduate Studies and Research, Alexandria University—Egypt, 1997.

of different ages were determined. EAF slag was crushed to the desired size and the applicability of slag in producing asphalt concrete was tested laboratory by the Marshall test. Table 1.15 shows some of the results obtained for asphalt concrete containing slag. The test results proved that slag asphalt concrete could, in general, fulfill the requirements of the road-paving design criteria. EAF slag was successfully used as a coarse material for the base layer in a field-scale test.

The study also covered the use of EAF slag as coarse aggregate for concrete, and the obtained results revealed that slump values for slag concrete were lower than those of gravel concrete by 33 percent for the same water/cement ratio. The unit weight of slag concrete was found to be 2.6 to 2.7 t/m³. It ranged from 2.35 to 2.38 t/m³ for gravel concrete. The higher unit weight is attributed to the higher specific gravity of slag compared to gravel, 3.5 and 2.65, respectively. For the same cement content and water/cement ratio, and at both early and later ages, slag concrete exhibited higher compressive strength than gravel concrete, with an average increase of 20 percent at 7 days age and 10 percent at 28 days age. The same classical effects of water/cement ratio, aggregate/cement ratio, and curing on gravel concrete were observed for slag concrete. From a durability point of view, no sign of self-deterioration was noticed for slag concrete. Slag concrete has been successfully applied in manufacturing sidewalk blocks and profiles, manhole covers, and balance weights.

Korany and El-Haggag investigated the utilization of different slag types as coarse aggregate replacements in producing building materials, such as cement masonry units and paving stone interlock.⁵³ Cement masonry specimens were tested for density, water absorption, and compression and flexural strengths. The paving stone interlocks were tested for bulk density, water absorption, compressive strength, and abrasion resistance. They also studied the likely health hazards of the proposed applications. The test results proved in general the technical soundness and suitability of the introduced ideas. Most of the slag solid brick units showed lower bulk density values than the commercial bricks used for comparison. All slag units exhibited absorption percentages well below the ASTM limit of 13 percent. A substantially higher compressive strength results

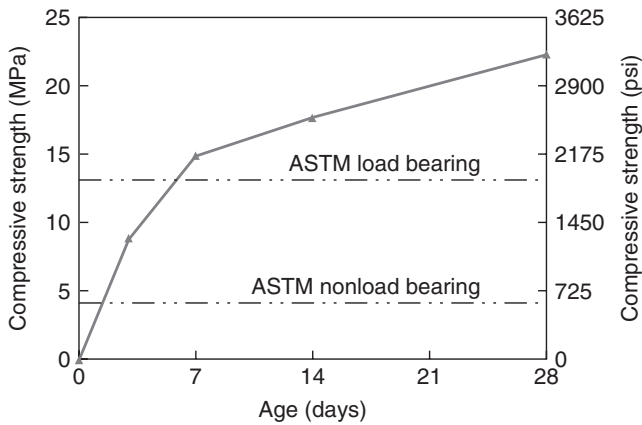


FIGURE 1.30 Development of compressive strength with age for solid brick groups at 100 percent slag replacement levels. (Source: Y. Kourany and S. M. El-Haggag, "Utilizing Slag Generated from Iron and Steel Industry in Producing Masonry Units and Paving Interlocks," 28th CSCE annual conference, June 7–10, 2000, London, Ontario, Canada.)

were reached for all masonry groups at 28-day age compared to the control and commercial bricks as seen in Figure 1.30. All test groups showed higher compressive strength than the ASTM limit of 4.14 MPa for nonload-bearing units. At slag replacement levels higher than 67 percent, all groups resulted in compressive strength higher than the ASTM requirement of 13.1 MPa for load-bearing units. All slag types resulted in paving stone interlocks having water-absorption values far below the ASTM limit, as shown in Figure 1.31. All slag paving stone interlocks showed higher compressive strength and abrasion resistance than the control specimens made of dolomite. Moreover, the proposed fields of application were found to be safe to the environment and have no drawbacks based on the heavy metals content and water-leaching test results.

Szekely proposed a comprehensive research program to reduce fume formation in the BOF and EAF, find an effective approach to reduce and utilize steel-making slag, and to effectively use the oily sludge produced in rolling mills.⁴⁴ Related environmental problem areas were discussed and preliminary solutions were identified. From Szekely's viewpoint, although several technologies are available for treating EAF dust, they are quite expensive, and satisfactory solutions for the EAF dust problem have not yet been produced. He suggested some possible solutions worthy of exploration, such as modifying the charging, blowing, and waste gas exhaustion system to minimize dust formation. Another proposed solution is to examine the composition of the dust produced during different phases of furnace operation and, if appropriate, segregates the recovered dust.

Some of the methods used to turn steel plant dust into a valuable raw material were described by one of the solid waste processing companies in its article published 1997.⁵⁴ One of the commonly used methods is micropelletizing, where dust is mixed with lime as a binder and is pelletized to produce a fine granular

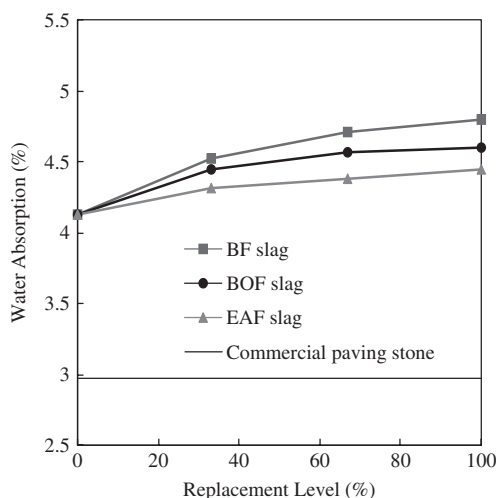


FIGURE 1.31 Comparison between absorption ratios of the different slag types with replacement level. (Source: Y. Kourany and S. M. El-Haggag, “Utilizing Slag Generated from Iron and Steel Industry in Producing Masonry Units and Paving Interlocks,” 28th CSCE annual conference, June 7–10, 2000, London, Ontario, Canada.)

form, the major proportion being in the size range of 2 to 3 mm with a total size range of 1 to 10 mm. The water content is adjusted to 12 percent during mixing and the pellets are air-cured for a minimum of three days before charging to the sinter plant, where they account for 3 percent of the total charge. The article also addressed the direct injection process currently on trial in Germany and the United Kingdom, where injection is used to pass fine dust into the liquid metal in the furnace. Fine dust is blended with hydrating dusts such as burnt lime and carbon. The metal oxide content of the material is about 70 percent and has a particle size range of 0 to 8 mm, making it ideal for direct injection into a range of furnaces.

Final Remarks

Besides the economic and technical importance of utilizing waste materials generated from the iron and steel industry, this activity is of great importance from the environmental protection point of view, as well as conservation of natural resources. The first environmental impact is the useful consumption of the huge stockpiles of these waste materials. When these waste materials are used as replacements for other products such as cement, the natural resources that serve as raw materials are preserved. Also, air pollution levels will be reduced due to the reduction in fuel consumption. All slag types should be treated as byproducts rather than waste materials. All existing and new steel plants should have a slag-processing unit within the factory property to extract steel from slag and to crush the slag and sieve it to the desired grading for ease of promotion.

WASTE INDUSTRY

This is a new industrial sector, and the most challenging industrial sector to be addressed all over the world. The challenging part came from the nature of the waste industry because it is a multi-industrial activity containing all types of wastes, including hazardous wastes. This sector will utilize the wastes as a byproduct in order to conserve the natural resources through the cradle-to-cradle concept and reach sustainability. Sustainability or sustainable development will never be achieved without conservation of natural resources. Therefore, the main indicator for sustainability is life cycle assessment (LCA), based on the cradle-to-cradle concept, not cradle-to-grave concept, as discussed before. In other words, *cradle to cradle* is the indicator for sustainability. The degree to which cradle to cradle is achieved will give an indication of how close the industry or any manmade activity is to sustainability.¹

Waste industrial sector can be classified into four categories: (1) direct waste recycling industry, (2) multiple waste recycling industry, (3) waste exchange network industry, and (4) environmentally balanced industrial complexes (EBICs). Direct waste industry that can relay on specific type of waste to be recycled on-site or off-site. This category is the most common type of waste industry to convert waste into products. Some additives might enhance the quality of products.

Multiple waste-recycling industries integrate more than one type of waste as a raw material in order to enhance the properties of the products. For example, use of spent foundry sand, which is hazardous waste from metal foundry industries, to enhance the properties of recycled mixed plastics from the plastics industry will be discussed next section (Multiple Waste Recycling Industry). Each waste stream represents an environmental problem for their related industry. Combining each waste together with a certain percentage will enhance the properties of new products. Some additives might be added according to product's specifications. Another example, discussed in Cement Industry section, is adding cement kiln dust (CKD) with agricultural waste to municipal sludge to produce soil conditioner. CKD will treat the sludge by killing all parasites including *Ascaris* eggs through high PH of CKD. Agricultural waste will act as a bulking agent to convert this mixture into a soil conditioner suitable for land reclamation.

The third category is the waste exchange network industry by integrating a new waste-related industry (based on waste generated from the current industry) into the current industry to recycle their waste, such as different new industries initiated in Kalunbourg industrial estate in Denmark located 75 miles west of Copenhagen based on waste generated from the current industries, as will be discussed later. This category can also be called *industrial symbiosis* or *byproduct exchange* (bpx) network.

The fourth category is environmentally balanced industrial complexes (EBICs), developed by Professor Nelson Nemerow to approach zero pollution.⁵⁵ EBICs can be defined as a selective collection of compatible industrial plants located together in one area "complex" to minimize both environmental impact and industrial production costs.

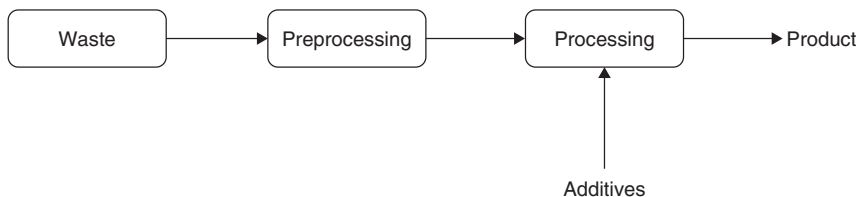


FIGURE 1.32 Direct waste recycling industry.

Direct Waste Recycling Industry

This category is commonly used within the industrial process (on-site recycling) to recycle the waste from within the process, or it could be off-site recycling within small microenterprises (SMEs) to recycle a certain type of waste, as shown schematically in Figure 1.32.

On-site recycling involves returning the waste material either to the original process as an input material or to another process as input material (inside the same factory). In other words, on-site recycling means re-entering the waste into the process as a substitute for an input material or sent as useful by products or raw material for other processes within the same factory. For example, in the plastic industry, any plastic waste from the industrial process can be added with a certain percentage to the virgin raw material to control the mechanical properties and costs. Another example in the pulp and paper industry, the fiber recovery from white paper, the surplus pulp fiber, paper mill off cuts and damaged paper rolls are recycled back into the pulping process. A third example, in oil and soap industry, the gravity oil separator (GOS) will separate the oil from the industrial wastewater stream by gravity and return it back to the industrial process.

Off-site recycling implies that the recycling process takes place by another party that recycles the industrial wastes or at the postconsumer stage such as municipal solid waste. There are companies that specialize in recycling the specific wastes. They buy certain types of wastes, recycle them, and then sell them back to other industries or direct to consumers.

Advanced direct waste recycling industry could also be included within this category such as converting recycled polypropylene (PP) into the properties of polycarbonate (PC) blends by adding some additives such as fire-retardant, impact modifier, ultraviolet stabilizer and antioxidant.⁵⁶ These additives will modify the properties of recycled PP into the properties of PC. This new material can replace the PC blends in some applications such as garden spotlights (outdoor lighting) and three-phase circuit breaker boxes. This new material based on recycled PP will maintain a good quality for the product with less cost.

Multiple Waste Recycling Industry

This category can include different wastes together to enhance the properties of a product and reach a certain specification. The famous waste exchange mechanism applied in different countries can help developing this category, such as:

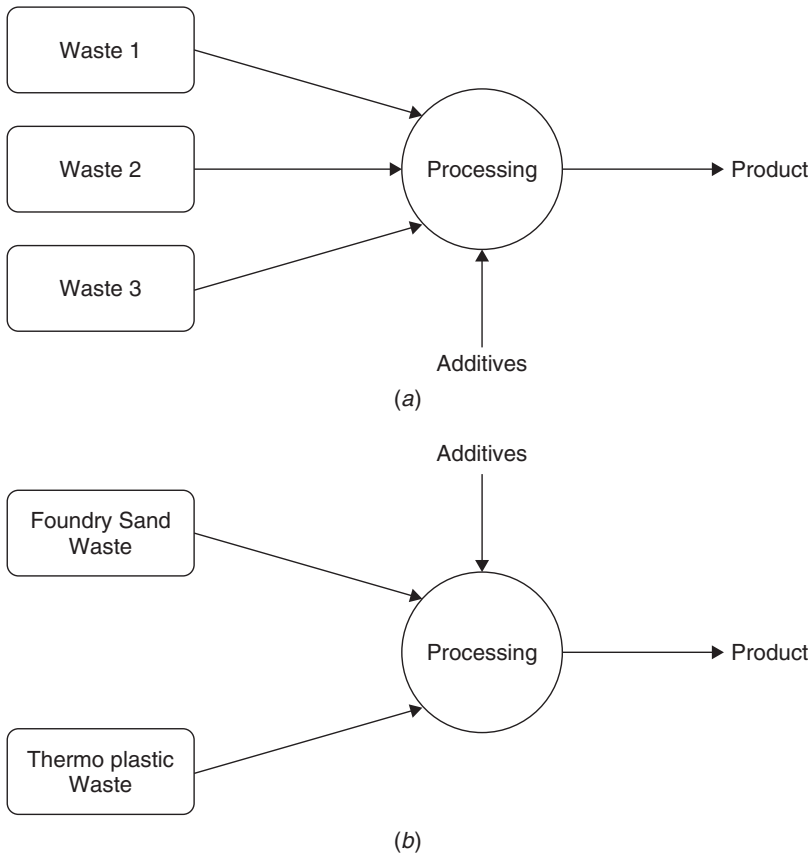


FIGURE 1.33 Multiple waste recycling industry (a) general (b) specific

- Use of foundry sand as a reinforcement to enhance the properties of plastics in different applications as will be discussed in the next section and represented schematically in Figure 1.33.
- Thermosets such as Milamean cannot be recycled directly by direct waste recycling method. Adding thermoset waste into thermoplastic waste will enhance the properties of the products as discussed before.
- Polystyrene foam can be recycled by crushing through shredding machine, and then melted. The melted product can be crushed again and mixed with PP to give the product some ductility and recycle the produced mixture.

Waste Exchange Network Recycling Industry

This is the most important category within the waste sector to develop a new industry within the existing industries and should be developed in *cooperation* with the mother industries to guarantee sustainability. Promoting this category will enhance not only the conservation of natural resources to approach

cradle-to-cradle concept and the protection of the environment, but also will disseminate the culture of waste industry within the industrial communities and decision makers. This promotion will lead to the end of construction of any new disposal facilities such as landfills or incinerators. The italicized word *cooperation* mentioned before is very important to guarantee a continuous supply of raw materials (wastes) and reach sustainable development. This industrial category should be located any where between the waste generators to minimize the transportation cost. The most famous examples of waste integration category are the new industries established within Kalundborg industrial estate in Denmark. New industries joined Kalunbork Industrial Estate (eco-industrial park) based on the waste of the core industries as a byproduct as shown in Figure 1.34. They ended up with the following added new industries:

- *Gyproc—plasterboard production*: Asnaes power station “mother company” installed a desulfurization unit to remove sulfur from its flue gases, which allows it to produce calcium sulfate (gypsum). This is the main raw material in manufacturing of plasterboard at Gyproc. By purchasing synthetic “waste” gypsum from Asnaes power station, Gyproc has been able to replace the natural gypsum that is imported from Spain.

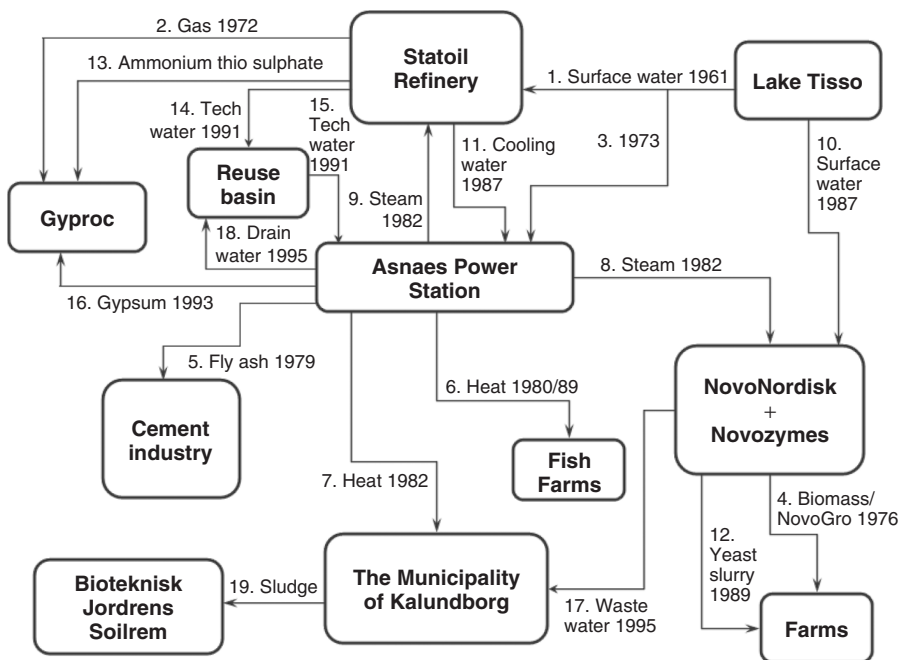


FIGURE 1.34 Waste exchange network recycling industry, Kalundborg Industrial symbiosis in 2000. (Source: Laura Saikkuu, “Eco-Industrial Parks: A Background Report for the Eco-Industrial Park Project at Rantasalmi,” Finland: Publications of Regional Council of Etela-Savo, 2006.)

- *Fish farm—consists of 57 fish ponds*: Asnaes Power Station started fish farming to solve the problem of thermal pollution generated from the cooling water. The seawater used to cool the condenser of the thermal power plant was utilized to develop an artificial fish farm; the fish grew faster in such a warm temperature.
- *Fertilizer*: Regulation in Denmark placed significant restriction on the discharge of organics into the sea. Since Novo Nordisk (main company) used to mix the industrial sludge (organic) with wastewater and discharge it to the sea, it found out the most cost-effective way for sludge disposal is to convert it into fertilizer and give it to the nearby farmers.
- *Cement company—Aalborg Portland and road paving*: Asnaes Power Station (main company) using coal as a fuel source and produced a huge quantity of ash to be landfilled. Asnaes Power Station started to sell fly ash to cement factories to reduce the cost of waste disposal in landfill and gain money for further development. They built Ash silo with an unloading facility to accomplish this duty.
- *Kemira—a sulfuric acid producer*: Statoil refinery process the oil and separate the sulfur from the oil to produce high quality fuel. Statoil refinery begins selling sulfur to Kemira in Jutland. Excess gas from the operations at the Statoil refinery is treated to remove sulfur, which is sold as raw material for the manufacturing of sulfuric acid at Kemira.

Another subcategory can also be fitted within this category to use the waste of one plant as one of the raw material to be replaced for another plant. The waste generated from iron and steel industry, such as water-cooled slag and air-cooled slag, can be used to replace natural resources as:

- Grinding water-cooled slag produced from iron and steel industry discussed before to be mixed with raw cement to produce a special type of cement
- Cutting air-cooled slag produced from iron and steel industry discussed before to be used as an aggregate in flexible pavement or interlocks to enhance the properties and reduce the use of natural resources

Environmentally Balanced Industrial Complexes

Environmentally balanced industrial complexes are a selective collection of compatible industrial plants located together in one area “complex” to utilize the waste of one plant as the raw materials for another plant with minimum transportation and storage facilities. This category will reduce the overall production cost significantly because it eliminates waste treatment cost, reduces raw material cost “substituted by waste,” minimizes storage facility and transportation cost as well as reducing pollution and protects the environment. A number of EBICs were investigated and proposed to produce zero waste out of such complexes, such as sugarcane complexes, tannery complexes, textile complexes, pulp and paper mill complexes, fertilizer–cement complexes, fossil fuel power plant complexes, steel mill fertilizer–cement complexes, cementlime, and power plant complexes.⁵⁵

MULTIPLE WASTE RECYCLING INDUSTRY

Thermoplastics bags generally may be recycled under the condition that they are not contaminated as discussed before in plastic industry section. If they are contaminated, then usually they are burned or landfilled. They are often referred to as *plastic rejects*, such as black garbage bags. This is basically due to the fact that it is too expensive to recycle these plastics. They require immense amounts of water, chemicals, and energy in order to clean them, which defeats the purpose of conservation in the first place. At this point, it is noteworthy to mention that the objective of this case study is to use rejected plastic waste that is no longer usable. Hence, the product that will be produced will naturally have lower physical and mechanical properties than that of virgin plastic material. It may be used as a basis of comparison, but the properties of the products can be improved by using foundry sand waste (hazardous waste) as a reinforcing material for thermoplastics.

The objective of this case study is to investigate the reinforcement of contaminated thermoplastic rejects discussed under “Unrecyclable Plastics” with foundry sand waste as a reinforcing material. Rejected plastics are either burned, producing harmful emissions into the air causing pollution; landfilled, causing the inefficient use of land that could otherwise be used for more beneficial purposes; or left on the streets, causing visual pollution and potential health hazards, as well as depleting the natural resources. The mechanism of utilizing rejected plastics would be by heating the rejects indirectly at high temperatures (150° to 250°C) and then reinforcing it with foundry sand waste and regular sand to enhance its strength. The case study investigates the mechanical and environmental properties of this new material. Each of these reinforcing materials will be used in combination with the rejected plastics in varying quantities. Through this, not only will this material be able to eliminate the pollution of air, water, and land, but will also be able to utilize a certain waste as a new material, and thus not deplete the earth’s natural resources. It will also be able to save energy through the means of conserving a certain waste, thus conserving material and energy, and it will be able to save costs of waste material by using it as a raw material for another product. This will not only save the cost of the waste material, but also make a profit from the new product made of this new recycled of unrecyclable material. It will be a tool in approaching the concept of cradle to cradle and will ultimately protect the environment by producing zero waste through this mechanism of efficient use.

Seven different samples were used in this case study to mix plastic rejects with different percentages of foundry sand waste and regular sand. The two reinforcing agents that were added to the plastic rejects were added in varying percentages to determine the most efficient combination. The percentages of each material are relative to the total weight of the mix. For simplicity and ease, each mix had a total weight of 1 kg. The seven mixes and their designated percentages are shown in Table 1.16.

As shown in Table 1.16, there were a total of seven mixes, including the control mix with 100 percent plastic rejects and no reinforcing agent. All the other

TABLE 1.16 Combination of Mixes with Designated Percentages

Sample No.	Plastic Rejects (percent)	Foundry Sand Waste (percent)	Regular Sand (percent)
1	100	0	0
2	90	10	0
3	80	20	0
4	70	30	0
5	90	0	10
6	80	0	20
7	70	0	30

Source: S. M. El-Haggar and L. El-Hatow, "Reinforcing Thermoplastics Rejects with Foundry Sand Waste," Submitted for publication to ASCE (2007).

variable mixes are compared to this control mix. The percentage reinforcements are a percentage of the total weight of the sample.

Mechanical Tests

Tensile strength and flexural strength were investigated for different sand contents to determine their impacts as a reinforcement material on the mechanical properties of plastic rejects.

Tensile Strength Test To determine the properties of tensile strength of the specimens, tests were done in accordance with ASTM D3039–00.⁵⁷ Tensile strength test was performed in order to determine the ultimate tensile strength. Specimens were machined to dimensions of 25 by 250 by 2.5 mm in accordance with ASTM D3039–00. Gauge length was 100 mm, with the grips firmly holding the tabs. The tensile test occurs on a universal testing machine (UTS). Standard ribbed grips were used to hold the specimen in place. A constant head speed of 5 mm/min was used to allow for failure anywhere between 1 and 10 minutes.

The tensile properties for the different reinforcing elements showed great significance in the way the material behaves, as shown in Figure 1.35. In terms of foundry sand reinforcement of the plastic rejects, the results show that 10 percent reinforcement was the most suitable percentage that gave the highest tensile strength of 19.13 MPa. As for regular sand, 10 percent reinforcement was also the most suitable percentage that gave the highest tensile strength of 19.11 MPa. However the trend of foundry sand reinforcement curve in comparison to the regular sand reinforcement curve shown in Figure 1.34, shows that both sands reached a highest tensile strength of 19 MPa at 10 percent reinforcement and then declined with 20 percent and 30 percent, however the degree of decline of the regular sand in comparison to the foundry sand was much steeper. The regular sand declined much worse than the foundry sand, indicating the possibility that the heavy metals within the foundry sand, in fact, have a promising effect on the tensile strength. Foundry sand was shown to be a better reinforcing

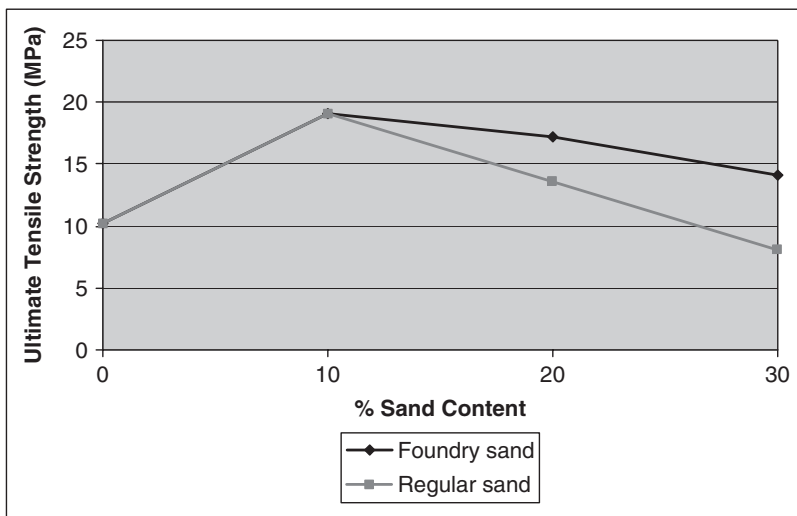


FIGURE 1.35 Tensile strengths of Composite material with foundry sand and regular sand. (Source: S. M. El-Haggag and L. El-Hatow, “Reinforcing Thermoplastics Rejects with Foundry Sand Waste,” Submitted for publication to ASCE (2007).)

element in plastic rejects than regular sand, which is an optimistic observation considering the fact that foundry sand is also a hazardous waste.

When the best percentages of both reinforcing elements were selected and compared, many observations can be seen. First, it can be noted that both reinforcing elements showed improvement from the 0 percent no-reinforcement specimens. Second, the highest tensile strength resulted from reinforcement with foundry sand waste with 10 percent reinforcement, followed by regular sand with 10 percent reinforcement.

Flexural Test To determine the properties of flexural strength of the specimens, tests were done in accordance with ASTM D 790-03 [2003]. The flexural test was performed on the specimens in order to determine the ductility of the specimens as well as their flexural strength. Specimens were machined to dimensions of 127 by 12.7 by 4.5 mm in accordance with ASTM D790-03. Gauge length was 70 mm, with a span to depth ratio of 16. The flexural test occurs on a universal testing machine (UTS). A flexural apparatus was constructed to hold the specimen in place and allows for a three-point bending test. The apparatus was placed and aligned on the UTS machine with two concentric compression plates below and above the apparatus to allow it to function properly. A constant head speed of 2 mm/min was used to allow for failure anywhere between 1 to 10 minutes. The flexural strength for the different reinforcing elements showed varying results. The maximum flexural load of the composite material, reinforced with foundry sand waste and regular sand, are shown in Figure 1.36.

The foundry sand reinforcement of the plastic rejects, the 10 percent reinforcement shown to have the highest flexural strength with a maximum flexural

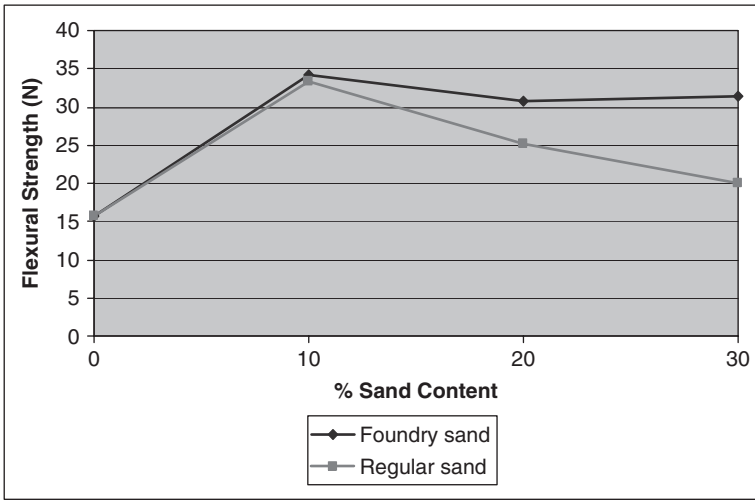


FIGURE 1.36 Maximum flexural load of composite material with foundry sand and regular sand. (Source: S. M. El-Haggar and L. El-Hatow, “Reinforcing Thermoplastics Rejects with Foundry Sand Waste,” Submitted for publication to ASCE (2007).)

load of 34.3 N, which is higher than the 0 percent no-reinforcement value. The regular sand reinforcement of the plastic rejects proved that the 10 percent reinforcement was the best percentage of regular sand reinforcement, with a 33.3 N maximum flexural load. This value was significantly greater than the 0 percent no-reinforcement value. All the regular sand and foundry sand percentage reinforcements were significantly higher than the 0 percent no-reinforcement specimens and thus showed that their addition was enhancing the flexural strength of the specimen by reinforcing it with either regular sand or foundry sand. From Figure 1.36, it is evident that 10 percent foundry sand reinforcement was the best reinforcement in terms of flexural strength and gave the highest value that superseded all other values. The 10 percent regular sand value came in second best.

Environmental Tests

Chemical Resistance Test To determine the properties of chemical resistance of the specimens, tests were done in accordance with ASTM D543-95.⁵⁸ Thus, the specimens were tested toward their resistance to an acidic solution. Sulfuric acid with a pH of 3 was chosen, due to the fact that it plays a dual role of examining the effect of its high acidity and its sulfates content. Sulfates may also be corrosive and thus must be investigated. The specimens were measured for dimensions and weight prior to immersion into the acid. They then remain immersed for seven days in the acid and are then removed and are measured for dimensions and weight. The difference is recorded, and the differences in the

specimens are examined and analyzed. It is expected that the acid should not affect the plastic specimens and that they should be able to withstand chemical resistance quite well. From this it can be assumed that the specimens will be quite resilient to chemicals.

The specimens were immersed in sulfuric acid for a week to determine their resistance to high acidic solutions of pH 3. The specimens' weight and dimensions were measured before and after the immersion. The results indicated that the specimens' dimensions did not change. Thus, it can be said that the composite material has high chemical resistance to acids and to sulfates, and will thus be useful in many applications such as manhole covers and bases.

Leachate of Heavy Metals The leachate test is necessary due to the heavy metals existing in the reinforcing element of foundry sand. According to both Abou Khatwa et al.⁹ and Ibrahim,⁵⁹ the recycled plastic rejects did not leach any heavy metals that were worth noting, and thus were deemed safe. The existence of heavy metals in these specimens with the foundry sand reinforcement is minimal. The leachate test is done in accordance with ASTM D3987-85.⁶⁰ The foundry sand waste was tested separately for heavy metals, as well as the mixed composite specimen in two separate containers. The specimen and the foundry sand waste were immersed in distilled water for 18 hours, and then tested for pH, total hardness, and heavy metals of magnesium and silicon. A MACH DR/2000 direct reading spectrophotometer was used to analyze the heavy metals in the composition.

The solid specimen and the foundry sand were separately immersed in distilled water for 18 hours with continuous shaking to allow for any leachate material to be extracted from the designated samples. The liquid was then filtered. When this was complete, the pH and total hardness were analyzed, upon which the Mg hardness and thus the Mg concentration were calculated. In order to determine the silicon concentration, however, the two samples were heated at 90°C until the liquid evaporated to 10 ml. This is done in order to separate any organic material from the liquid. The samples are then tested on the spectrophotometer for silicon concentration. Table 1.17 shows the results of the leachate test; it can be seen that the foundry sand as a separate entity contained a significant composition of heavy metals of Mg and Si, while the solid specimen of recycled plastic with reinforced foundry sand contained no leachate material with these

TABLE 1.17 Results of Leachate Test

Sample	pH	Total Hardness (mg/L)	Mg Hardness (mg/L)	Mg Concentration (mg/L)	Si Concentration (mg/L)
Specimen	6.45	0.0	0.0	0.000	0.001
Foundry Sand	9.58	1.6	1.6	0.384	41.11

Source: S. M. El-Haggag and L. El-Hatow, "Reinforcing Thermoplastics Rejects with Foundry Sand Waste," Submitted for publication to ASCE (2007).

heavy metals composition. The pH of the solid specimen is quite close to that of distilled water, although that of the foundry sand waste was quite alkaline with a pH of 9.58. From these results it can be inferred that foundry sand waste as an entity contains the heavy metals of Mg and Si; however, when it is used as a reinforcing element in plastic rejects, the melting and thus solidification process enables these heavy metals to dissolve and thus does not pose a threat to the final recycled plastic specimen in terms of leachate material.

Final Remarks

It was shown from the data within the case study that contaminated plastic rejects combined with hazardous waste as a reinforcing elements proved to have durable and environmentally friendly properties that allow this new material to be used as an application in different products such as manhole cover and base. Through analysis of the material with difference percentage reinforcements, it was shown that foundry sand waste at 10 percent reinforcement showed the most promising results.

The environmental-related tests proved to show that material is highly resistant to acidity and thus will not corrode away in many applications of highly acidic applications such as sewer systems. The environmental-related tests also showed that the material does not produce any harmful leachate that may be toxic to the waters or surrounding areas, even though the leachate of the foundry sand contained heavy metals and thus might contaminate the soil and surface water as a result of land disposal. The heavy metals in the foundry sand dissolved upon the solidification process with the plastic rejects to become the new paste, and thus no longer became a problem.

In terms of economics, this new material made out of two hazardous waste will have a lot of benefits, such as saving the disposal cost and saving the natural resources, as well as protecting the environment. In order to recycle contaminated plastic rejects, the plastic first must be washed and cleaned with water in order to be deemed recyclable. This has often been very costly, and consumes a lot of water, energy, and labor. However, by recycling this contaminated material as is, we are not only saving water, energy, and labor, but also using a waste that previously had been incinerated, causing harmful emissions. This case study has shown that the mechanical properties of this new recycled material in no way match the properties of virgin plastic; however, when reinforced with different reinforcing elements such as foundry sand waste (a potential health hazard and waste), the properties of this material increase to an extent that enables it to be used in many applications. Foundry sand waste is in fact a waste material, and thus generally has no cost. Regular sand has also shown promising results in terms of durability; however, regular sand may be considered a natural resource of considerable use and thus might not be the more suitable material. Through this analysis, it can be seen that the benefits outweigh the costs incurred to produce a product out of this new composite material to alleviate the environmental hazards associated with this product.

DISPOSAL OF INDUSTRIAL WASTES

Disposal of industrial waste can be done according to a cradle-to-grave system through incineration and/or landfill. Incineration will convert the industrial solid wastes (hazardous or nonhazardous) into ash that requires landfill for final disposal. According to international regulations, industrial hazardous wastes should be treated first before landfill.

Incineration is the process of thermally combusting solid waste and converting it into ash or briefly incinerating it in a thermal treatment process. There are various types of incinerators. The type used depends on the type of waste to be burnt. Conceptually, incinerators for solid wastes can be classified into (1) rotary kiln incinerator, (2) grate type incinerator, and (3) fluidized bed incinerator. Rotary kiln incinerator can handle both liquid wastes as well as solid wastes. Grate type incinerators are used for large, irregular-shaped solid waste to allow air to pass through the grate from below into the wastes. The fluidized-bed type incinerator is used for liquid, sludge, or uniformly sized solid waste.

The main advantage of the incineration process is to reduce the amount of solid waste into 10 percent (ash). Energy may be recovered from the incineration process. But, the cost of energy produced from waste is higher than the traditional system of energy conversion system. The main disadvantages of incineration are (1) high capital cost, (2) high running cost for operation and management, and (3) disposal of ash resulting from incineration is another added cost. The mismanagement of incineration process may cause severe damage to the environment.

Industrial solid waste and/or ash produced from the incineration process should be landfilled. A landfill is a very complicated structure, very carefully designed either into or on top of the ground in which industrial solid waste is isolated from the surrounding environment. There are many steps before starting to construct a landfill. The first step is to choose a suitable site. Site location is one of the very important steps to avoid any impacts on the surrounding environment. After choosing the appropriate location for a landfill, the designing process starts. Beside the design of the lining and coverage of the landfill, a leachate collection system, biogas collection system and a stormwater drainage system should also be designed and planned for implementation during operation. The bottom liner isolates the industrial solid waste from the soil preventing the groundwater contamination. The liner is usually some type of durable, puncture-resistant synthetic plastic (polyethylene, high-density polyethylene, polyvinyl chloride). In landfills constructed below surface level, a side-liner system is used in mechanical resistance to water pressure, drainage of leachate, and prevention of lateral migration of biogas.

The main disadvantage of landfill is high capital cost for construction as well as high operation cost for compaction, daily cover, leachate treatment, and so on. The mismanagement of landfill may cause a severe impact on the environment. The major disadvantage of both incineration and landfill, over and above the previously

mentioned disadvantages, is depletion of natural resources that lead to unsustainable solid waste management system.

Thus, one can see the tragedy of depleting the natural resources under the title “waste disposal,” through incineration or landfill. For example, 60 percent of our precious stone resource is wasted in the marble and granite industry, our environment is polluted, and our health is put at risk. We need to put an end to this disaster by conserving the natural resources through cradle-to-cradle concepts as discussed before. We need to close our material and energy cycles, and apply cradle-to-cradle concepts. Industrial sectors should be approached as discussed throughout this chapter. All parties should cooperate to reduce wastes and emissions. The governments should issue strict rules controlling or prohibiting the use of landfills and/or incinerators and providing alternatives. *Alternatives* is the key word for sustainable industrial waste management to be able to develop a full utilization of natural resources and cradle-to-cradle approaches. Utilization of the waste needs to be researched through academic institutions and research centers to add value not only to individuals but also to the globe.

REFERENCES

1. M. El Haggag, *Sustainable Industrial Design and Waste Management: Cradle to Cradle for Sustainable Development*, Elsevier Academic Press, 2007.
2. Japan Environmental Agency, *Ippan Haikibutsu No Life Cycle to Mondaiten (Life Cycle and Problem of Waste)*, Tokyo, 1998.
3. Tec Eco Pty. Ltd. Sustainable Technologies, “Life Cycle Analysis,” 2006, www.tececo.com/sustainability.life_cycle_analysis.php
4. S. M. El-Haggag, “Cradle-to-Cradle For Industrial Ecology,” *Advances in Science and Technology of Treatment and Utilization of Industrial Waste*, CMRDI and University of Florida, US–Egypt Joint Fund, Cairo, Egypt, June 6–10, 2004.
5. Recycling Plastics. ODNR, 2005, <http://www.dnr.state.oh.us/recycling/plastics/rates.htm>.
6. E. Wogrolly, M. Hofstatter, and E. Langshwert, “Recycling of Plastic Waste,” *Advances in Material Technology Monitor*, 2 (4) (1995): 1–6, Vienna: United Nations Industrial Development Organization (UNIDO).
7. S. M. El-Haggag and E. M. Hamdy, “Chemical Recycling of Aluminum Plastic Composites,” IAPS, Bibliotheca Alexandria—Egypt, October 16, 2006.
8. S. M. El-Haggag, “Solid Waste Management: Alternatives, Innovations and Solutions,” *Fundamentals and Mechanisms for Sustainable Development Series (3)*, Dar El-Fikr El-Araby Book Co., 2004.
9. M. K. Abou Khatwa, H. Salem, and S. M. El-Haggag, “Building Material from Waste,” *Canadian Metallurgical Quarterly*, 44 (3) (2005).
10. S. M. El-Haggag, M. F. Hamouda, and M. A. Elbieh, “Composting of Vegetable Waste in Subtropical Climates,” *Int. J. Environment and Pollution*, 9 (4) (1998).
11. A. Mostafa, S. M. El-Haggag, and A. Gad El-Mawla, “Matching of an Anaerobic Animal Waste Digester with a Dual-Fuel Generator Unit,” *Int. J. Environment and Pollution*, 12 (1) (1999): 97–103.

12. G. Tchobanoglous et al. *Integrated Solid Waste Management*, McGraw–Hill, New York, 1993.
13. S. M. El-Haggar, S. M. Ahmed, and M. M. Hamdy, “Production of Compost from Organic Agriculture Enriched with Natural Rocks,” *Egyptian Journal of Applied Sciences*, **19** (7B) (July 2004): 784–799.
14. S. M. El-Haggar, B. E. Ali, S. M. Ahmed, and M. M. Hamdy, “Increasing Nutrients Solubility from Natural Rocks During Composting of Organic Wastes,” *Minia Journal of Agricultural Research and Development*, **24** (1) (2004): 71–88.
15. S. M. El-Haggar, “Solid Waste Management Using Cleaner Production Technologies,” Chapter 7 from the book titled “Environmental Balance and Industrial Modernization,” Cairo: Dar El-Fikr El-Araby, 2003.
16. Practical Action, “Biogas and Liquid Biofuels,” 2006, www.itdg.org/docs/technical_information_service/biogas_liquid_fuels.pdf.
17. PCA, Portland Cement Association, 2007, <http://www.cement.org>.
18. H. G. Van Oss and A. C. Padovani. “Cement Manufacture and the Environment, Part 2: Environmental Challenges and Opportunities,” *Journal of Industrial Ecology*, **7** (1) (2002): 93–126.
19. K. H. Karstensen, *Formation and Release of POPs in the Cement Industry*, 2nd ed., World Business Council for Sustainable Development, Geneva, Switzerland, 2006.
20. WBCSD, *Guidelines for Emissions Monitoring and Reporting in the Cement Industry*, World Business Council for Sustainable Design, Geneva, Switzerland, March 2005.
21. Edward Cohen-Rosenthal, “Top Myths about Eco-Industrial Parks,” 1996, <http://www.cfe.cornell.edu/wei/EIDP/design.html>.
22. Reid Lifset, “A Metaphor, a Field, a Journal,” *Journal of Industrial Ecology*, **1** 1 (1997): 1–2.
23. L. W. Jelinski et al., “Industrial Ecology: Concepts and Approaches,” Proceedings of National Academy of Sciences, 1992.
24. Nicholas Gertler, “Industrial Ecosystems: Developing Sustainable Industrial Structures,” 1995, <http://www.sustainable.doe.gov/business/gertler2.shtml>.
25. Andy Garner and Gregory A. Keoleian, “Industrial Ecology: An Introduction,” www.umich.edu, National Pollution Prevention Center for Higher Education, University of Michigan, 1995.
26. W. Braungart and M. McDonough, “Cradle to Cradle: Remaking the Way We Make Things,” North Point Press, 2002.
27. S. M. El-Haggar, N. N. Taha, and S. M. Ahmed, “Wastewater Treatment System for Rural Community, 2nd International conference on Environmental Engineering, Ain Shams University, April 10–12, 2007.
28. Flooring Guide, “Marble,” http://www.flooringguide.com/how-to/stone/ss002_i.php3. Accessed July 5, 2007.
29. Minerals Zone, “Marble,” <http://www.mineralszone.com/stones/marble.html>. Accessed July 5, 2007.
30. Granite Sandstone, “Granite Composition, <http://www.granite-sandstone.com/granite-composition.html>. Accessed July 5, 2007.
31. Azza Kandil and Tarek Selim, “Characteristics of the Marble Industry in Egypt,” www.aucegypt.edu/academic/economics/papers/wk6.pdf. Accessed July 5, 2007.

32. Siddharth Pareek, "Gainful Utilization of Marble Waste: An Effort towards Protection of Ecology and Environment," 2007, www.cdos-india.com/papers/18%20-%20Gainful%20Utilization%20of%20Marble%20Waste%20-%20Siddharth%20Pareek.doc.
33. Almeida, Nuno, Fernando Branco and José Roberto Santos, "Recycling of Stone Slurry in Industrial Activities: Application to Concrete Mixtures," 2005, <http://www.sciencedirect.com/science>
34. J. M. F. Ferreira et al., "Recycling of Granite Sludges in Brick-Type and Floor Tile-Type Ceramic Formulations" University of Aveiro, 2007.
35. Zhki's Gallery, 2005, <http://www.zhkis.com/index.asp?PageAction=Custom&ID=28>.
36. Everlife Memorials 2000, <http://www.everlifememorials.com/bonded-marble-statues.htm>. Accessed July 5, 2007.
37. "Biocycle World," *Bio Cycle* **45** (7) (July 2004): 6–12.
38. Highway Research Center, U.S. Department of Transportation: Federal Highway Administration, "Foundry Sand," American Foundrymen's Society, Inc. Illinois. <http://www.tfhrcc.gov/hnr20/recycle/waste/fs1.htm>. Accessed October 2, 2006.
39. CWC, Clean Washington Center, "Beneficial Reuse of Spent Foundry Sand, Technology Brief, Seattle, August 1996, <http://www.cwc.org/industry/ibp951fs.pdf>. Accessed October 2, 2006.
40. Patrick J. Fox and David G. Mast, "Salvaged Sand," *Civil Engineering*, American Society of Civil Engineers, **67** (11), (1997): 53–56.
41. R. J. Collins and S. K. Ciesielski, "Recycling and Use of Waste Materials and Byproducts in Highway Construction," *National Cooperative Highway Research Program Synthesis of Highway Practice 199*, Transportation Research Board, Washington, DC, 1994.
42. Bio Cycle, "Cutting the Cost of Foundry Sand Disposal," *BioCycle*, JG Press Inc. New York, **38** (2), (Feb. 1997): 12.
43. CWC, Clean Washington Center (1996), "Beneficial Reuse of Spent Foundry Sand," Technology Brief, Seattle, August, 1996. <http://www.cwc.org/industry/ibp951fs.pdf>. Accessed October 2, 2006.
44. J. Szekely, "A Research Program for the Minimization and Effective Utilization of Steel Plant Wastes," *Iron and Steelmaker* (January 1995): 25–29.
45. W. B. Featherstone and K. A. Holliday, "Slag Treatment Improvement by Dry Granulation," *Iron and Steel Engineer* (July 1998): 42–46.
46. W. T. Lankford, N. L. Samways, R. F. Craven, and H. E. McGaannon, *The Making, Shaping and Treating of Steel*, Herbrick and Held, Pittsburgh, 1985.
47. M. El-Raey, *Utilization of Slag Produced by Electric Arc Furnace at Alexandria National Iron and Steel Company*, Institute of Graduate Studies and Research, Alexandria University–Egypt, 1997.
48. A. Foster, "How to Make a Heap From Slag," *The Engineer*, **282** (April 1996): 22.
49. A. W. Cooper, M. Solvi, and M. Calmes "Blast Furnace Slag Granulation," *Iron and Steel Engineer*, **63** (July 1986), 46–52.
50. R. N. Swamy, "Concrete with Slag: High Performance and Durability without Tears," 4th International Conference on Structural Failure Durability and Retrofitting, Singapore (1993), 206–236.
51. Y. Nagao et al., "Development of New Pavement Base Course Material Using High Proportion of Steel Making Slag Properly Combined with Air-Cooled and Granulated Blast Furnace Slags," Nippon Steel Technical Report No. 43, 1989.

52. M. M. Morsy and M. S. Saleh, "Industrial and NonIndustrial Solid Waste Utilization in Road Building and as Ballast for Railroads," Transportation and Communications Research Council Report, Scientific Research and Technology Academy, Egypt, 1996.
53. Y. Kourany and S. M. El-Haggar, "Utilizing Slag Generated from Iron and Steel Industry in Producing Masonry Units and Paving Interlocks," 28th CSCE annual conference, June 7–10, London, Ontario, Canada, 2000.
54. Heckett MultiServ, "Reprocessing Steel Plant Fines," *Steel Times*, **225** (1), (January 1997): 19–24.
55. N. L. Nemerow, *Zero Pollution for Industry*, John Wiley and Sons, New York, 1995.
56. M. N. R. Demian, "Effect of Different Additives on Properties of Virgin PP/Recycled PP to Substitute PC," M.Sc. Thesis, Mechanical Engineering Department, The American University in Cairo, 2006.
57. ASTM D3039, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, ASTM Standards Source, Philadelphia, 2000.
58. ASTM D543, Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents, ASTM Standards Source, Philadelphia, 1995.
59. Yasser Ibrahim, "Utilization of Municipal Solid Waste Rejects in Producing Wave Dispersion and Shoreline Erosion Protection Structures (Breakwaters)," M. Sc. Thesis, The American University in Cairo, 2006.
60. ASTM D3987-85, Standard Test Method for Shake Extraction of Solid Waste with Water, ASTM Standards Source, Philadelphia, 2004.

BIBLIOGRAPHY

- ASTM D790, Standard Test Methods for Flexural Properties of Un-reinforced and Reinforced Plastics and Electrical Insulating Materials, ASTM Standards Source, Philadelphia, 2003.
- ASTM D792, Standard Test Method for Density and Specific Gravity (Relative Density) of Plastics by Displacement, ASTM Standards Source, Philadelphia, 2000.
- Crawford, R. J., "Plastics Engineering," 3rd Ed., Butterworth–Heinemann, Oxford, 1998.
- El-Haggar, S. M., L. El-Hatow, "Reinforcing Thermoplastics Rejects with Foundry Sand Waste," Submitted for publication to ASCE, 2007.
- El-Haggar, S. M., "Rural and Developing Country Solutions," Chapter 13 in "Environmental Solutions," Ed. by Nelson Nemerow and Franklin Agardy, Elsevier Academic Press, 2005, pp. 313–400.
- El-Haggar, S. M., S. M. Ahmed and M. M. Hamdy, "Production of Compost from Organic Agriculture Enriched with Natural Rocks," *Egyptian Journal of Applied Sciences*, **19** (7B), (July 2004c): 784–799.
- http://www.euroceram.org/en/news/news_14_1.cfm, Accessed May 11, 2007.
- Gouin, F. R., et al, "On-Farm Composting," Northeast Regional Agricultural Engineering Services, NRAES-54, Cooperative Extension, 1993.
- Istituto nazionale per Commercio Estero, "Egitto Reference Period: 2003," www.ice.gov.it/new_settori/main/egitto_II_03.pdf. Accessed July 5, 2007.
- Lardinois, Inge, and Arnold van de Klunder, "Plastic Waste," TOOL Publications and WASTE Consultants, Gouda, The Netherlands, 1995.
- Lowe, Ernest, "Industrial Ecosystems—Methods for Creating Byproduct Exchanges Among Companies," 1999.

- Plöchl, Matthias, and Monika Heiermann, "Biogas Farming in Central and Northern Europe: A Strategy for Developing Countries?" 2006, <http://cigr-ejournal.tamu.edu/submissions/volume8/Invited27Feb2006.pdf>.
- Saikkuu, Laura, "Eco-Industrial Parks: A Background Report for the Eco-Industrial Park Project at Rantasalmi," Finland: Publications of Regional Council of Etela-Savo, 2006.
- Singh, Sanjay, and V. Vijayalakshmi, "Marble Slurry—A New Building Material," Technology Information, Forecasting, and Assessment Council, 2006, <http://www.tifac.org.in/news/marble.htm>.
- Torres, P., H. R. Fernandes, S. Agathopoulos, D. U. Tulyaganov, and J. M. F. Ferreira, "Incorporation of Granite Cutting Sludge in Industrial Porcelain Tile Formulations," **24** (10–11) (September 2004).

CHAPTER 2

RESIDENTIAL AND INSTITUTIONAL ENVIRONMENT

XUDONG YANG

Tsinghua University, Beijing, China

The World Health Organization (WHO) Expert Committee on the Public Health Aspects of Housing defined housing (residential environment) as

the physical structure that man uses for shelter and the environs of that structure including all necessary services, facilities, equipment and devices needed or desired for the physical and mental health and social well-being of the family and individual.¹

Every family and individual has a basic right to a *decent home* and a *suitable living environment*. However, large segments of the population in urban and rural areas throughout the world do not enjoy one or both of these fundamental needs. Therefore, housing must be considered within the context of and relative to the total environment in which it is situated, together with the structure, supplied facilities and services, and conditions of occupancy.

The realization of a decent home in a suitable living environment requires clean air, pure water and food, adequate shelter, and unpolluted land. Also required are freedom from excessive noise and odors, adequate recreational and neighborhood facilities, and convenient community services in an environment that provides safety, comfort, and privacy. These objectives are not achieved by accident but require careful planning of new communities and conservation, maintenance, and redevelopment of existing communities to ensure that the public does not inherit conditions that are impossible or very costly to correct. In so doing, that which is good or sound, be it a structure or a natural condition, should be retained, restored, and reused.

SUBSTANDARD HOUSING AND ITS EFFECTS

Growth of the Problem

Practically all urban and rural areas contain substandard, slum, and blighted areas.* The causes are numerous; they are not easily detected in the early stages or, for that matter, easily controlled.

In the United States there has been a rapid growth in population in the suburbs. Many of the older cities have not enlarged their boundaries and are no longer experiencing a population increase.† Many have shown decline. The population trend graphs (see Figure 2.1) of the city of Buffalo and Erie County, New York, are typical of population shifts in older cities and metropolitan areas.

Between 1800 and 1910, a very rapid growth took place in the cities of the United States due to the mass movement of people from rural to urban areas and heavy immigration from outside the United States. Many of the newer immigrants

Year	Buffalo	Population	
		Erie Co.	Total
1900	352,387	81,399	433,686
1910	423,715		
1920	506,775	127,913	634,688
1930	573,076	189,332	762,408
1940	575,901	222,476	798,377
1950	580,132	319,106	899,238
1960	532,759	530,931	1,064,688
1970	462,768	650,723	1,113,491
1980	357,381	657,545	1,014,926
1990	328,123	640,409	968,532
2000	292,648	657,617	950,265

FIGURE 2.1 Population trends in city of Buffalo and in Erie County, New York.

*Substandard housing is said to exist when there are 1.51 or more persons per room in a dwelling unit, when the dwelling unit has no private bath or is dilapidated, or when the dwelling unit has no running water. Other bases used are described under "Appraisal of Quality of Living." An extensive definition of substandard buildings is given in the *Uniform Housing Code* (International Conference of Building Officials, 5360 South Workman Mill Road, Whittier, CA 90601, 1997 edition, pp. 22–24).

A slum is "a highly congested, usually urban, residential area characterized by deteriorated unsanitary buildings, poverty, and social disorganization" (*Webster's Third International Dictionary*, 1966). A slum is a neighborhood in which dwellings lack private inside toilet and bath facilities, hot and cold running water, and adequate light, heat, ventilation, quiet, clean air, and space for the number of persons housed. It is also a heavily populated area in which housing and other living conditions are extremely poor.

To blight is to "prevent the growth and fertility of; hence to ruin; frustrate" (*Webster's*). A blighted area is an area of no growth in which buildings are permitted to deteriorate.

†The 1980 U.S. Census of Housing showed a general population increase in the "Sun Belt" states in the South and the Southwest, but a decline or stabilizing in many other states. The U.S. Department of Commerce, Bureau of the Census, in *Patterns of Metropolitan Area and County Population Growth: 1980 to 1987*, shows continuation of this trend in the South and West but a stabilization or decline in the Northeast and Midwest regions. Between 1950 and 1986, the percent of the total population in the suburbs outside metropolitan statistical areas increased from 23.30 to 45.05.

sought out their relatives and compatriots, who usually lived in cities, thereby straining the available housing resources.

With the movement of large numbers of people to cities, urban areas became congested, and desirable housing became unobtainable. Inadequate facilities for transporting people rapidly and cheaply to and from work made it necessary for many people to accept less-desirable housing in the cities, close to their work. The inability of the ordinary wage earner to economically afford satisfactory housing left little choice but to accept what housing was available. Some landlords and speculators took advantage of the situation by breaking up large apartments into smaller dwelling units, by minimizing maintenance, and by constructing “cheap” housing.

Unfortunately, assistance or leadership from local government units to control potential problems is slow; there is usually a lag between the creation of housing evils and the enactment of suitable corrective legislation and enforcement. Obsolescence is another factor that causes the growth of slums. Land and property used for purposes for which they may have been well suited in the first place may no longer be suitable for that purpose. An example is the slum frequently found on the rim of a central business area—originally a good residential district convenient to work and business. This may start with the expansion or spillover of business into the contiguous residential areas, thereby making the housing less desirable. People next door or in the same building, desiring quiet and privacy, move. Owners are hesitant to continue maintenance work, causing buildings to deteriorate. The landlord, to maintain income, must either convert the entire building to commercial use or lower rents to attract lower-income tenants. If the landlord converts, more people leave. If the landlord lowers the rents, maintenance of the building is reduced still further, and overcrowding of apartments frequently follows. The progressive degradation from blight to slum is almost inevitable. As blight spreads, so do crime, delinquency, disease, fire, housing decay, and welfare payments.

There are areas that are slums from the start. The absence of or failure to enforce suitable zoning, building, sanitary, and health regulations leads to the development of *shanty towns*, or poor housing areas. Add to this small lots and cheap, new, and converted dwellings and tenements that are poorly located, designed, and constructed, just barely meeting what minimum requirements may exist, and a basis for future slums is assured.

An indifferent or uninformed public can permit the slums to develop. The absence of immediate and long-range planning and zoning, lack of parks and playgrounds, poor street layout, weak laws, inadequately trained personnel to enforce laws, pressure groups, lack of leadership from public officials, and local key citizens, and poor support from the courts and press make the development of slums and other social problems only a matter of time.

Population growth has been taking place outside the major older cities (Figure 2.1), but the rate of housing construction and rehabilitation has not kept pace with its growing needs. Federal grants and loans encouraging low-cost housing and rehabilitation of sound housing; the high cost of new housing,

facilities, and services; and the high cost of gasoline have slowed down the migration of people from the cities to the suburbs. The loss of housing due to obsolescence, abandonment, decay, vandalism, and demolition further compounds the problem. The National Association of Home Builders estimated that more than 2 million new housing units were needed each year in the 1980s, but costs are high and construction is not keeping pace.

According to a 1974 housing survey, lack of plumbing, leaking roofs, inadequate heating, and generally bad housing repair—common problems in the late 1940s—have almost been eliminated. In 1987, only 2.4 percent of the housing units lacked complete, private plumbing, compared to 45 percent in 1940.² Generally, however, low-income families still occupy homes with defects, and housing and neighborhoods in some sections of U.S. cities show obvious signs of deterioration.³ In 1983, 8.9 percent of all occupied housing units were considered physically substandard.⁴

It is apparent that unless the rate of new home construction is accelerated, the rehabilitation of sound substandard dwelling units strongly encouraged, and the conservation and maintenance of existing housing required, a decent home for every American family will never be realized. Added to this is the continued need to provide public housing and financial assistance to the low-income family.

Critical Period

There comes a time in the ownership of income property, particularly multiple dwellings, when the return begins to drop off. This may be due to obsolescence and reduced rents or an increase in operation and maintenance costs, including utilities, fuel, and taxes. At this point, the property may be sold (unloaded); repairs may be made to prevent further deterioration of the property; the property may be abandoned, sold, or demolished for a more appropriate use; or a minimum of repairs may be made consistent with a maximum return and tax payments delayed. This is a critical time and will determine the subsequent character of a neighborhood. In situations where repairs are not made or where a property is sold and repairs are not made and taxes are not paid, the annual rental from substandard property may equal or exceed the assessed valuation of the property. A complete return on one's investment in five to seven years is not considered unusual in view of the so-called risks involved.

Because of this, housing ordinances should be diligently enforced and owners required to reinvest a reasonable part of the income from a property in its conservation and rehabilitation, *at the first signs of deterioration*. This would tend to prevent rapid deterioration, the "milking" of a property, and nonpayment of taxes. The burden on the community to acquire and demolish a worthless structure for nonpayment of taxes or to maintain an eyesore and fire and accident hazard would be lessened. Shortening the time, from the usual five years to one or two years, required for the initiation of *in rem** proceedings to foreclose for real estate

*Legal actions or judgments to seize property.



FIGURE 2.2 Run-down, filthy, vermin-infested backyards present many real health hazards.

tax delinquencies, while the property still has value, would reduce abandonment if coupled with firm but reasonable code enforcement. Cause for further property devaluation and extension of the blighting influence would also be reduced. See Figures 2.2 and 2.3. In New York City, *in rem* proceedings on one- and two-family dwellings can be taken only after three years, but after one year for multiple dwellings. An owner can redeem a building after four months and may, at the city's discretion, within two years if all back taxes and repair costs are repaid.⁵

It is an unfortunate practical fact, because of the complexity of the problem, that effective code enforcement for housing conservation and rehabilitation is in many places not being accomplished. Efforts suffer from frustration and lack of support, aided and abetted by government apathy or sympathy and marginal financial assistance through welfare payments. A greater return can be realized by giving greater assistance to those communities and property owners demonstrating a sincere desire to conserve and renew basically sound areas. Evidence of actual maintenance and improvement of the existing housing supply, code enforcement, encouragement of private building, low-interest mortgages, and provision of low- and middle-income housing are some of the facts that should guide the extent and amount of assistance a community receives.

Rent controls, however, can place the owners of rental properties in poor neighborhoods in a financially untenable position. An inadequate return on an investment usually leads to reduced services and maintenance and to property

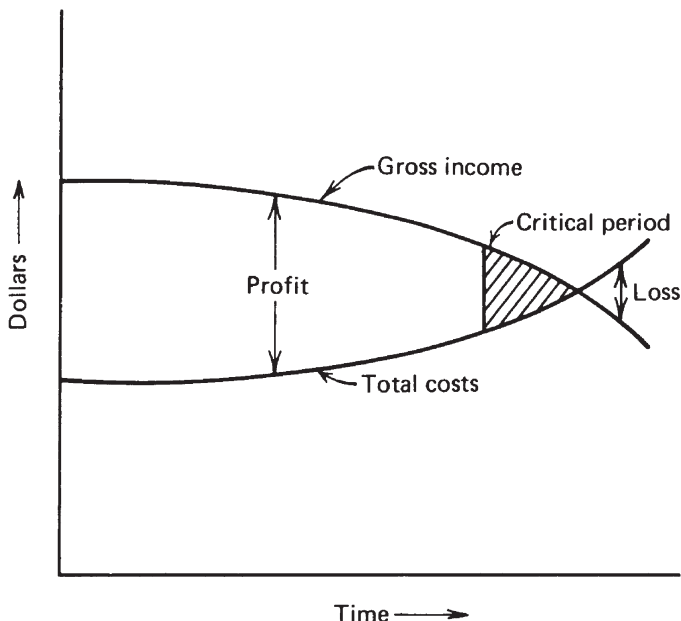


FIGURE 2.3 Rental housing gross income versus total costs with time, showing critical period. Gross income tends to go down and total costs up as property ages.

deterioration. Since a significant number of renters in poor neighborhoods may be on welfare, it would appear sound to provide higher welfare rent allowances and rent subsidies tied to property maintenance and housing code compliance. But an adequate return or profit may be distorted by the sale and resale of property by speculators to dummy corporations at increasing cost. Hence, fairness and caution are necessary.

Another factor may add to the housing problem. When there is a shortage of dwelling units and rentals are high, there is pressure to purchase rather than rent. There is also an incentive to purchase since an income-tax deduction can be taken as a homeowner, which is not available to a renter. However, there is likely to be a concurrent rise in property values when this occurs because of the shortage of rental units at a moderate price. These factors favor the conversion of existing multifamily units to condominiums and construction of new condominiums, thereby excluding from the housing market many who are poor or not sufficiently affluent and those on fixed incomes who cannot afford the higher cost of a condominium. If not protected, those displaced may be forced into less desirable housing and possible exploitation, thus contributing to the spread of slums.

Health, Economic, and Social Effects

The interrelationship of housing and health is complex and not subject to exact statistical analysis. For example, poverty, malnutrition, and lack of education

and medical care also have important effects on health. These may mean long hours of work with resultant fatigue, improper food, and lack of knowledge relating to disease prevention, sanitation, and personal hygiene. The problem is compounded by poor job and income opportunities and by the slum itself, through the feelings of inferiority and resentment of the residents against others who are in a better position. In addition, slums are characterized as having high delinquency, prostitution, broken homes, and other social problems. Who can say if people are sick because they are poor or poor because they are sick. Although a real association is perceived to exist between poor health and substandard housing, it has not been possible to definitely incriminate housing as *the* cause of a specific illness. Many factors contribute to the physical and mental health and social well being of the family and individual, of which housing or the housing environment is one.^{6,7} Studies show that as a matter of practical fact, many factors associated with substandard housing are profoundly detrimental to the life, health, and welfare of a community. The results of a few early studies and reports are summarized in Table 2.1.

The higher morbidity and mortality rates and the lower life expectancy associated with bad housing are also believed to be the cumulative effect or result of continual pressures on the human body. Dubos⁸ points out in a related discussion that many medical problems have their origin in the biological and mental adaptive responses that allowed a person earlier in life to cope with environmental threats. He adds:

The delayed results of tolerance to air pollutants symbolize the indirect dangers inherent in many forms of adaptation, encompassing adaptation to toxic substances, microbial pathogens, the various forms of malnutrition, noise, or other excessive stimuli, crowding or isolation, the tensions of competitive life, the disturbances of physiological cycles, and all other uncontrolled deleterious agencies typical of urbanized and technicized societies. Under normal circumstances, the modern environment rarely destroys human life, but frequently it spoils its later years.

Emphasis must be on preventive sanitation, medicine, architecture, and engineering to avoid some of the contributory causes of early and late disability and premature death. This avoidance includes the insidious, cumulative, long-term insults to the human body and spirit, as well as maintenance and improvement of those factors in the environment that enhance the well being and aspirations of people.

Although this discussion concentrates on the environmental health aspects of housing, it is extremely important that concurrent emphasis be placed on the elimination of poverty and on improved education for those living in poor housing and neighborhoods. It is essential that the causes of poverty and low income be attacked at the source, that usable skills be taught, and that educational levels be raised. In this way, more individuals can become more productive and self-sufficient and develop greater pride in themselves and their communities.

TABLE 2.1 Effects Associated with Substandard Housing

Diseases	Tuberculosis	Health and Other	Police	City Costs
CD rate 65% higher, VD rate 13 times higher, CD death rate as high as 50 years ago ^a	Half of cases from one-fourth of population ^a	Source of 40% of mentally ill in state institutions ^a	Juvenile delinquency twice as high ^a	20% of area in city brings in 6% of real estate tax ^f
	Tuberculosis rate 8 times higher ^b	Infant death rate 5 times higher ^a	20% of area in city accounts for 50% of arrests, 45% of major crimes, 50% of juvenile delinquency ^f	Contributes 5.5% of real estate tax but takes 53% of city service ^f
Intestinal disease rate 100% higher in homes lacking priv. flush toilet ^b	Secondary attack rate 200% ^e Death rate 8.6 times higher ^c 20% of area in city accounts	Infant mortality as high as 50 years ago ^a Life expectancy 6.7 years less ^d	2.6 times more arrests, 1.9 times more police calls, 2.9 times more criminal cases, 3.7 times more juvenile delinquents ⁱ	Slums cost \$88 more per person than they yield; good areas yield \$108 ^j
Meningococcus rate 5.5 times higher ^c Infective and parasitic disease death rate 6.6 times higher ^d	for 60% of cases ^f	64% of out-of-wedlock cases ^g		20% of area in city accounts for 45% of city service costs, 35% of fires ^f
Pneumonia and influenza death rate 2 times higher ^c		Interest rate for mortgages higher in blighted areas Fire insurance rates higher	50% of murders, 60% of manslaughter, 49% of robberies ^g	1.5 times more fires, 15.7 times more families on welfare, 4 times more nursing visits ⁱ

TABLE 2.1 (continued)

Diseases	Tuberculosis	Health and Other	Police	City Costs
Lead poisoning in children higher.		Accidental death rate 2.3 times higher ^d		Account for most of the welfare benefits.
Rat and roach infestation higher. Carbon monoxide poisoning.		Injuries, burns, and accidental poisoning 5–8 times the national average ^h		Slums yielded one-half of cost of services required ^k

^aRelease by Dr. L. Scheele, Surgeon General, PHS Pub. 27, 1949, regarding six cities having slums.

^bNational Health Survey by U.S. Health Service, 1935–1936.

^cB. Blum, *J. Am. Pub. Health Assoc.*, **39**, 1571–1577 (December 1949).

^dErie County Health Department, NY, 1953 Annual Report.

^ePaper on housing and progress in public health by W. P. Dearing, M.D., presented at the University of North Carolina, April 16, 1950.

^fMiscellaneous city studies.

^gThe Twenty-seventh Annual Report of the Buffalo Urban League, Inc., NY.

^hA. H. Stevenson, Airlie House Conference, Department of Health, Education, and Welfare, Washington, DC, March 17–19, 1970.

ⁱReport from City of Louisville, Kentucky.

^jR. M. Foley, “To Eradicate our Vast Slum Blight,” *New York Times*, Magazine section, November 27, 1949.

^kJ. P. Callahan, “Local Units Fight Problem of Slums,” *New York Times*, July 22, 1956.

APPRAISAL OF QUALITY OF LIVING

APHA Appraisal Method

The American Public Health Association (APHA) appraisal method for measuring the quality of housing was developed by the Committee on the Hygiene of Housing between 1944 and 1950. This method attempts to eliminate or minimize individual opinion to arrive at a numerical value of the quality of housing that may be compared with results in other cities and may be reproduced in the same city by different evaluators using the same system. It is also of value to measure the quality of housing in a selected area, say at five-year intervals, and to evaluate the effects of an enforcement program or lack of an enforcement program. The appraisal method measures the quality of the dwellings and dwelling units, as well as the environment in which they are located.

The items included in the APHA dwelling appraisal (see Tables 2.2 and 2.3) are grouped under “Facilities,” “Maintenance,” and “Occupancy.” Additional information obtained includes rent, income of family, number of lodgers, race, type of structure, number of dwelling units, and commercial or business use. The environmental survey (see Table 2.4) reflects the proximity and effects of industry,

TABLE 2.2 Appraisal Items and Maximum Standard Penalty Scores (APHA)

Item	Maximum Score
A. Facilities	
Structure:	
1. Main access ^a	6
2. Water supply ^a (source)	25
3. Sewer connection ^a	25
4. Daylight obstruction	20
5. Stairs and fire escapes	30
6. Public hall lighting	18
Unit:	
7. Location in structure	8
8. Kitchen facilities	24
9. Toilet ^a (location, type, sharing) ^b	45
10. Bath ^a (location, type, sharing) ^b	20
11. Water supply ^a (location and type)	15
12. Washing facilities	8
13. Dual egress ^a	30
14. Electric lighting ^a	15
15. Central heating	3
16. Rooms lacking installed heat ^a	20
17. Rooms lacking window ^a	30
18. Rooms lacking closet	8
19. Rooms of substandard area	10
20. Combined room facilities ^c	
B. Maintenance	
21. Toilet condition index	12
22. Deterioration index ^a (structure, unit) ^b	50
23. Infestation index (structure, unit) ^d	15
24. Sanitary index (structure, unit) ^d	30
25. Basement condition index	13
C. Occupancy	
26. Room crowding: persons per room ^a	30
27. Room crowding: persons per sleeping room ^a	25
28. Area crowding: sleeping area per person ^a	30
29. Area crowding: nonsleeping area per person	25
30. Doubling of basic families	10

^aCondition constituting a basic deficiency.

^bItem score is total of subscores for location, type, and sharing of toilet or bath facilities.

^cItem score is total of scores for items 16–19, inclusive. This duplicate score is not included in the total for a dwelling but is recorded for analysis.

^dItem score is total of subscores for structure and unit.

Notes: (1) Maximum theoretical total dwelling score is 600, broken down as facilities, 360; maintenance, 120; and occupancy, 120. (2) Housing total = Dwelling total + Environmental total.

Source: An Appraisal Method for Measuring the Quality of Housing, Part II, Vol. A, "Appraisal of Dwelling Conditions," American Public Health Association, Washington, DC, 1946. Copyright by the American Public Health Association. Reprinted with permission.

TABLE 2.3 Basic Deficiencies of Dwellings (APHA)

Item ^a	Condition Constituting a Basic Deficiency ^b
A. Facilities	
2.	Source of water supply specifically disapproved by local health department
3.	Means of sewage disposal specifically disapproved by local health department
9.	Toilet shared with other dwelling unit, outside structure, or of disapproved type (flush hopper or nonstandard privy)
10.	Installed bath lacking, shared with other dwelling unit, or outside structure
11.	Water supply outside dwelling unit
13.	Dual egress from unit lacking
14.	No electric lighting installed in unit
16.	Three-fourths or more of rooms in unit lacking installed heater ^c
17.	Outside window lacking in any room unit ^c
B. Maintenance	
22.	Deterioration of class 2 or 3 (penalty score, by composite index, of 15 points or over)
C. Occupancy	
26.	Room crowding: over 1.5 persons/room
27.	Room crowding: number of occupants equals or exceeds 2 times the number of sleeping rooms plus 2
28.	Area crowding: less than 40 ft ² of sleeping area/person

^aNumbers refer to items in Table 2.2.

^bOf the 13 defects that can be designated basic deficiencies, 11 are so classified when the item penalty score equals or exceeds 10 points. Bath (item 10) becomes a basic deficiency at 8 points for reasons involving comparability to the U.S. Housing Census, deterioration (item 22) at 15 points for reasons internal to that item.

^cThe criterion of basic deficiency for this item is adjusted for number of rooms in a unit.

Note: Some authorities include as a basic deficiency unvented gas space heater, unvented gas hot water heater, open gas burner for heating, and lack of hot and cold running water.

Source: *An Appraisal Method for Measuring the Quality of Housing*, Part II, "Appraisal of Dwelling Conditions," American Public Health Association, Washington, DC, 1946. Copyright by the American Public Health Association. Reprinted with permission.

heavy traffic, recreational facilities, schools, churches, business and shopping centers, smoke, noise, dust, and other factors that determine the suitability of an area for residential use.

The rating of housing quality is based on a penalty scoring system, shown in Table 2.2. A theoretical maximum penalty score is 600. The practical maximum is 300; the median is around 75. A score of zero would indicate that all standards are met. An interpretation of the dwelling and environmental scores is shown in Table 2.5. It is apparent, therefore, according to this scoring system, that either the sum of dwelling and environmental scores or a dwelling or environmental score of 200 or greater would classify the housing as unfit.

TABLE 2.4 Environmental Survey—Standard Penalty Scores (APHA)

Item		Maximum ^a Penalty Score
A. Land Crowding		
1.	Coverage by structures—70% or more of block area covered	24
2.	Residential building density—ratio of residential floor area to total = 4 or more	20
3.	Population density—gross residential floor area per person 150 ft ² or less	10
4.	Residential yard areas—less than 20 ft wide and 625 ft ² in 70% of residences	16
B. Nonresidential Land Areas		
5.	Areal incidence of nonresidential land use—50% or more nonresidential	13
6.	Linear incidence of nonresidential land use—50% or more nonresidential	13
7.	Specific nonresidential nuisances and hazards—noise and vibration, objectionable odors, fire or explosion, vermin, rodents, insects, smoke or dust, night glare, dilapidated structure, unsanitary lot	30
8.	Hazards to morals and the public peace—poolrooms, gambling places, bars, prostitution, liquor stores, nightclubs	10
9.	Smoke incidence—industries, docks, railroad yards, soft coal use ^b	6
C. Hazards and Nuisances from Transportation System		
10.	Street traffic—type of traffic, dwelling setback, width of streets	20
11.	Railroads or switchyards—amount of noise, vibration, smoke, trains	24
12.	Airports or airlines—location of dwelling with respect to runways and approaches	20
D. Hazards and Nuisances from Natural Causes		
13.	Surface flooding—rivers, streams, tide, groundwater, drainage, annual, or more	20
14.	Swamps or marshes—within 1,000 yd, malarial mosquitoes	24
15.	Topography—pits, rock outcrops, steep slopes, slides	16
E. Inadequate Utilities and Sanitation		
16.	Sanitary sewage system—available (within 300 ft.), adequate	24
17.	Public water supply—available, adequate pressure, and quantity	20
18.	Streets and walks—grade, pavement, curbs, grass, sidewalks	10
F. Inadequate Basic Community Facilities		
19.	Elementary public schools—beyond 2/3 mi, 3 or more dangerous crossings	10
20.	Public playgrounds—less than 0.75 acres/1,000 persons	8

TABLE 2.4 (continued)

Item	Maximum ^a Penalty Score
21. Public playfields—less than 1.25 acres/1,000 persons	4
22. Other public parks—less than 1.00 acres/1,000 persons	8
23. Public transportation—beyond 2/3 mi, less than 2 buses/hr	12
24. Food stores—dairy, vegetable, meat, grocery, bread, more than 1/3 mi	6

^aMaximum environment total = 368.

^bInclude other sources of air pollution.

Source: *An Appraisal Method for Measuring the Quality of Housing*, Part III, "Appraisal of Neighborhood Environment," American Public Health Association, Washington, DC, 1950. Copyright by the American Public Health Association. Reprinted with permission.

TABLE 2.5 Housing Quality Scores (APHA)

Factor	Good (A)	Acceptable (B)	Borderline (C)	Substandard (D)	Unfit (E)
Dwelling score	0–29	30–59	60–89	90–119	120 or greater
Environmental score	0–19	20–39	40–59	60–79	80 or greater
Sum of dwelling and environmental scores	0–49	50–99	100–149	150–199	200 or greater

Source: *An Appraisal Method for Measuring the Quality of Housing*, Part III, "Appraisal of Neighborhood Environment," American Public Health Association, Washington, DC, 1950. Copyright by the American Public Health Association. Reprinted with permission.

Application of the APHA appraisal method requires trained personnel and experienced supervision.* The survey staff should be divorced from other routine work to concentrate on the job at hand and to produce information that can be put to use before it becomes out of date. In practice, it is desirable to select a limited area(s) for pilot study. The information thus obtained can be used as a basis for determining the need for extension of the survey, need for new or revised minimum housing standards, extent of the housing problem, development of coordination between existing official and voluntary agencies, the part private enterprise and public works can play, public information needs, and so on.

*A trained sanitarian can inspect about 10 dwelling units per day. For every four inspectors, there should be one trained field supervisor, three office clerks, and one office supervisor.

Census Data

Much valuable information is collected and summarized by the U.S. Bureau of the Census. The census data* include the number of one family and multifamily dwelling units, trailers and mobile homes, and condominiums; the population per owner- and renter-occupied unit†; the number of dwelling units with private bath, including hot and cold piped water as well as flush toilet and bathtub or shower and the number lacking some or all these facilities; the number of dwelling units occupied by persons of Spanish/Hispanic origin or descent; the number of rooms and bedrooms per dwelling unit; the number on public water supply, drilled well, dug well, spring or other; the number on public sewerage, septic tank or cesspool, or other system; the type of heating and fuel used; size of plot; information on occupation and income; the monthly rental; and the value or sale price of owner-occupied one-family homes. Other statistics on selected population characteristics for areas with 2,500 or more inhabitants and for counties are available. This information, if not too old, can be used as additional criteria to supplement reasons for specific program planning. Plotting the data on maps or overlays will show concentrations sometimes not discernible by other means.

The accuracy of census data for measuring housing quality has been questioned and, hence, should be checked locally, particularly if it is to be used for appraisal or redevelopment purposes. Nevertheless, it is a good tool in the absence of a better one.

Health, Economic, and Social Factors

It is frequently possible to obtain morbidity and mortality data for specific diseases or causes by census tracts or selected areas. Also available may be the location of cases of juvenile delinquency, public and private assistance, and probation cases. Sources of fires, nuisances, and rodent infestation and areas of social unrest give additional information. Health, fire, police, and welfare departments and social agencies should have this information readily available. See Table 2.1. Tabulation and plotting of these data and overlays will be useful in establishing priorities for action programs.

Planning

The location of existing and proposed recreational areas, business districts, shopping centers, churches, schools, parkways and thruways, housing projects, residential areas, zoning restrictions, redevelopment areas, airports, railroads, industries, lakes, rivers, and other natural boundaries help to determine the

*The latest published census data are *Census 2000*.

†The average number of persons per housing unit was 3.28 in 1940, 3.33 in 1960, 3.14 in 1970, 2.76 in 1980, 2.69 in 1985, and 2.62 in 1989.

best usage of property. Where planning agencies are established and are active, maps giving this, as well as additional information, are usually well developed. Analysis and comprehensive planning on a continuing basis are essential to the proper development of cities, villages, towns, counties, and metropolitan areas. The availability of state and federal aid for communitywide planning should be investigated. Plans for urban development, housing code enforcement, rehabilitation, and conservation should be carefully integrated with other community and state plans before decisions are made. These subjects are discussed in greater detail in Chapter 5.

Environmental Sanitation and Hygiene Indices

Most modern city and county health departments can carry on a housing inspection program based on minimum housing standards, provided competent personnel are assigned. Where housing inspections are made on a routine basis and records are kept on a computer, data processing punch-card system, visible card file, or by combination methods, problem streets and areas can be detected with little difficulty. A survey and follow-up form based on a modern housing ordinance are shown in Figure 2.4. The form should list recommendations for correction based on what is practical from field observation so as to serve as the basis for an accurate confirmatory letter to the owner. The type of deficiencies found, such as the lack of a private bath and toilet, dwelling in disrepair, or lack of hot and cold running water, can give a wealth of information to guide program planning. Usually the origin of complaints—which, if plotted on a map will give a visual picture of the heavy workload areas—can be added to the survey. Reliable cost estimates for complete rehabilitation of selected buildings and a simple foot survey should be made to confirm administrative judgment and decisions before any major action is taken. Many apparently well-thought-out plans have fallen down under this simple test. For example, deterioration may have proceeded to the point where rehabilitation is no longer economically or structurally feasible under existing market conditions. Other criteria are tax delinquency, welfare clients, vandalism, age, ownership turnover, housing vacancy, property value, illnesses, rodent and insect infestation, and the amount of housing demolished.

Other Survey Methods

These include aerial surveys, external ground-level surveys, and the Public Health Service Neighborhood Environmental Evaluation and Decision System (NEEDS).⁹ The selection of a small number of significant environmental variables can also provide a basis for a rapid survey if checked against a more comprehensive survey system.

NEEDS This is a five-stage systems technique designed to provide a rapid and reliable measure of neighborhood environmental quality. The data collected are adapted for electronic data processing to reduce the time lapse between data collection, analysis, program planning, and implementation.

Address _____				Dates inspected _____					
Owner and Address _____				Type of Structure and Occupancy _____ (frame, stucco, brick veneer, solid brick; residential, factory, store)					
No.	Item	Yes	No	CM	No.	Item	Yes	No	CM
1.	Water supply in each apt. satisfact. quality and quantity (no X-conn).					and fixtures clean and sanitary.			
2.	Private in each apt.				12.	Space and water heaters adequate, properly connected, and vented to outer air; back-draft guard; smoke alarm.			
	(a) water closet				13.	Premises free of rodent and vermin infestation; rodent-proof.			
	(b) washbasin				14.	Refuse, garbage, and trash storage proper and adequate.			
	(c) shower/tub				15.	One or more apartments above 2nd floor have 2 means of egress.			
	(d) kitchen sink				16.	Public halls and stairs lighted, daylight and artificial in MD.			
	(e) cabinets and counter				17.	Property and dwelling are properly drained and sewered.			
	(f) refrig. and stove				18.	Owner keeps public areas of building and premises clean.			
3.	Piped hot water for				19.	Living in cellar prohibited.			
	(a) washbasin				20.	Dwelling in good repair, safe, sanitary, and weatherproof (handrails, stairs, walls, wiring, floors, siding, doors, frames, plaster, porch, eaves, roof, foundation beams firm and sound).			
	(b) shower/tub				21.	Lodging house has one washbasin, shower or tub, and water closet per 6 persons.			
	(c) kitchen				22.	Lodging house supplies clean linen and towels prior to letting and weekly.			
4.	Plumbing, heating, electricity, and fixtures are properly installed and maintained.				23.	Cooking in lodging house done in approved and lawful kitchen or kitchenette only.			
5.	Water-repellent floor and base in toilet room and bathroom.								
6.	Window $\frac{1}{10}$ floor area in every room; openable, adequate light and air or induced ventilation for bath.								
7.	Dwelling unit provides 150 ft ² for one and 100 ft ² area for each additional occupant.								
8.	Dwelling can be heated to 68°F.								
9.	Sleeping rooms provide 70 ft ² for one person and 50 ft ² for each additional person.								
10.	Every habitable room has 2 electric outlets; bathroom, w.c. stall, laundry, and hall have a min. 10ft-c on floor.								
11.	Occupant keeps dwelling unit								

NOTE: Explain each "No" item on back by item number and follow with recommendation for correction. "CM" is checked or dated when correction is made. "MD" denotes three or more dwelling units.

Floor	Apt.	Total Hab. Area	Total Hab. Rooms	Bedrooms		Persons	Shelter monthly rental	Remarks: (tenant names, agent, change in ownership)
				No.	Area			

Inspected by: _____

EH-49,5

FIGURE 2.4 Dwelling survey.

Stage I An exterior sidewalk survey is made of 10 to 20 blocks in each problem neighborhood of a city to determine those in greatest need of upgrading. The conditions analyzed include structural overcrowding, population crowding, premises conditions, structural condition of housing and other buildings, environmental stresses, condition of streets and utilities, natural deficiencies, public transportation, natural hazards and deficiencies, shopping facilities, parks and playgrounds, and airport noise. (Time: 1 person-hour per block.)

Stage II The neighborhood(s) selected are surveyed in some depth to determine the physical and social environmental problems facing the residents. About 300 dwelling units and families are sampled in the study area. This phase includes interviews to determine demographic characteristics, health problems, health services, interior housing conditions, and resident attitudes.

Stage III The data collected in stage II are computer processed and analyzed with local government and community leaders. Problems are identified and priorities for action are established.

Stage IV Programs are developed to carry out the decisions made in stage III. The community participates and is kept aware of the study results and action proposed.

Stage V The decisions made and programs developed are implemented. Federal fiscal assistance is also solicited, and the information and support made possible by this technique are used to strengthen applications for grants.⁹

Health Principles

The APHA Committee on the Hygiene of Housing has listed the criteria to be met for the promotion of physical, mental, and social health. Thirty basic principles, with specific requirements and suggested methods of attainment for each, are reported in *Basic Principles of Healthful Housing*, originally published by the APHA in 1938.

The “basic principles” have been expanded to reflect progress made and present-day aspirations of people to help achieve total health goals such as defined by the World Health Organization (WHO). The APHA Program Area Committee on Housing and Health prepared a comprehensive statement of principles available to guide public policy and goal formulation.¹⁰ These can also serve as a basis for performance standards to replace specification standards for building construction, living conditions, and community development. The major headings, or objectives, of the committee report are quoted as follows.

Basic Health Principles of Housing and Its Environment*

- I. **Living Unit and Structure** “Housing” includes the living unit for man and family, the immediate surroundings, and the related community services

*From *Housing: Basic Health Principles & Recommended Ordinance* (ref. 10). Copyright by the American Public Health Association. Reprinted with permission.

and facilities; the total is referred to as the “residential environment.” The following are basic health principles for the residential environment, together with summaries of factors that relate to the importance and applicability of each principle.

A. Human Factors

1. Shelter against the elements.
2. Maintenance of a thermal environment that will avoid undue but permit adequate heat loss from the human body.
3. Indoor air of acceptable quality.
4. Daylight, sunlight, and artificial illumination.
5. In family units, facilities for sanitary storage, refrigeration, preparation, and service of nutritional and satisfactory foods and meals.
6. Adequate space, privacy, and facilities for the individual and arrangement and separation for normal family living.
7. Opportunities and facilities for home recreational and social life.
8. Protection from noise from without, other units, and certain other rooms and control of reverberation noises within housing structures.
9. Design, materials, and equipment that facilitate performance of household tasks and functions without undue physical and mental fatigue.
10. Design, facilities, surroundings, and maintenance to produce a sense of mental wellbeing.
11. Control of health aspects of materials.

B. Sanitation and Maintenance

1. Design, materials, and equipment to facilitate clean, orderly, and sanitary maintenance of the dwelling and personal hygiene of the occupants.
2. Water piping of approved, safe materials with installed and supplied fixtures that avoid introducing contamination.
3. Adequate private sanitary toilet facilities within family units.
4. Plumbing and drainage system designed, installed, and maintained to protect against leakage, stoppage, or overflow and escape of odors.
5. Facilities for sanitary disposal of food waste, storage of refuse, and sanitary maintenance of premises to reduce the hazard of vermin and nuisances.
6. Design and arrangement to properly drain roofs, yards, and premises and conduct such drainage from the buildings and premises.
7. Design and maintenance to exclude and facilitate control of rodents and insects.
8. Facilities for the suitable storage of belongings.

9. Program to ensure maintenance of the structure, facilities, and premises in good repair and in a safe and sanitary condition.

C. Safety and Injury Prevention

1. Construction, design, and materials of a quality necessary to withstand all anticipated forces that affect structural stability.
2. Construction, installation materials, arrangement, facilities, and maintenance to minimize danger of explosions and fires or their spread.
3. Design, arrangement, and maintenance to facilitate ready escape in case of fire or other emergency.
4. Protection against all electrical hazards, including shocks and burns.
5. Design, installation, and maintenance of fuel-burning and heating equipment to minimize exposure to hazardous or undesirable products of combustion, fires, or explosions and to protect persons against being burned.
6. Design, maintenance, and arrangement of facilities, including lighting, to minimize hazards of falls, slipping, and tripping.
7. Facilities for safe and proper storage of drugs, insecticides, poisons, detergents, and deleterious substances.
8. Facilities and arrangements to promote security of the person and belongings.

II. **Residential Environment** The community facilities and services and the environment in which the living unit is located are essential elements in healthy housing and are part of the total residential environment.

A. Community or Individual Facilities

1. An approved community water supply or, where not possible, an approved individual water supply system.
2. An approved sanitary sewerage system or, where not possible, an approved individual sewage disposal system.
3. An approved community refuse collection and disposal system or, where not possible, arrangements for its sanitary storage and disposal.
4. Avoidance of building on land subject to periodic flooding and adequate provision for surface drainage to protect against flooding and prevent mosquito breeding.
5. Provision for vehicular and pedestrian circulation for freedom of movement and contact with community residents while adequately separating pedestrians from vehicular traffic.
6. Street and through-highway location and traffic arrangements to minimize accidents, noise, and air pollution.
7. Provision of such other services and facilities as may be applicable to the particular area, including public transportation, schools,

police, fire protection, and electric power, health, community, and emergency services.

8. Community housekeeping and maintenance services, like street cleaning, tree and parkway maintenance, weed and rubbish control, and other services requisite to a clean and aesthetically satisfactory environment.

B. Quality of the Environment

1. Development controls and incentives to protect and enhance the residential environment.
2. Arrangement, orientation, and spacing of buildings to provide for adequate light, ventilation, and admission of sunlight.
3. Provision of conveniently located space and facilities for off-street storage of vehicles.
4. Provision of useful, well-designed, properly located space for play, relaxation, and community activities for daytime and evening use in all seasons.
5. Provision for grass and trees.
6. Improved streets, gutters, walks, and access ways.
7. Suitable lighting facilities for streets, walks, and public areas.

C. Environmental Control Programs

Maintenance of a healthy environment necessitates an educational and enforcement program to accomplish the following.

1. Control sources of air and water pollution and local sources of ionizing radiation.
2. Control rodent and insect propagation, pests, domestic animals, and livestock.
3. Inspect, educate, and enforce so that premises and structures are maintained in such condition and appearance as not to be a blighting influence on the neighborhood.
4. Community noise control and abatement.
5. Building and development regulations.

In an article based on a working paper prepared for the WHO consultation on housing and implications for health, Schaefer¹¹ listed the following principles of health need and action to be taken to increase the health potential of housing internationally:

Principles of Health Needs

1. Communicable diseases can be reduced if housing provides for safe water supply, sanitary excreta and garbage disposal, adequate drainage of surface waters, and necessary facilities for domestic hygiene and safe food storage and preparation.

2. Housing should protect against avoidable injuries, poisonings, and exposure that contributes to chronic diseases and malignancies.
3. Housing may promote mental well-being; since prehistoric times, the home has been a place of refuge from danger and stress.
4. The neighborhood and community, as well as the dwelling itself, affect health.
5. Health depends also on how residents use their housing.
6. The dwelling conditions of certain groups put them at special health risk, leaving them especially vulnerable to multiple health hazards.

Principles of Health Action

1. Health advocacy in housing decisions should be strongly emphasized by health authorities, in alliance with other concerned groups, at all levels of administration and through multiple channels and media.
2. In the government sphere, health advocacy should be directed at a broad range of policies.
3. To implement socially desirable policies, health advocacy should be intersectoral in its orientation; moreover, it should be integrated into the technical and social processes that countries use to develop and maintain community resources.
4. For policies and standards to be effective, extensive public and professional education is required to promote the provision and use of housing in ways that improve health status.
5. Finally and emphatically, community involvement at all levels should support self-help, neighbor-help, and communal cooperative action in dealing with the needs and problems of the human habitat.

Minimum Standards Housing Ordinance

Building divisions of local governments have traditional responsibility over the construction of new buildings and their structural, fire, and other safety provisions as specified in a building code. Fire departments have responsibility for fire safety. The health department and such other agencies with an interest and responsibility are concerned with the supplied utilities and facilities, their maintenance, and the occupancy of dwellings and dwelling units for more healthy living. This latter responsibility is best carried out by the adoption and enforcement of a housing ordinance.

In an enforcement program, major problems of structural safety or alterations involving structural changes for which plans are required would be referred to the building division. Serious problems of fire safety would be referred to the fire department. Interdepartmental agreements and understanding can be mutually beneficial and make possible the best use of the available expertise. This requires competent staffing and day-to-day cooperation.

Housing and Health APHA-CDC Recommended Minimum Housing Standards has been prepared for local adoption.¹² Other model ordinances are also available.¹³ The standards should apply to *all* existing, altered, and new housing. These standards give the conditions to be complied with before and during occupancy. They are minimum standards and in many instances should be exceeded.

A housing code or ordinance should reflect the need for safety devices and the hazards associated with new construction materials. Provision should also be made for compliance assistance and enforcement flexibility.

Smoke detectors have been found to be effective safety devices that belong in all dwellings and dwelling units. These devices afford major protection to life and property, particularly when coupled with alarms and sprinklers in multiple dwellings.

Energy conservation concerns have emphasized the importance of insulation materials to prevent heat losses from buildings. It is necessary to ensure that such materials are not flammable and do not release toxic fumes or materials when installed or subjected to high temperatures.

The administrative section of a housing code should permit the phased improvement of sound dwellings and dwelling units first in selected areas having identifiable grossly substandard living conditions. The expected level of compliance would be consistent with the intent of the housing code regulations and the achievable environmental quality of the neighborhood. Low-interest loans, fiscal and technical guidance, limited grants, craftsmen and labor assistance, tax relief, and other inducements are essential to encourage rehabilitation, stem the tide of deterioration and blight, and make possible compliance with the housing code. Concurrently, community services and facilities would need to be improved and maintained at an adequate level.

HOUSING PROGRAM

Approach

Housing can be a complex human, social, and economic problem that awakens the emotions and interests of a multitude of agencies and people within a community. Government agencies must decide in what way they can most effectively produce action; that is, whether in addition to their own efforts it is necessary to give leadership, encouragement, and support to other agencies that also have a job to do in housing.

Resolution of the housing problem involves just about all official and non-official groups or agencies. Organization begins with the housing coordinator, as representative of the mayor or community executive officer. The groups involved include an interagency coordinating committee; citizens advisory committee; health, building, public works, law, and fire departments; urban development agency; housing authority; financing clinic; planning board; air pollution control agency; office of community relations; public library; rent control office; universities and technical institutes; welfare department; council

of social agencies; neighborhood and community improvement associations; banking institutions; real estate groups; consulting engineers and architects; general contractors; builders and subcontractors; press; and service organizations.

Components of a Good Housing Program

Good housing does not just happen. It is the result of far-sighted thinking by individuals in many walks of life. In some cases, a few houses are built here and there and areas grow with no apparent thought given to the future pattern being established. This is typical of small subdivisions of land and developments where there is no planning. In other instances, typical of large-scale developments, construction proceeds in accordance with a well-defined plan. The growth of existing communities, the quality of service and facilities provided, and the condition in which they are maintained usually depend on the leadership and coordination provided by the chief executive officer and legislative body and the controls or guides followed. The more common support activities are described later in this chapter.

Planning Board A planning board can define the area under control and, by means of maps, locate existing facilities and utilities. Included, for example, are highways, railroads, streams, recreational areas, schools, churches, shopping centers, residential areas, commercial areas, industrial areas, water lines, and sewer lines. In addition, plans are made for future revisions or expansion for maximum benefit to the community. A zoning plan is needed to delineate and enforce the use to which land will be put, such as for residential, farm, industrial, and commercial purposes. This also provides for protection of land values. Subdivision regulations defining the minimum size of lots, width and grading of roads, drainage, and utilities to be provided may also be adopted. New roads or developments would not be accepted unless in compliance with the subdivision standards. The planning board, if supported, can guide community changes and, if established early, direct the growth of a community, all in the best interest of the people.

Department of Public Works A public works department usually has jurisdiction over building, water, sewers, streets, refuse, and, if not a separate department, fire prevention and protection.

The building division's traditional responsibility is regulation of all types of building construction through the enforcement of a building code. A building code includes regulations pertaining to structural and architectural features, plumbing, heating, ventilation and air conditioning, electricity, elevators, sprinklers, and related items. Fire structural regulations are usually incorporated in a building code, although a separate or supplementary fire prevention code may also be prepared. Certain health and sanitary regulations, such as minimum room sizes, plumbing fixtures, and hot- and cold-water connections, should, of course, be an integral part of a building code. This ensures that new construction and alterations

will comply with the health department's housing code minimum standards regulating occupancy, maintenance, and supplied facilities.

The water and sewer division would have the fundamental responsibility of making available and maintaining public water supply and sewerage services where these sanitary facilities are accessible. In new subdivisions of land, the provision of these facilities, particularly when located outside the corporate limits of a city or village, is usually the responsibility of the developer.

The division of streets would maintain streets, including snowplowing, cleaning, rebuilding old roads, and ensuring the proper drainage of surface water. In unincorporated communities the highway department assumes these functions. New roads would not be maintained unless dedicated to the city, village, or township and of acceptable design and construction.

Refuse collection would include garbage, rubbish, and trash. This function may be handled by the municipality, by contract, or by the individual.

Public Housing and Urban Development In existing urban communities, the housing authority is generally responsible for the construction and operation of dwellings for low-income families and for the rehousing of families displaced by slum clearance. The urban development agency assembles and clears land for reuse in the best interest of the community and rehouses persons displaced as a result of its actions. In basically good neighborhoods, unsalvable housing is demolished, good housing is protected, and sound substandard housing is rehabilitated. In general, large-scale demolition involving the destruction of viable neighborhoods having structurally sound housing should be avoided.

Health Department State and local health departments have the fundamental responsibility of protecting the life, health, and welfare of the people. Although most cities have health departments, many areas outside of cities do not have the services of a completely staffed county or city-county health department. However, where provided, the health department responsibilities are given in a public health law and sanitary code. In addition to communicable disease control, maternal and child health care, clinics, nursing services, and environmental sanitation, the health department should have supervision over housing occupancy, maintenance and facilities, food sanitation, water supply, sewage and solid waste disposal, pollution abatement, air pollution control, recreation, sanitation, control, radiation hazards, and the sanitary engineering phases of land subdivision. The environmental sanitation activities, being related to the planning, public works, housing, and redevelopment activities, should be integrated with the other municipal functions. For maximum effectiveness and in the interest of the people, it is also equally proper that the services and talents available in the modern health department be consulted and utilized by the other municipal and private agencies.

Health departments have the ideal opportunity to redirect and guide nuisance and complaint investigations; lead-poisoning elimination; carbon monoxide poisoning prevention; and insect, rodent, and refuse control activities into a planned and systematic community sanitation and housing hygiene program. By coordination with nursing, medical care, and epidemiological activities, as well as

with those of other agencies, the department is in a position to constructively participate in the elimination of the causes contributing to the conditions associated with slums and substandard housing. The health department should also assist in the training of building, sanitation, welfare, and fire inspectors and others who have a responsibility or interest in the maintenance and improvement of living conditions.

Private Construction New construction and rehabilitation of housing in accordance with a good building and housing code are essential to meet the normal needs of people. Private construction and rehabilitation of sound structures should be encouraged and controlled to meet community goals and objectives in accordance with an adopted plan. In complete rehabilitation of a sound structure, the supporting walls, facade, and floor beams are preserved and new kitchens, bathrooms, bedrooms, living rooms, public areas, and utilities are installed. The availability of streets, water, sewers, and other utilities minimizes the total cost of providing “new” rental units, particularly if supported by some federal grant and low-interest loans. This could be accompanied by the establishment of cooperative ownership by qualified families and by self-help programs (Habitat for Humanity).

Rehabilitation is sometimes discouraged by contractors and architects because it can be full of surprises, depending on the extent of the preliminary investigation and the completeness of plans and specifications.

Loan Insurance Mortgage loan insurance by the government to stimulate homeownership has been fundamental to the construction and preservation of good housing. However, private financial institutions also have a major function and obligation. The reluctance or refusal of some lending institutions to make loans in certain urban areas for housing rehabilitation or purchase, known as *redlining*, and the similar practice by insurance companies for fire and property insurance, confound efforts to upgrade neighborhoods. Such practices should be reviewed.

Outline of a Housing Program

Several approaches have been suggested and used in the development of a housing program. They all have several things in common and generally include most of the following steps.¹⁴

1. Establishment of a committee or committees with representation from official agencies, voluntary groups, the business community, and outstanding individuals as previously described.
2. Identification of the problem—the physical, social, and economic aspects and development of a plan to attack each.
3. Informing the community of survey results, housing needs, and the recommended action.

4. Designation of a board or commission to coordinate and delegate specific functions to be carried out by the appropriate agency—for example, urban renewal, redevelopment, public housing, code enforcement, rehousing, rehabilitation, and refinancing.
5. Appropriation of adequate funds to support staffing and training of personnel.
6. Appraisal of housing and neighborhoods and designation of urban, suburban, and rural areas for (a) clearance and redevelopment, (b) rehabilitation, and (c) conservation and maintenance. This involves identification of structures and sites selected for preservation, interim code enforcement, rehabilitation of basically sound structures not up to code standards, spot clearance, provision or upgrading of public facilities and services, and land-use control.
7. Preparation and adoption of an enforceable housing code and other regulations that will upgrade the living conditions and provide a decent home in a suitable living environment.
8. Institution of a systematic and planned code enforcement program, including education of tenants and landlords, *prompt* encouragement and *requirement* of housing maintenance, improvement, and rehabilitation where indicated.
9. Concurrent provision and upgrading of public facilities and services where needed.
10. Provision of new and rehabilitated housing units through public housing, private enterprise, nonprofit organizations, individual owners, and other means.
11. Aid in securing financial and technical assistance for homeowners.
12. Liaison with federal, state, and local housing agencies, associations, and organizations.
13. Requirement that payments to welfare recipients not be used to subsidize housing that does not meet minimum health standards.
14. Evaluation of progress made and continual adjustment of methods and techniques as may be indicated to achieve the housing program goals and objectives.

These efforts need to be supplemented by control of new building construction, land subdivision, and mobile home parks. Also to be included are migrant-labor camps, camp and resort housing, commercial properties, and housing for the aged, chronically ill, handicapped, and those on public assistance.

Solutions to the Problem

The more obvious solutions to the housing problem are production of new housing, rehabilitation of sound housing, redevelopment, slum clearance, and public housing for low-income families. Increasing emphasis is being

placed on cooperative ownership and on the conservation and rehabilitation of existing sound housing to prevent or slow down blight.* It is probably the most economical way of providing additional, healthier dwelling units and at the same time protecting the existing surrounding supply of good housing. Privately financed housing, redevelopment, and public housing cannot reach their full usefulness unless the neighborhood in which they are carried out is also brought up to a satisfactory minimum standard and is protected against degradation.

Federal, state, and local governments have an essential role in providing leadership and support. Federal programs usually make assistance available to finance housing for low- and moderate-income families, for urban development of programs including rehabilitation and conservation, and for redevelopment of urban communities. The federal programs include community development block grants, urban development action grants, low-income housing assistance, loan guarantees, and rehabilitation loans to eligible communities. Their implementation varies with the availability of federal funds. A local legally constituted agency is necessary to represent the municipality.

For example, eligibility for urban redevelopment funds may require formulation of a program to effectively deal with the problem of urban slums and blight within the community and to establish and preserve a well-planned community with well-organized residential neighborhoods of decent homes and suitable living environment for family life. The program can also make a municipality eligible for assistance for concentrated code enforcement, special help to blighted areas, demolition grants, rehabilitation grants and loans, and neighborhood facilities improvement and development. A workable program would require the following:

1. Adoption of adequate minimum standards of health, sanitation, and safety through a comprehensive system of codes and ordinances effectively enforced.
2. Formulation of a “comprehensive community plan” or a “general plan”—implying long-range concepts—and including land use, thoroughfare, and community facilities plans; a public improvement program; and zoning and subdivision regulations. See Chapter 5.
3. Identification of blighted neighborhoods and analysis for extent and intensity of blight and causes of deterioration to aid in delineation for clearance or other remedial action.
4. Establishment of an adequate administrative organization, including legal authority, to carry on the urban renewal program.
5. Development of means for meeting the financial obligations and requirements for carrying out the program.

*Careful analysis is advised, as the hidden costs and problems associated with major building rehabilitation cannot as a rule be fully anticipated. (M. Federman, “Building Rehabilitation: The Last Resort,” *Civil Eng.*, ASCE (July 1, 1981), pp. 72–73.)

6. Provision of decent, sanitary housing for all families displaced by urban renewal or other government activities.
7. Development of active citizen support and understanding of the urban renewal program.

The restoration of a substandard housing area in an otherwise sound and healthy neighborhood must include removal of the blighting influences to the extent feasible and where indicated. These include heavy traffic, air pollution, poor streets, lack of parks and trees, poor lighting, dirty streets and spaces, inadequate refuse storage and collection, inadequate water supply and sewerage, unpainted buildings, noisy businesses and industries, and tax increases for housing maintenance and improvement.

Further explanations and specifics to carry out some of these program functions are given in the sections that follow.

Selection of Work Areas

A housing program must keep in proper perspective community short- and long-term plans, special surveys and reports, area studies, pilot block enforcement, and the routine inspection work to enforce a minimum standards housing ordinance. Continual evaluation of the program is necessary to ensure that the control of blight and deterioration of buildings and neighborhoods, as well as the rehabilitation of substandard dwellings, is being carried out where encountered. When indicated and possible, such action should be carried out on a planned block or area basis. This makes accomplishments more apparent and also awakens community pride, which can become "infectious." A blighted block does not always have a neon sign at the head of the street. The very insidiousness of blight makes it difficult to recognize and will have to be deliberately sought out and attacked. It may be only one or two houses in a block, which are recognized by a dilapidated outward appearance, by the inspector's intimate knowledge of the neighborhood and people, by office records showing a history of violations, or by routine survey reports. Signs of deterioration and dilapidation should be attacked immediately before decay and blight take over and incentive to make and support repairs becomes an almost impossible task.

The selection of conservation, rehabilitation, clearance, and redevelopment areas should take into consideration and adapt the following nine criteria:

1. The grading of socioeconomic areas using a weighted composite consisting of overcrowding, lack of or dilapidated private bath, lack of running water, and other measurable factors reported by the Bureau of the Census, including income and education.
2. The grading of areas using health indices and mortality and morbidity data.
3. The grading of areas on the basis of social problems, juvenile delinquency, welfare and private agency case load, adult probation, early venereal diseases, social unrest, and so on.

4. The areas having the high, average, and low assessed valuation, dilapidation, and overcrowding.
5. The grading of neighborhoods using the APHA or equal appraisal system, health and building department surveys, and plotted data. A sampling of 20 percent of the dwellings can give fairly good information.
6. Results of surveys and plans made by planning boards, housing authorities, and redevelopment boards.
7. Selection of work areas with reference to these criteria, as well as existing and planned housing projects, parks, redevelopment areas, parkways or thruways, railroads, and industrial or commercial areas; also existing barriers such as streams or lakes, good housing areas, swamps, and mountains.
8. Health department environmental sanitation and nursing division office records and personal knowledge of staff.
9. Visual foot surveys and combinations of items 1 through 8.

The superimposition of map overlays showing these characteristics will bring out areas having the most problems.

Enforcement Program

Enforcement of a housing conservation and rehabilitation ordinance involves use of the same procedures and techniques that have been effective in carrying out other environmental sanitation programs. The development of a proper attitude and philosophy of the intent of the law and its fair enforcement should be the fundamental theme in a continuing in-service training program. A housing enforcement program can proceed along the following lines:

1. Inspection of a pilot area to develop and perfect inspection techniques and learn of problems and practical solutions to obtain rehabilitation of substandard areas.
2. Routine inspection of all hotels and rooming and boarding houses for compliance with minimum standards housing ordinance. A satisfactory report could be a condition to the issuance of a permit and a license to operate.
3. Routine inspection of multiple dwellings. An initial inspection on a two-or three-year plan will reveal places requiring reinspection.
4. Inspections throughout a city, village, or town on an individual structure, block, and area basis to obtain rehabilitation and conservation of sound housing or demolition of unsalvable structures. This may be made a requirement by local ordinance before a dwelling or multiple dwelling can be resold. It could also apply before rental.
5. Concentration of inspection in and around salvable areas to spread the border of improved housing so that it will merge with a satisfactory area.
6. Redirection of complaint inspections to complete housing surveys when practical. This can make available a large reservoir of personnel for more productive work.

7. Continuing in-service training with emphasis on law enforcement through education and persuasion, alteration and reconstruction, letter reporting, and financing to obtain substantial rehabilitation, not patchwork.
8. Close liaison with all city departments, especially city planning and building divisions, urban renewal agency, welfare, and the courts.
9. Continuing public education, including involvement of community and neighborhood organizations, to support the housing program and help or guide owners to conserve and rehabilitate their homes.

The enforcement program should take into consideration the problems, attitudes, and behavior of the people living in the dwelling units and the changes that need to be effected with the help of other agencies. The enforcement program must also recognize that, to be effective, subsidies and other forms of assistance to low-income families will usually be necessary to support needed alterations and rehabilitation.

Staffing Patterns Various staffing patterns have been suggested to administer a housing code enforcement program. One basis is a program director supported by one assistant to supervise up to eight inspectors, each making an estimated 1,000 inspections per year. Slavet and Levin suggest the following seven ratios¹⁵:

1. One inspector per 10,000 population or one inspector per 1,000 substandard dwelling units (this assumes inspection and reinspection to secure compliance at an average of 200 substandard dwelling units per year over a five-year period)
2. One inspector per 3,000 standard dwelling units, assuming inspection of 600 units per year over a five-year period, in addition to the staff needed to handle complaints
3. One financial specialist for every three or four housing inspectors
4. One community relations specialist for every three or four housing inspectors
5. One rehabilitation specialist for every two or three inspectors
6. One clerk for every three or four inspectors
7. One supervisor for every six to eight inspectors

Some Contradictions An enforcement program will reveal many contradictory facts relating to human nature. These only serve to emphasize that the housing problem is a complex one. The social scientist and anthropologist could study the problems and assist in their solution, provided he or she works in the field with the sanitarians and engineers:

For example, it has been found that a person or family living in a substandard housing area may be very reluctant to move away from friends and relatives to a good housing area where the customs, religion, race, and very environment are different.

A housing survey may show that a structure is not worth repairing, and the expert construction engineer or architect may be able to easily prove that conclusion. But the owner of a one-, two-, or three-family building will rarely agree. He will go on to make certain minimum repairs or even extensive repairs to approach the standards established in the housing ordinance, leaving you wondering if there really is any such thing as a nonsalvable dwelling.

There is the not-infrequent situation where two old structures are located on the same lot, one facing the street and the other one the rear-lot line. If one structure is demolished, another cannot be built on the same lot because zoning ordinances usually prohibit such intensive lot usage by new structures. Therefore, the owner, rather than lose the vested right due to prior existence of the structure, with respect to the zoning ordinance, may choose to practically rebuild the dwelling at great cost rather than tear it down.

Another common occurrence is the tendency for some landlords to seize upon health or building department letters recommending improvements to bring the building into compliance with the housing ordinance as the opportunity to evict tenants and charge higher rentals. This is not to say that the owner is not entitled to a fair return on an investment, but the intent is that no one should profit from human misery. (A fair return on one's investment has been given as 10 percent of the assessed valuation or purchase price of the property.) Since the department's objective is to improve the living conditions of the people, it should not become a party to such actions. As a matter of fact, it is the unusual situation where needed housing improvements cannot be made with the tenant living in the dwelling unit, even though some temporary inconvenience may result. Hence, in such situations, it is proper for the department to opine that the needed repairs can be made without evicting tenants, thereby leaving the final determination in the exceptional cases with the owner and the courts.

A rather unexpected development may be the situation where an owner agrees to make repairs and improvements, such as new kitchen sink and provision of a three-piece bath with hot as well as cold water under pressure, only to be refused admittance by the tenant. The tenant knows that the rent may be increased and suddenly decides that a new bathroom is a luxury he or she can get along without. In such case, the courts have granted eviction orders and have sanctioned the reasonable increase in rent.

Rent control makes possible affordable housing for many families, but inadequate rents (income) discourage maintenance and promote decay and eventual building abandonment. See Figure 2.3. A fair balance must be reached.

Fiscal Aspects The financing of improvements is sometimes an insurmountable obstacle to the lay person. As an aid to the people affected by a housing enforcement program, a "financing clinic" can be formed to advise homeowners

in difficult cases. The clinic may be a committee consisting of a banker, an architect, a general contractor, a plumbing contractor, and a representative of the building division, redevelopment board, federal agencies, and community. The department representative would help the owner present the problem. If the homeowner is instructed to submit estimates of cost from two or three reliable contractors, a sounder basis for assistance is established.

An enforcement program must recognize that many investors use the criterion that a dwelling is not worth purchasing unless it yields a gross annual income equal to one-quarter to one-fifth of the selling price. Another rule of thumb for rehabilitation of a dwelling is that the cost of alteration plus selling or purchase price shall not be more than five times the gross annual income, or an individual's income shall be at least 25 to 28 percent of the cost of the dwelling unit (taxes, mortgage, maintenance).

Enforcement Procedures

The fair and reasonable enforcement of the *intent* of a minimum standards housing ordinance requires the exercise of trained judgment by the administrators, supervisors, and field inspectors. Continuing in-service training of the housing staff is essential to carry out the purpose of the housing ordinance in an effective manner.¹⁸ A trained educator can offer valuable assistance and guidance in planning the training sessions and in interpreting the program to the public and legislators. Health department sanitarians are admirably suited to carry out the housing program because of their broad knowledge in the basic sciences and their ability to deal effectively with the public.

The enforcement measures and procedures can be summarized as follows:

1. Prepare a housing operating manual giving a background of the housing program, guides for conduct, inspection report form based on the housing ordinance, interpretation of sections of the ordinance needing clarification for field application, suggested form paragraphs for routine letters, including typical violations and recommendations for their correction, follow-up form letters, building construction details, and related information. A few form paragraphs and architectural details are included in the text to suggest the type of material that can be included in a housing manual to obtain a certain amount of uniformity and organization in a housing enforcement program.
2. Complete an inspection of all types of premises and dwelling units occupied as living units. A comprehensive checklist or survey form based on the housing ordinance similar to Figure 2.4 could be used.
3. Prepare a complete rough-draft letter by the sanitarian based on field inspection, listing what was found wrong, together with recommendations for correction.
4. Review the inspection report and suggested letter by a supervising sanitarian for completeness and accuracy. The letter is signed by the supervisor and a tickler date confirmed for a follow-up inspection. See Figure 2.5.

JAS/er (1) 9/54:1000

5. Maintain a visible card-index file or computer entry on each multiple dwelling, boarding house, rooming house, and hotel, in addition to a file on each dwelling, including one- and two-family structures.
6. Send a reinspection letter based on the findings reported in the first letter and remaining uncorrected. This may take the form of an abridged original letter listing what remains to be done, a letter calling for an informal hearing, a letter giving 30 days in which to show substantial progress, or a special letter. See Figure 2.6.
7. In some instances, substantial improvements are requested that justify a reasonable rent adjustment. This should be brought out at the time of

COUNTY OF
HEALTH DEPARTMENT

Re: _____, New York

Dear _____

This department notified you by letter on _____ of the housing deficiencies existing on your premises and the need for making corrections. However, a reinspection showed that no substantial progress had been made, and to date we have received no reply from you.

Inasmuch as the conditions enumerated in our letters to you are violations of the _____ Minimum Housing Standards Ordinance, it is imperative that the needed improvements be made. Your failure to reply must be interpreted as an indication of lack of good faith or misunderstanding of the intent of our letters.

Under the circumstances, you are requested to appear in Room _____, City Hall, at _____ to show cause why legal action should not be started. It is hoped that you will come prepared with an itemized report, indicating when the needed improvements will be completed, so as to make unnecessary further action by this department.

We wish to emphasize that it is our intention and obligation to follow up on violations of the Minimum Housing Standards Ordinance until such time as all work is done. It is only in this way that existing housing in the City of _____ can be conserved and rehabilitated.

Very truly yours,
J. A. Salvato, Jr., P. E.,
Chief, Bureau of General Sanitation
By.....

JAS/er(3)
9/54:500

FIGURE 2.6 Administrative hearing letter.

informal hearings when financial hardship is pleaded. Informal administrative hearings are very useful.

8. Conduct office consultation with owners to investigate long-range improvement programs within the limits of the law and the federal, state, and private assistance available.
9. Maintain a list of competent contractors who perform alteration work.
10. Review cost estimates with the owner for completeness.
11. Arrange for expert consultation to finance improvements, including a hearing before a "financing and construction clinic," which should have

representation from the lending institutions as well as from the contractors, architects, and engineers.

12. In recalcitrant cases, secure a letter from the chief city judge or justice providing for a pretrial hearing to show cause why a summons should not be issued, followed by the hearing. A similar procedure could be followed by the corporation counsel or county attorney. The courts could also establish a special session to hear housing cases.
13. Issue a summons by the corporation counsel at the request of the enforcement agency when other measures have failed, if authorized by local law. A record of appearances and results should be kept.
14. Issue a summons by an authorized member of the enforcement agency in emergencies, if authorized by local law.
15. Cooperate with the press with a view toward obtaining occasional special reports, feature articles, and community support.
16. Cooperate and liaison with all private and public agencies having an interest in housing.
17. Notify the welfare department when public assistance is being given for rental because payment for housing should be made only when the facilities and conditions of maintenance and occupancy meet minimum standards.
18. Educate the legal department to obtain an aggressive, trained, and competent attorney who can become experienced in housing problems and be able to guide the legal enforcement phase of housing work.
19. Stimulate resurgence of neighborhood pride in the rehabilitation and conservation of all buildings on a block or area basis. Information releases and bulletins explaining what community groups and individuals can do to improve their housing is an excellent approach.
20. Discourage profit at the expense of human misery by making it possible through state law to file a lien in the county clerk's office against a property that is in violation of health ordinances, for the information of all interested and affected persons.
21. Notify the mortgage holders and insurance carriers of existing conditions.
22. Propose legislation requiring those who purchase city-owned property at public auctions to first list all the property they have owned in the past five years, properties they own with delinquent city taxes, the name and address of all major stockholders if a corporation, whether the purchaser owns vacant or abandoned buildings, and whether the city had ever taken title to the purchaser's property for back taxes.
23. In the case of corporate ownership, propose legislation requiring that name, address, and the number or percentage of shares owned in the corporation be filed in the county clerk's office.

24. Require registration and periodic reregistration of current ownership to facilitate the service of notices and enforcement. Require an in-state agent for receipt of legal notices.
25. Require a certificate of occupancy each time an apartment is rented to a new tenant.
26. Propose legislation authorizing payment of rent into an escrow account to correct code violations, after which the account is turned over to the owner.
27. Fund a municipal emergency repair program through attachment of rents or a property lien.
28. Arrange low-interest loans and grants to make repairs.
29. Push for legislation permitting tax foreclosure proceedings within two years or less to permit acquisition of property while it still has value, before it has deteriorated beyond hope of economic rehabilitation, with safeguards for the sincere resident owner who is temporarily in financial difficulty. This requires a systematic inspection system, early identification of deficiencies, prompt and vigorous enforcement, or foreclosure, where indicated.

The enforcement procedure generally includes news releases and information bulletins, inspection, notification, reinspection, second notification, third notification, informal hearings, administrative hearings, pretrial hearings, and summonses. In brief, therefore, the enforcement procedure consists of education and persuasion, with legal action being a last resort.

Not to be forgotten is stimulation of the possible role of nongovernment agencies having a direct or indirect interest and concern in the maintenance of good housing and in housing rehabilitation. The role could consist of seminars and individual assistance for home improvement given by banks, material supply companies, builder and contractor organizations, community colleges, urban development and redevelopment agencies, and fire insurance companies. The assistance could include financing methods for improvements; available federal (and state) grants and loans; filing of applications for assistance; owner-contractor relations; value of architectural services; and information on materials, supplies, and equipment for home repairs and improvements, their advantages, disadvantages, and costs.

HOUSING FORM PARAGRAPHS FOR LETTERS

It is necessary to have some reasonable uniformity and accuracy when writing letters or reports to housing code violators. This becomes particularly important when a housing code enforcement unit has a large staff and when court action is taken. By using a dwelling inspection form such as Figure 2.4, and the form paragraphs listed here, it should be possible for the inspector to readily prepare

a draft of a suitable letter for review by that inspector's supervisor. The form paragraphs can and should be modified as needed to reflect more precisely the unsatisfactory conditions actually observed and practical suggestions for their correction. Reference to the pages that follow will be helpful in describing violations for use in the form letter (Figure 2.5). All construction must comply with the local or state building and fire prevention code.

Structural Safety

To be considered structurally safe, a building must be able to support two and a half to four times the loads and stresses to which it is or may be subjected.

Certain conditions that may be deemed dangerous or unsafe need explanation. For example, a 12-inch beam that has sagged or slanted more than one-quarter out of the horizontal plane of the depth of floor structural members in any 10-foot distance would be more than 3 inches out of level in 10 feet and, hence, unsafe. An interior wall consisting of 2×4 -inch studs or 4-inch terracotta tile blocks more than one-half out of the vertical plane of the thickness of those members between any two floors would be more than 2 inches out of plumb and, hence, unsafe. See Figure 2.7.

A stair, stairway, or approach is safe to use when it is free of holes, grooves, and cracks that are large enough to constitute a possible accident hazard. Rails and balustrades are expected to be firmly fastened and maintained in good condition. Stairs or approaches should not have rotting or deteriorating supports, and stairs that have settled more than 1 inch or pulled away from the supporting or adjacent structure may be dangerous. Stair treads must be of uniform height and sound and securely fastened in position. Every approach should have a sound floor and every tread should be strong enough to bear a concentrated load of at least 400 lb without danger of breaking through. See Figure 2.8.

Incomplete Bathroom

The (first floor rear apartment) did not have a tub or shower. A complete bathroom—including a water closet, tub or shower, and washbasin connected with hot and cold running water—is required to serve each family. See Figures 2.9 and 2.10. The bathroom shall have a window or skylight not less than 10 percent of the floor area, with at least 45 percent openable, providing adequate light and ventilation. A water-repellent floor with a sanitary cove base or its equivalent is necessary. A ventilation system may be approved in lieu of a window or skylight.

No Hot Water

There was no piped hot water in the (kitchen of the first floor-front apartment). This apartment shall be provided with hot water or water-heating facilities of adequate capacity, properly installed and vented. The heater shall be capable of heating water to permit water to be drawn at every required kitchen sink, lavatory basin, bathtub, or shower at a temperature of approximately 110°F (43°C).

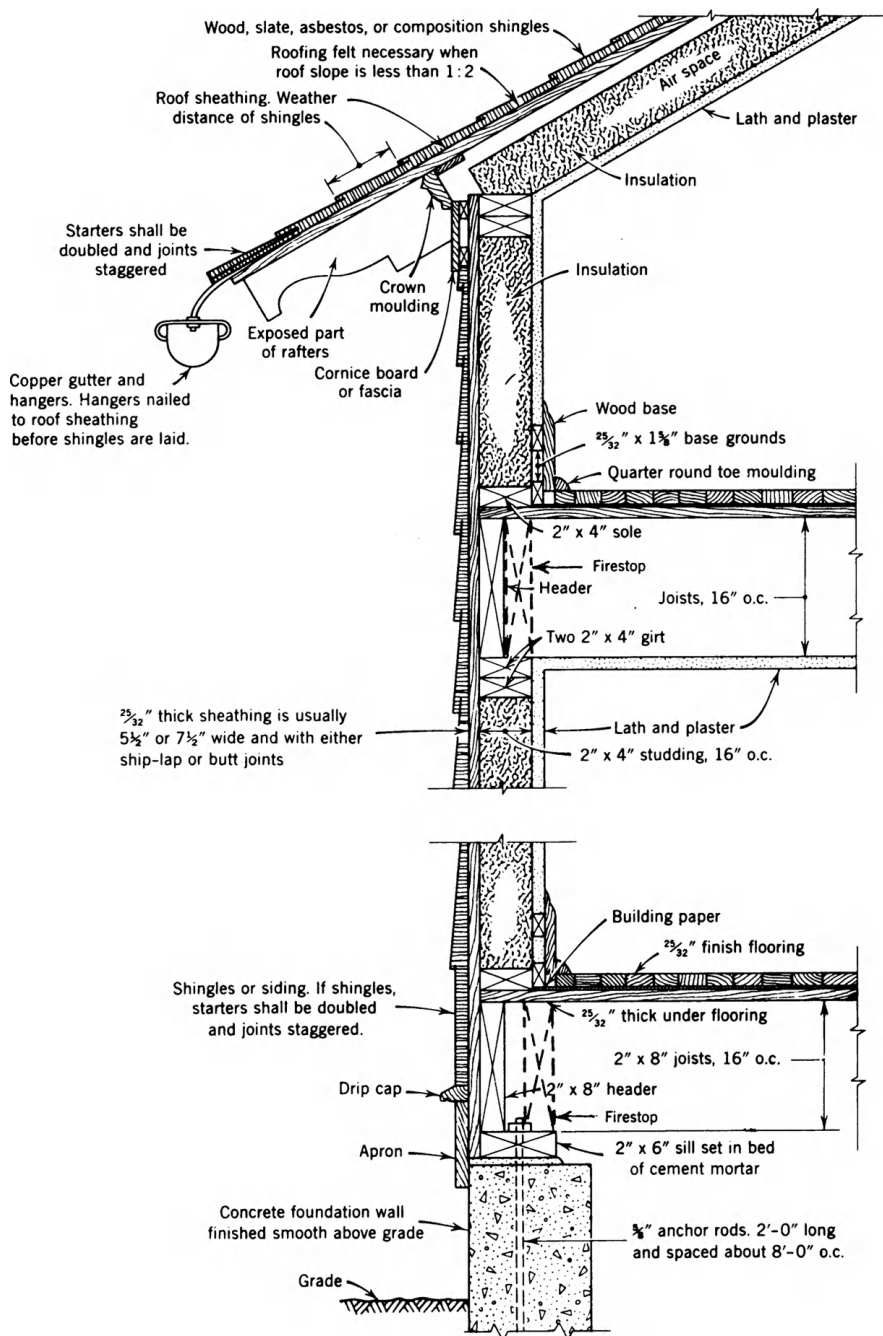


FIGURE 2.7 Wall construction.

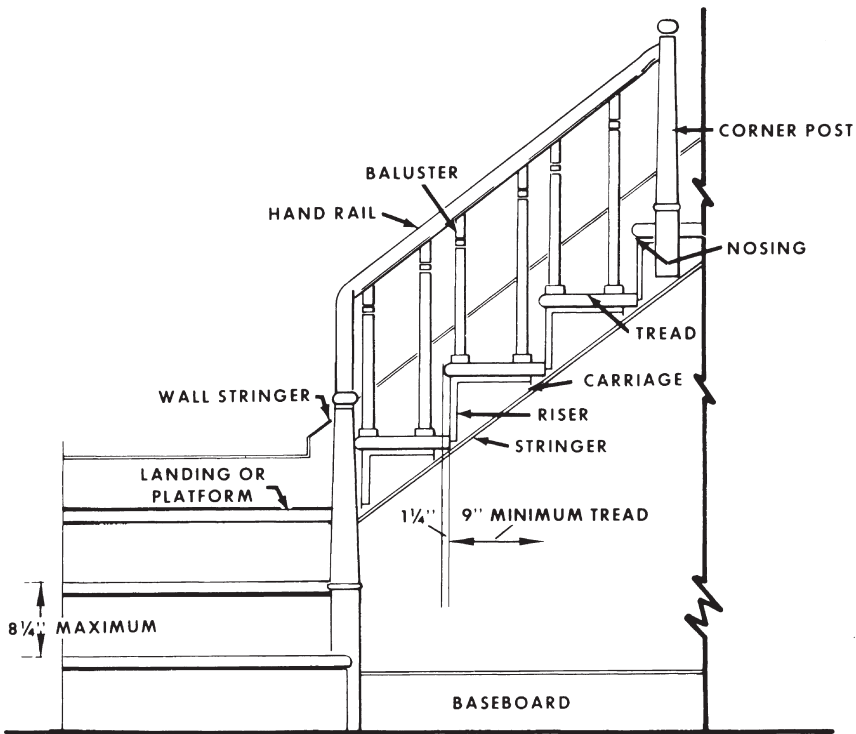


FIGURE 2.8 Stairway details. (Source: *Basic Housing Inspection*, DHEW Pub. (CDC) 80-8315, U.S. Government Printing Office, Washington, DC, p. 38.)

Leaking Water Closet

The water-closet bowl in the (describe location) apartment was (loose) (leaking) at the floor. (When the toilet is flushed, the water drains onto the floor and seeps through the ceiling to the lower apartment.) The water closet should be securely fastened to the floor, floor flange, and soil pipe so that it will be firm and not leak when flushed. (It will also be necessary to repair the loose ceiling plaster in the lower floor and repaint or repaper as needed.)

Floors Not Water Repellent

The bathroom (water-closet compartment) (floor covering) was (worn through) (broken) (bare wood with open joints). The floor should be (repaired) (made reasonably watertight), and the floor covering should extend about 6 inches up the wall to provide a sanitary cove base. Satisfactory material for the floor covering is inlaid vinyl, rubber or composition tile, smooth cement concrete, tile, terrazzo, and dense wood with tightly fitted joints covered with varnish or other similar coating providing a surface that is reasonably impervious to water and easily cleaned.

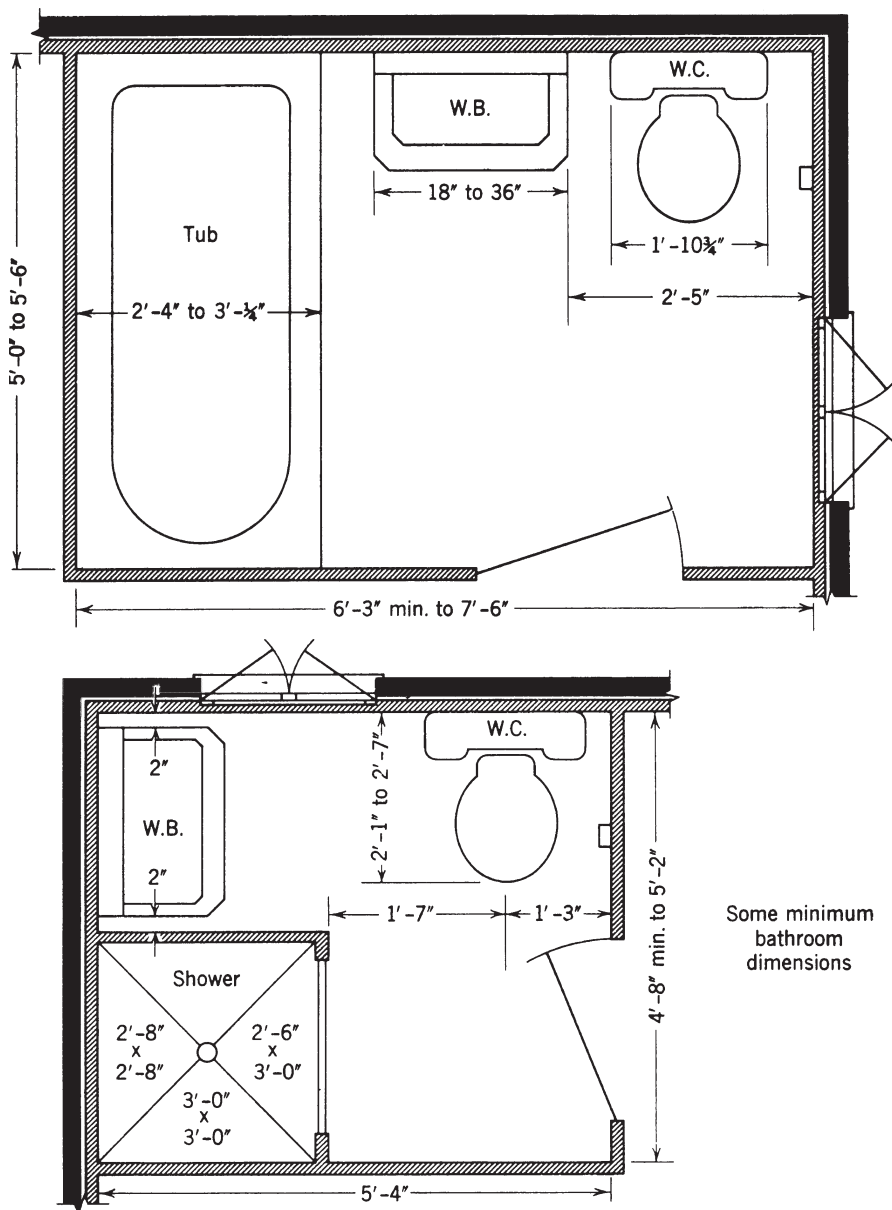


FIGURE 2.9 Three-piece bathroom showing minimum dimensions.

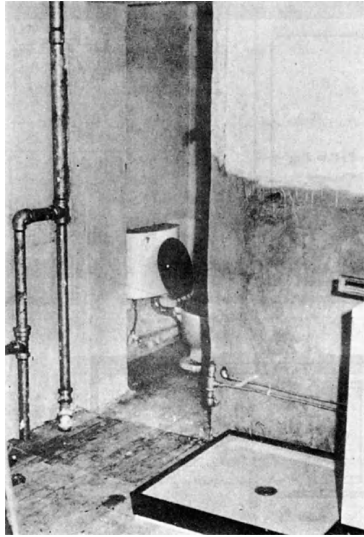


FIGURE 2.10 Alteration for shower and washbasin addition.

Exterior Paint Needed

The exterior paint has (peeled, worn off), exposing the bare wood, rusting the nails, causing splitting and warping of the siding. This will lead to the entrance of rainwater, rotting of the siding, sheathing, and studs, as well as inside dampness and falling of the plaster. You are urged to immediately investigate this condition and make the necessary repairs, including painting or other weather- and decay-resistant treatment of the house, to prevent major repairs and expenses in the future.

Rotted and Missing Siding

The (shingles, siding, apron, cornice, exposed rafters) (on the north side of the house at the second-floor windows and foundation) is (are) (rotted and missing). Decayed material should, of course, all be removed, the sheathing repaired wherever necessary, and the shingles, siding, and so on, replaced. Following the carpentry work, all unpainted or unprotected material exposed to the elements should be treated to prolong its life.

Sagging Wall

The (door frames and window frames) in the (location) are out of level, making complete closure of the doors and windows impossible. Outside light could be easily seen through the openings around the (window rails and door jambs). The supporting beams, girders, posts, and studs should be carefully inspected, as there was evidence that some of these members were rotted, causing the outside wall

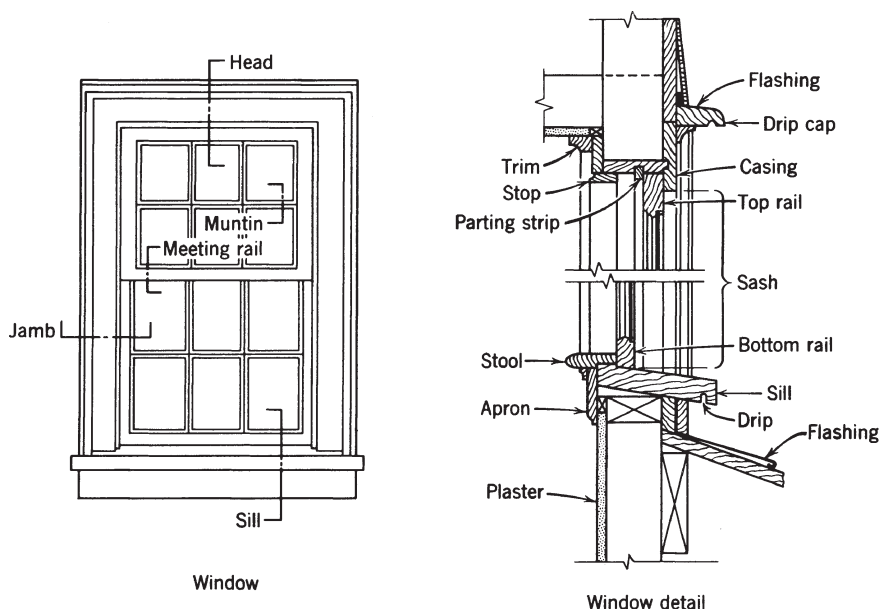


FIGURE 2.11 Window details.

to sag. The building should be shored and made level wherever necessary. The unsound material should be replaced, and the improperly fitting doors, windows, and framing repaired to fit and open properly. See Figures 2.7 and 2.11.

Loose Plaster

The plaster is (loose) (and buckled) (and has fallen) from the living room ceiling and walls in the (name apartment or other location) over an area of approximately 10ft². All loose plaster should be removed and the wall replastered; following curing, it should be painted or papered to produce a cleanable, smooth, and tight surface.

Leaking Roof

There is evidence of the roof leaking over or near the (kitchen, living room, etc., in the tenant apartment). The (paint, paper) was stained and peeling. It is essential that the leak be found and repaired, not only to prevent the entrance of water and moisture in the apartment but also to prevent loosening of the plaster, rotting of the timbers, and extension of the damage to your property.

No Gutters or Rain Leaders

There are no gutters or rain leaders on this building. Gutters and rain leaders should be placed where needed and connected to the sewer if permitted to ensure proper

drainage of rainwater. This will also make rotting and seepage of water through siding and window frames and entrance of water into the basement less likely.

No Handrails

There are no handrails in the stairway between the (first and second floors at the rear). This is a common cause of preventable serious accidents. Handrails should be provided and securely fastened at a height of 30 to 32 in., measured above the stair tread.

Lead Paint

Children living in apartment (10B) have been screened for lead and were found to have high levels of lead in their blood. Lead is a cumulative poison that causes mental retardation, behavioral changes, anemia, and other impairments. Lead-based paint found on window and door frames in the apartment had flaked and peeled. Lead-based paint must be removed, but it requires special precautions to protect children and adults from the paint dust. Use a contractor who has been licensed to do this type of work.

Refuse in Attic

There are (rags, refuse, paper, and trash) in the attic. These materials are a fire hazard and provide harborage for mice and other vermin. All rags, paper, and trash must be removed from the attic, and the attic maintained in a clean and sanitary condition at all times.

Water-Closet Flush Tank Not Operating Correctly

The (water runs continuously) in the water-closet flush tank in the (John Jones's apartment); OR the water closet in the (John Jones's apartment) cannot be flushed. The broken, worn, or missing ball-cock valve, ball-cock float, flush-valve ball, flush lever, or flush handle should be repaired or replaced to permit proper flushing of the water closet. See Figure 2.12.

Garbage Stored in Paper Box or Bag

Garbage is being stored in (open, uncovered baskets) (paper bags) (paper boxes) (in the rear yard). This encourages rodent, fly, and vermin breeding. All garbage should be drained, wrapped, and properly stored in tightly covered containers. It will be necessary for you to procure needed receptacles for the proper storage of all garbage until collected.

Dilapidated Garbage Shed

The garbage shed in the (specify location) is in a dilapidated, rotted, and unsanitary condition. Garbage sheds tend to accumulate garbage and encourage rodent,

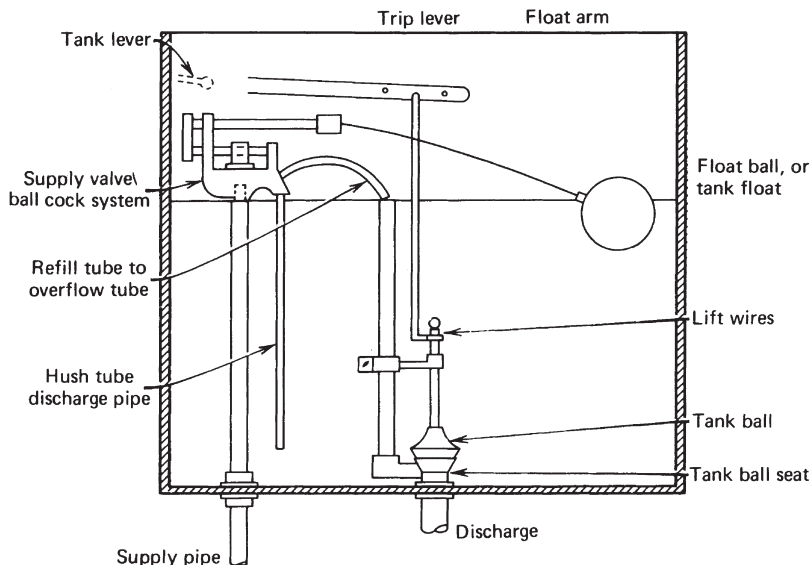


FIGURE 2.12 Water-closet tank. (Flapper valve can replace tank ball. Unvented supply valve requires backflow preventer.)

fly, and vermin breeding. This dilapidated garbage shed should be removed and the premises cleaned. Store the garbage cans on an elevated rack or concrete platform. (Enclose pamphlet showing some suggested storage racks.)

Debris in Yard or Vacant Lot

The vacant lot located at (specify location) was found littered with (old lumber, tin cans, and rubbish). This is unsightly and may serve as rat harborage and as an invitation to dump on the property. It is requested that you make a personal investigation of the conditions reported and arrange to have the lot cleared and cleaned. It is also recommended that you post a “No Dumping” sign to discourage future littering of the property.

Dirty Apartment

The apartment on the (second floor) is in a very unsanitary condition. (Describe.) All occupants are expected to keep their apartment and the premises they control in a clean and sanitary condition at all times. (Give a copy of the letter to the tenant.)

Overcrowded Sleeping Room

The bedroom(s) in the (specify location) are overcrowded. There are (three) persons in a room having an area of (80) ft² and (four) persons in a room (85) ft².

Every room occupied for sleeping purposes shall contain at least 70 ft² of floor space for one person and 50 ft² for each additional person. (Suggest correction.) This apartment should not be rerented for occupancy by more persons than can be accommodated in accordance with this standard.

No Window in Habitable Room

No window to the outside air is provided in the (living room, kitchen, bedroom). Every room used or intended to be used as a living room, kitchen, or bedroom is required to have a total unobstructed window area of at least 10 percent of the floor area. Consideration should be given to the possibility of cutting in a new window or providing a skylight if the room is to be continued in use as a bedroom, living room, or kitchen.

Unlawful Third-Floor Occupancy

The third floor of this building had been converted and was occupied for living purposes. The conversion or alteration of a third floor or attic in a frame building for living or sleeping purposes is prohibited by Chapter X of the city ordinances. This is a major hazard in case of fire. Discontinue the use of the third floor immediately. (Refer a copy of the letter to division of buildings.)

Unlawful Cellar Occupancy

The cellar is being used for (sleeping, living, purposes). A cellar may not be used for living purposes; hence, this space must be permanently vacated. (The housing ordinance defines a cellar as “a room or groups of rooms totally below ground level and usually under a building.”)

Clogged Sewer

The (soil stack, building drain, or sewer) is apparently clogged, for sewage from the upper apartment(s) backs into the (kitchen sink, water closet) in the (first-floor front apartment). The clogged sewer must be cleared and, if necessary, repaired to eliminate cause for future complaint.

Unvented Heater

The gas water heater(s) (burning carbonaceous fuel) in the (name room or space and locate) is (are) not vented. Unvented heaters in bathrooms and sleeping rooms have been the cause of asphyxiation, carbon monoxide poisoning, and death. These heaters must be properly vented to the chimney or outside air, supplied with sufficient air to continuously support combustion of the fuel, and be protected to prevent fires and minimize accidental burns. See “Venting of Heating Units,” this chapter.

Furnace Flue Defective

The furnace flue has rusted through in several places (and the connection to the chimney is loose), causing waste gases to escape into the basement. Since such gases rise and seep into the upper apartment(s) and have been known to cause asphyxiation, it is imperative that the flue be repaired and the collar sealed to prevent leakage of any waste gases. This should also improve the efficiency of the furnace.

Rubber-Hose Gas Connection

The gas heater(s) in the (tenant apartment) has (have) (plastic pipe, rubber hose) connection(s). Such materials eventually leak and may cause death in the household. It will be necessary to replace all plastic and rubber-hose connections with rigid, metal pipe.

Rat Infestation

There is evidence of a very bad rat condition existing in this building, as indicated by (explain condition). All holes in the foundation (floors) should be sealed with cement mortar and openings around wood framing closed with metal flashing or with cement mortar where possible. Traps and repeated use of a rodenticide such as Warfarin are suggested to kill rats inside the building. All sources of food and harborages must be eliminated. Such control measures should be continuous for at least two or three weeks to be effective. (Enclose pamphlet giving additional details dealing with accepted control measures.)

Roach Infestation

The apartment is apparently infested with roaches, as indicated by the roachy odor and roaches observed hiding under the sink, baseboard, moldings (stains in the kitchen cabinet, pellets of excrement in the dish cabinet). Roaches are sometimes brought in with boxes of food, baskets, or bags; dirt and filth encourage their reproduction in large numbers. Thorough cleaning, filling of cracks around frames with plaster or plastic wood, followed by the proper application of an insecticide in selected places and in accordance with the manufacturer's directions should bring the problem under control. (Enclose pamphlet that gives additional detailed information.)

Overflowing Sewage Disposal System

The sewage disposal system serving the dwelling is (seeping out onto the surface) (discharging into the ditch in front of your home). This is a health hazard not only to those living there but also to neighbors and pets. Immediate steps should be taken to determine the cause and make corrections.

Improperly Protected Well-Water Supply

A sanitary survey of the well-water supply shows it to be subject to contamination. *The well (is uncapped) (has a hole around the casing where surface water can drain down and into the well) (does not have a tight seal at the point where the pump line(s) pass into the casing as noted by drippage observable from looking into the well).* The necessary repairs should be made to prevent contamination of the water supply and then the well should be disinfected as explained in (enclosed) instructions.

Major Repairs

In view of the major repairs and improvements needed, only some of which have been reported above, plans prepared by a registered architect should be submitted showing the existing conditions and all proposed alterations for approval by this Department and the Division of Buildings, before any work is done. This procedure makes possible the receipt of comparable bids from several contractors and usually results in more orderly prosecution of the work at a minimum cost.

Minor Repairs

In view of the repairs and improvements needed, a sketch drawn to scale should be prepared showing existing and proposed work to ensure that the work can be done as intended. The sketch should be submitted to and approved by the Division of Buildings and this Department before any work is done. This procedure makes possible the receipt of comparable bids from several contractors and usually results in more orderly prosecution of the work at a minimum cost.

Obtain at Least Three Estimates

We urge you to obtain at least three estimates from reputable contractors before having any work done. Written bids should be requested and assurance obtained from the contractor that the estimate is all inclusive.

PLUMBING

Plumbing Code

Sanitary plumbing principles that are based on the latest scientific studies should be fundamentally similar but will be varied in application, depending on the local conditions. Some plumbing designs and standards currently in existence are based on an unsound old rule of thumb or prejudice. They could be reviewed with profit in the light of present-day knowledge.

The *National Plumbing Code*,¹⁶ the *Uniform Plumbing Code*,¹⁷ and the *Standard Plumbing Code* (also called the *Southern Code*)¹⁸ are the three major

plumbing codes currently being used in the United States. Public Health Service Pub. 1038¹⁹ is also a comprehensive standard code of minimum requirements for use. Some of the major codes have combined to form the *International Plumbing Code*.²⁰ The interested person would do well to have copies in a reference file. The sizing of water supply, drainage, vent, and storm-drain piping is concisely covered.

In addition to the major codes, different parts of the country frequently have their local plumbing codes (state, county, or city level). These local code requirements must be checked before doing any plumbing work.

One term used frequently is *plumbing fixture*. This term includes installed receptacles, devices, or appliances either supplied with water or receiving on discharge liquids or liquidborne wastes or both. The bathtub, sink, water closet, dishwasher, and drinking fountain are examples of plumbing fixtures. In practice, the probable flow is estimated based on the fixture unit. A *fixture unit* is the load-producing flow effect for comparing different plumbing fixtures. One water supply fixture unit (wsfu) is usually taken as 7.5 gpm. The drainage fixture unit (dfu) for different fixtures can also be found in most plumbing codes.

Approval of plans for plumbing systems must usually be obtained before construction is started. Health departments can accomplish more in the interest of public health by seeing that proper standards of plumbing exist and are enforced than by actually doing the plumbing inspection. For example, the health department can see to it that plumbing and building codes prohibit dangerous cross-connections and interconnections and require a private three-piece bathroom and kitchen sink served by hot and cold water in every new dwelling unit. This is fundamental to the prevention of disease, the promotion of personal hygiene, and sanitation. Plumbing codes should prohibit the use of lead piping for water distribution and the use of tin-lead (50:50 and 60:40) solder for joining copper piping.

Plumbing codes should specify an adequate number of fixtures for private public, and industrial use, all properly supplied, trapped, vented, and sewered, as noted in Tables 2.6 through 2.9. Water connections with unsafe or questionable water supplies would be prevented, and connections or conditions whereby used or unsafe water could flow back into the potable water system would be prohibited. Of course, a safe water supply and proper sewage disposal should be ensured.

Housing codes should make reference to a modern plumbing code. Housing codes would be of little value unless they were applicable to all new, altered, and existing one-, two-, or multifamily dwellings, hotels, boarding houses, and rooming houses.

The health department should serve as a consultant to the building, plumbing, water, and sewer divisions. Any new or revised codes or regulations should first be reviewed and approved by the health department before being considered for adoption to ensure that the fundamental principles of public health and sanitary engineering are not violated.

TABLE 2.6 Minimum Number of Plumbing Facilities

Fixtures Number of fixtures per number of occupants		Water Closets					Bathrooms			Service	
Building Occupancy		Males	Females	Lavatories	Shower		Bathtubs/ Showers	Drinking Fountains	Sink		
A	Theaters	1 per 125	1 per 65	1 per 200	—	—	—	1 per 1,000	1		
	Night Clubs	1 per 40	1 per 40	1 per 75	—	—	—	1 per 500	1		
	Restaurants	1 per 75	1 per 75	1 per 200	—	—	—	1 per 500	1		
	Halls, museums, etc.	1 per 125	1 per 65	1 per 200	—	—	—	1 per 1,000	1		
	Coliseums, arenas	1 per 75	1 per 40	1 per 150	—	—	—	1 per 1,000	1		
	Churches (b)	1 per 150	1 per 75	1 per 200	—	—	—	1 per 1,000	1		
	Stadiums, pools, etc.	1 per 100	1 per 50	1 per 150	—	—	—	1 per 1,000	1		
	Business	1 per 25	—	1 per 40	—	—	—	1 per 100	1		
	Retail sales	1 per 500	—	1 per 750	—	—	—	1 per 1,000	1		
	Factory and industrial	1 per 100	—	1 per 100	—	—	emergency showers and eyewash	1 per 400	1		
S	Storage	1 per 100	—	1 per 100	—	—	emergency showers and eyewash	1 per 1,000	1		
E	Educational	1 per 50	—	1 per 50	—	—	—	1 per 100	1		
H	Hazardous	1 per 100	—	1 per 100	—	—	emergency showers and eyewash	1 per 1,000	1		
I	Hospitals (c)	1 per room (f)	1 per room (f)	1 per room (f)	1 per 15	1 per 15	1 per 15	1 per 100	1 per floor		
	I-1 Nurseries, day care centers, sanitariums, and nursing homes with nonambulatory patients (c)	1 per 15	1 per 15	1 per 15	1 per 15	1 per 15	1 per 15 (g)	1 per 100	1		
	I-2 Nursing homes for ambulatory patients (c)	1 per room (f)	1 per room (f)	1 per room (f)	1 per 15	1 per 15	1 per 15	1 per 100	1 per floor		
I-3	Mental hospitals, mental sanitariums, etc.	1 per 15	1 per 15	1 per 15	1 per 15	1 per 15	1 per 15	1 per 100	1		

(continues)

TABLE 2.6 (continued)

Fixtures Number of fixtures per number of occupants						
Building Occupancy	Males	Females	Lavatories	Bathubs/ Showers	Drinking Fountains	Service Sink
I-3 Jails/ reformatories cells	1 per cell		1 per cell	1 per 8	—	—
I-3 Dormitory or other institutional rooms with 24 hour access to sanitary facilities	1 per 12	1 per 8	1 per 12	1 per 8	—	—
I-3 Exercise rooms	1 per room		1 per room	—	—	—
I-3 Employees (c)	1 per 25		1 per 25	—	1 per 100	—
I-3 Visitors	1 per 75		1 per 100	—	1 per 500	—
R Lodges, dormitories, and bed and breakfast facilities	1 per 10		1 per 8	1 per 10	1 per 100	1
Hotels and motels	1 per guest room	1 per guest room	1 per guest room	1 per guest room	—	1
Multiple family housing (d)	1 per dwelling unit	1 per dwelling unit	1 per dwelling unit	1 per dwelling unit	—	1 kitchen sink per dwelling unit

Note (a) The fixtures shown are based on one (1) fixture being the minimum required for the number of persons indicated or any fraction of the number of persons indicated.

Note (b) Fixtures located in adjacent buildings under the ownership or control of the church may be made available during periods the church is occupied.

Note (c) Toilet facilities for employees shall be separate from the facilities for inmates or patients.

Note (d) One (1) automatic clothes washer connection shall be required per twenty (20) dwelling units.

Note (e) One (1) automatic clothes washer connection shall be required per dwelling unit.

Note (f) A single-occupant toilet room and one (1) water closet and one (1) lavatory servicing not more than two (2) adjacent patients rooms shall be permitted where such room is provided with direct access from each patient room and with provisions for privacy.

Note (g) For nurseries, a maximum of one (1) bathtub shall be required.

Source: Indiana General Assembly. TITLE 675 FIRE PREVENTION AND BUILDING SAFETY COMMISSION. <http://www.in.gov/legislative/iac/20080423-IR-675070476FRA.xml.html>.

TABLE 2.7 Minimum Sizes of Fixture Supply and Drain

Type of Fixture/Device	Pipe Size (in.) Supply	Drain
Bathtubs	$\frac{1}{2}$	$1\frac{1}{2}$
Combination sink and tray	$\frac{1}{2}$	$1\frac{1}{2}$
Drinking fountain	$\frac{3}{8}$	1
Dishwasher, domestic	$\frac{1}{2}$	$1\frac{1}{2}$
Kitchen sink	$\frac{1}{2}$	$1\frac{1}{2}$
Residential		
Commercial	$\frac{3}{4}$	$1\frac{1}{2}$
Lavatory	$\frac{3}{8}$	$1\frac{1}{4}$
Laundry tray, 1 or 2 compartments	$\frac{1}{2}$	$1\frac{1}{2}$
Shower, single head	$\frac{1}{2}$	$1\frac{1}{2}$
Sink, service, P trap	$\frac{1}{2}$	2
Sink, service, floor trap	$\frac{3}{4}$	3
Urinal, flush tank, wall	$\frac{1}{2}$	$1\frac{1}{2}$
Urinal, direct, flush valve	$\frac{3}{4}$	2
Urinal, pedestal, flush valve	1	3
Water closet, tank-type	$\frac{3}{8}$	3
Water closet, flush valve type	1	3
Hose bibs	$\frac{1}{2}$	—
Wall hydrant	$\frac{1}{2}$	—

Note: The minimum water pressure at the outlet, at times of maximum demand, shall not be less than 8 psi, except for direct flush valves, where 15 psi is required, and where special equipment requires other pressure.

Source: PHS Pub. No. 1038, Department of Health, Education, and Welfare, Washington, DC. See also Chapter 4 for trap sizes and fixture unit ratings.

TABLE 2.8 Distance of Fixture Trap from Vent

Size of Fixture Drain (in.)	Maximum Distance (ft)
$1\frac{1}{4}$	$2\frac{1}{2}$
$1\frac{1}{2}$	$3\frac{1}{2}$
2	5
3	6
4	10

Tables 2.6 through 2.9, respectively, give the minimum number of plumbing fixtures for different building occupancies, the minimum sizes of fixture supply and drain, maximum distance of fixture trap from vent, and hot-water demands for different types of buildings. Some plumbing details, with particular emphasis on backflow prevention, recommended minimum number of plumbing

TABLE 2.9 Hot Water Demands and Use for Various Types of Buildings

Type of Building	Maximum Hour	Maximum Day	Average Day
Men's dormitories	3.8 gal/student	22.0 gal/student	13.1 gal/student
Women's dormitories	5.0 gal/student	26.5 gal/student	12.3 gal/student
Motels: number of units			
20 or less	6.0 gal/unit	35.0 gal/unit	20.0 gal/unit
60	5.0 gal/unit	25.0 gal/unit	14.0 gal/unit
100 or more	4.0 gal/unit	15.0 gal/unit	10.0 gal/unit
Nursing homes	4.5 gal/bed	30.0 gal/bed	18.4 gal/bed
Office buildings	0.4 gal/person	2.0 gal/person	1.0 gal/person
Food service establishments			
Type A, full-meal restaurants and cafeterias	1.5 gal/max. meals/hr	11.0 gal/max. meals/hr	2.4 gal/avg. meals/day ^a
Type B, drive-ins, grilles, luncheonettes, sandwich and snack shops	0.7 gal/max. meals/hr	6.0 gal/max. meals/hr	0.7 gal/avg. meals/day ^a
Apartment houses			
20 or less	12.0 gal/apt.	80.0 gal/apt.	42.0 gal/apt.
50 apartments	10.0 gal/apt.	73.0 gal/apt.	40.0 gal/apt.
75 apartments	8.5 gal/apt.	66.0 gal/apt.	38.0 gal/apt.
100 apartments	7.0 gal/apt.	60.0 gal/apt.	37.0 gal/apt.
130 apartments or more	5.0 gal/apt.	50.0 gal/apt.	35.0 gal/apt.
Elementary schools	0.6 gal/student	1.5 gal/student	0.6 gal/student ^a
Junior and senior high schools	1.0 gal/student	3.6 gal/student	1.8 gal/student ^a

^aPer day of operation

Note: The table remains unchanged in the latest ASHRAE publication—2007 *ASHRAE Handbook: HVAC Applications*. Heaters should be preset to deliver water at 130°F (54°C). The Consumer Product Safety Commission (CPSC) recommends a maximum of 120°F (49°C).

Source: *ASHRAE Guide and Data Book*, Atlanta, GA, 1970. Copyright by the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. Reprinted with permission.

fixtures, the application of indirect waste piping, and other details are discussed below.

Backflow Prevention

The backflow of polluted or contaminated water or other fluid or substance into a water distribution piping system through back pressure or back siphonage is a very real possibility. The best way to eliminate the danger is to prohibit any connections between the water system and any other system, fixture vat, or tank containing polluted or questionable water. This can be accomplished by terminating the water supply inlet or faucet a safe distance above the flood-level rim of the fixture. The distance, referred to as the air gap is 1 inch for a 0.5-inch-or-smaller-diameter faucet or inlet pipe, 1.5 inches for a 0.75-inch-diameter faucet, 2 inches for a 1-inch-diameter faucet, and twice the

effective opening (cross-sectional area at point of water supply discharge) when its diameter is greater than 1 inch. When the inside edge of the faucet or pipe is close to a wall—that is, within three or four times the diameter of the effective opening—the air gap should be increased by 50 percent.

Sometimes, as with water closets and urinals equipped with flushometer valves, it is not possible or practical to provide an air gap. Under such circumstances, where the water connection is not subject to back pressure, an approved nonpressure-type backflow preventer, such as that shown in Figure 2.13, may be used to prevent back siphonage. The backflow preventer

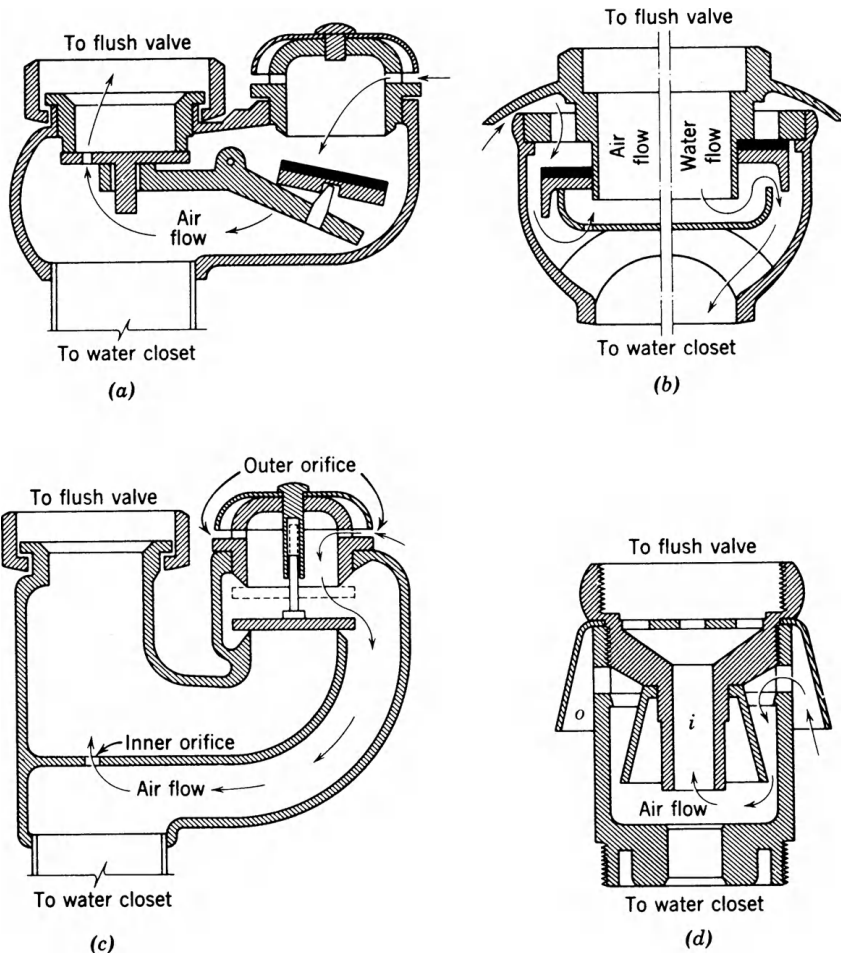


FIGURE 2.13 Vacuum, nonpressure-type siphon-breakers: (a), (b), (c) Moving parts; (d) Nonmoving part. Installed *after* fixture valve. (Source: R. B. Hunter, G. E. Golden, and H. N. Eaton, "Cross-Connections in Plumbing Systems," Research Paper RP 1086, *J. Res. Natl. Bur. Stand.*, 20 (April 1938).)

must be installed on the outlet side of the control valve, at a distance not less than four times the nominal diameter of the inlet, measured from the control valve to the flood-level rim of the fixture, and in no cases less than 4 inches.

A pressure-type vacuum breaker (see Figure 2.14) is installed on a pressurized system and will function only when a vacuum occurs. It should not be installed where backpressure may occur. Figure 2.14 also shows a hose bib vacuum breaker and an atmospheric vacuum breaker.

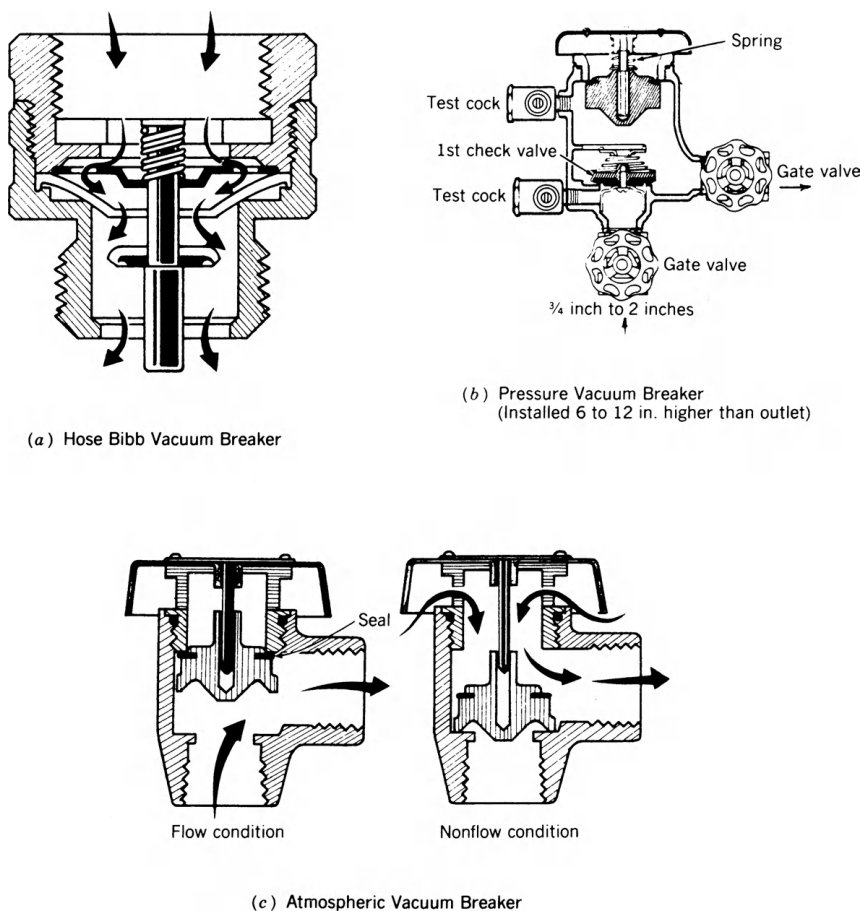


FIGURE 2.14 Vacuum breakers: (a) Generally attached to sill cocks and, in turn, are connected to hose supplied outlets such as garden hoses, slop sink hoses, and spray outlets, (b) A spring on top of the disc and float assembly, two added gate valves, test cocks, and an additional first check make possible its utilization under constant pressure, (c) Must be installed vertically, must not have shutoffs downstream, and must be installed at least 6 in. higher than the final outlet. (Source: *Cross-Connection Control Manual*, EPA 570/9-89-007, U.S. Environmental Protection Agency, Office of Water, Washington, DC, June 1989, pp. 17–18.)

In some instances, an air gap cannot be installed and it is necessary to connect a potable water supply to a line, fixture, tank, vat pump, or other equipment to permit backflow of nonpotable water due to backpressure or back siphonage. Under such circumstances, an approved reduced-pressure-principle backflow preventer *may* be permitted by the regulatory authority. It is essentially a modified double check valve with an atmospheric vent capability placed between the two checks.

Indirect Waste Piping

Waste pipes from fixtures or units in which food or drink is stored, prepared, served, or processed must not connect directly to a sewer or drain. Stoppage in the receiving sewer or drain would permit polluted water to back up into the fixture or unit. Waste piping from refrigerators, iceboxes, food-rinse sinks, cooling or refrigerating coils, laundry washers, extractors, steam tables, egg boilers, steam kettles, coffee urns, dishwashing machines, sterilizers, stills, and similar units should discharge to an open-water-supplied sink or receptacle so that the end of the waste pipe terminates at least 2 inches above the rim of the sink or receptacle, which is directly connected to the drainage system.

A commercial dishwashing machine waste pipe may be connected to the sewer side of a floor drain trap when the floor drain is located next to the dishwashing machine, if permitted by the regulatory agency.

An alternate to the installation of a water-supplied sink waste receptor is the provision of an air gap in the fixture waste line, at least twice the effective diameter of the drain served, located between the fixture and the trap.

The water-supplied sink or air-gap waste receptor should be in an accessible and ventilated space and not in a toilet room.

Plumbing Details

A few typical details and principles are illustrated for convenient reference and as guides to good practice. There are many variations, depending on local conditions and regulations. See Figure 2.15.

INDOOR AIR QUALITY

Causes and Sources of Indoor Air Pollution

Improved building construction and insulation, including weather stripping, caulking, and storm and thermopane windows, reduce infiltration and air exchange, which results in less air dilution and an increase in the concentration of indoor air pollution. Inadequate ventilation and the recirculation of contaminated used air to save on energy costs for heating and cooling further aggravate the problem. Good practice would dictate that at least one-third of the recirculated air should be clean fresh air, even though this would increase energy costs, unless an air-to-air heat exchanger is used.

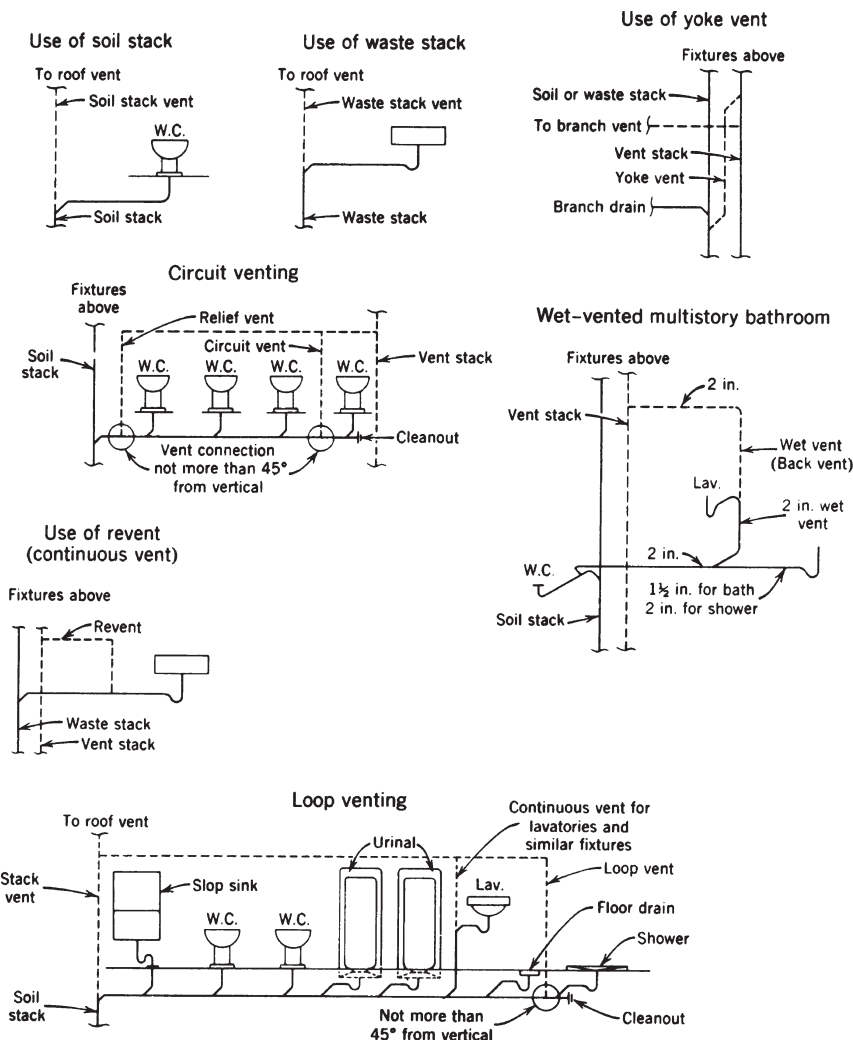


FIGURE 2.15 Some fixture plumbing details. (Source: *New York State Uniform Fire Prevention and Building Code*, Division of Housing and Community Renewal, New York, January 1, 1984.)

Household appliances, aerosol applications, cleaning products, pesticides, photocopying machines (ozone), interior furnishings and building materials (formaldehyde and volatile organic compounds), tobacco smoke, dry-cleaned clothing, and radon may also contribute to the indoor air pollution problem. Noise might also be included. Table 2.10 lists major pollutant/sources, specific contaminants, and acceptable levels. The contaminants may be found in the new or rehabilitated home, office, or other workplace; in the automobile, airplane, or

TABLE 2.10 Sources and Exposure Guidelines of Indoor Air Contaminants

Pollutant/Sources ^a	Guidelines
<i>Asbestos and other fibrous aerosols</i> : friable asbestos—fireproofing, thermal and acoustic insulation, decoration; hard asbestos—vinyl floor and cement products, automatic brake linings (O)	0.2 fibers/ml for fibers longer than 5 μm (based on ASHRAE ^b guidelines of 1/10 of U.S. 8-hr occupational standard)
<i>Biological aerosols</i> : human and animal metabolic activity products, infectious agents, allergens, fungi, bacteria in humidifiers, bacteria in cooling devices	None available
<i>Carbon monoxide</i> : kerosene heaters, gas stoves, gas space heaters, wood stoves, fireplaces, smoking, and automobiles (O)	9 ppm for 8 hr (NAAQS ^c); 35 ppm for 1 hr (NAAQS)
<i>Formaldehyde</i> : particleboard, paneling, plywood, ceiling tile, urea-formaldehyde foam insulation, other construction materials	0.1 ppm (based on Dutch and West German guidelines as reported in ASHRAE Guidelines, 1981, and National Research Council report, 1981)
<i>Inhalable particulates</i> : smoking, vacuuming, combustion sources (O), industrial sources, fugitive dust (O), and other organic particulate constituents	55–110 $\mu\text{g}/\text{m}^3$ annual ^d
<i>Metals and other inorganic particulate contaminants</i> :	150–350 $\mu\text{g}/\text{m}^3$ for 24 hr ^d
Lead—old paint, automobile exhaust (O)	1.5 $\mu\text{g}/\text{m}^3$ for 3 months (NAAQS)
Mercury—old paint, fossil fuel combustion (O)	2 $\mu\text{g}/\text{m}^3$ for 24 hr (ASHRAE)
Cadmium—smoking, use of fungicides (O)	2 $\mu\text{g}/\text{m}^3$ for 24 hr (ASHRAE)
Arsenic—smoking, pesticides, rodent poisons	None available
Nitrates—outdoor air	None available
Sulfates—outdoor air	4 $\mu\text{g}/\text{m}^3$ annual, 12 $\mu\text{g}/\text{m}^3$ for 24 hr (ASHRAE)
<i>Nitrogen dioxide</i> : Gas stoves, gas space heaters, kerosene space heaters, combustion sources (O), automobile exhaust (O)	0.05 ppm annual (NAAQS)
<i>Ozone</i> : photocopying machines, electrostatic air cleaners, outdoor air	Not exceeding 0.12 ppm once a year (NAAQS)
<i>Pesticides and other semivolatile organics</i> : Sprays and strips, drift from area applications (O)	5 $\mu\text{g}/\text{m}^3$ for chlordane (NRC) ^e
<i>Polyaromatic hydrocarbons and other particulate constituents</i> : woodburning, smoking, cooking, coal combustion, and coke ovens (O)	None available

(continues)

TABLE 2.10 (continued)

Pollutant/Sources ^a	Guidelines
<i>Radon and radon progeny:</i> diffusion through floors and basement walls from soil in contact with a residence, construction materials containing radium, untreated groundwater containing dissolved radon, combustion of natural gas used in cooking and unvented heating, radon from local soil emanation (O)	0.01 working level (ASHRAE guidelines)
<i>Sulfur dioxide:</i> kerosene space heaters, coal and oil fuel combustion sources (O)	80 $\mu\text{g}/\text{m}^3$ annual; 315 $\mu\text{g}/\text{m}^3$ for 24 hr (NAAQS)
<i>Volatile organics:</i> Cooking, smoking, room deodorizers, cleaning sprays, paints, varnishes, solvents and other organic products used in homes and offices, furnishings such as carpets and draperies, clothing, furniture, emissions from waste dumps (O)	None available

^a(O) refers to outdoor sources.

^bAmerican Society of Heating, Refrigerating and Air Conditioning Engineers.

^cU.S. National Ambient Air Quality Standards.

^dThese numbers indicate the probable range for the new NAAQS for particulates of 10 μm or less in size. Based on "Recommendations for the National Ambient Air Quality Standards for Particulates—Revised Draft Paper," Strategies and Air Standard Division, Office of Air Programs, U.S. Environmental Protection Agency, Washington, DC, October 1981.

^eNational Research Council, 1982, "An Assessment of Health Risk of Seven Pesticides Used for Termite Control," National Academy Press, Washington, D.C.

Source: N. L. Nagada, H. E. Rector, and L. A. Wallace, *Project Summary Guidelines for Monitoring Indoor Air Quality*, EPA-600/S4-83-046, U.S. Environmental Protection Agency, Office of Monitoring Systems and Quality Assurance, Washington, DC, January 1984.

bus; or in the school, auditorium, indoor ice skating rink, restaurant, enclosed shopping center, commercial and public building, hospital, and nursing home.

Most urban dwellers spend as much as 80 to 90 percent of their time indoors including transportation vehicles. The primary types of indoor air quality problems are inadequate ventilation (52 percent), contamination from inside the building (17 percent), contamination from outside the building (11 percent), microbiological contamination (5 percent), contamination from building fabrics (3 percent), and unknown (12 percent).²¹

Biological Contaminants and Health Effects

Bacteria, viruses, fungi, pollens, house dust, and mite droppings are found in indoor air. Fungi, including spores and molds, multiply in the presence of increased humidity level (greater than 70 percent, some say 45 to 60 percent).²²

Pollens, fungi, and other allergens are also brought indoors by ventilation systems, clothing, tracking, and open doors and windows. Substantial reduction in ventilation rates will tend to increase concentrations of contaminants and the probability of infection and allergy to the extent contaminants remain viable and airborne.

Sources of biological contaminants include air-conditioning systems; humidifiers; air ducts; cooling towers; grass, tree, and weed pollens; occupants; and household pets. Keep air-conditioning systems clean and empty, clean humidifiers and sanitize frequently, and minimize household dust.²³ Some unit air cleaners are effective in removing particulates but may also incubate fungi and microorganisms. Air cleaners, such as electrostatic precipitators, ionizers, or filters, are not designed to remove radon or other gases. Humidifiers and filters require scheduled cleaning or filter replacement. Prevent the accumulation of water in equipment; ensure proper drainage. Recirculating or independent steam humidification is said to be preferable to the filter-type humidifier for room humidification. Ensure that the water used is not contaminated with toxic volatile compounds.

The spread of respiratory diseases is facilitated by infectious agents and particulates in contaminated air. Overcrowding and the recirculation of contaminated air, if not adequately diluted, cleaned, or disinfected, permit continual seeding and accumulation of pathogenic microorganisms at a rate exceeding the natural die-off rate. A study at U.S. Army training centers showed a 45 percent increase in respiratory infection in energy-efficient buildings providing 1.8 ft³ per minute per person outside air. This was compared to older barracks providing 14.4 ft³ per minute per person outside air where the infection rate was lower.²⁴

Legionnaires' disease, meningococcal meningitis, the common cold, influenza, and other respiratory diseases may be transmitted by airborne aerosols. Comprehensive studies on the health effects of long- and short-term exposure to indoor (and outdoor) contaminants are limited. Young children, the elderly, and people suffering from respiratory diseases will be the first to show signs of discomfort from indoor air contamination. Some common complaints are headache; fatigue; eye, nose, and throat irritation; fever; and dizziness. See also "Respiratory Illness Control."

Other Contaminants

Some air contaminants are associated with noninfectious and communicable disease and are environmentally related. They may also aggravate respiratory and heart diseases and cause nausea, headache, eye, nose, and throat irritation, discomfort, and allergies. Death from chronic or acute exposure may also result. More information on the health effects of specific indoor contaminants is needed, but this does not preclude taking preventive action, particularly where information is available, such as for carbon monoxide, formaldehyde, asbestos, radon, and biological aerosols. Review of a few air contaminants and sources are given next. More detailed information can be found from public health literature.

Radon Radon is an odorless, colorless, and tasteless chemically inert radioactive gas released in the decay of radium from uranium in most soils and rocks. It is found naturally in soil gas, underground water, and outdoor air. It is 60 times more soluble [at 50°F (10°C)] than oxygen in water. Radon has a half-life of 3.8 days. Thorium, one of the uranium decay products, also releases radon. Radon and primarily its alpha-emitting decay products (especially polonium) contribute a major portion of the biologically significant dose associated with natural background radiation. The beta and gamma emissions are not significant. The alpha particles, however, adhere to dust particles that, when inhaled, can become attached to the lungs and remain to irradiate the surrounding tissue, contributing to the cause of cancer.

It has been estimated that exposure to “one working-level month” over a lifetime (assumed to be 70 years) would result in about 350 additional lung cancer deaths per million people exposed. Exposure to a radon level of 4 pCi/l* for 12 hours per day would result in an annual exposure of 0.5 working-level months.^{25†} *Working level* is explained later. It has also been estimated that radon causes 13,000 cancer deaths per year.[‡] Smokers are at much greater risk. In view of this, a screening program to identify problem areas and recommend mitigation alternatives to homeowners is indicated. Also indicated is radon measurement before the purchase of a new or existing home.

The hazard associated with radon is related to the concentration and time of exposure. Radon should not exceed 2 to 5 pCi/l indoors. The U.S. Environmental Protection Agency (EPA) has set a guideline limit of 4 pCi/l per 24 hours for homes (this is believed to be conservative) and a standard of 20 pCi/l in underground uranium mines. Special problems exist at uranium tailings and phosphate slag sites. The EPA estimates 20 million homes exceed the 4-pCi/l limit.[§] The action level for existing dwellings in the United Kingdom is 10 pCi/l and 20 in Canada, with 2.5 in new dwellings in the United Kingdom.²⁷

Major potential entry sources of indoor radon from the soil are cracks in dwelling concrete floor slabs and basement walls; pores and cracks in concrete blocks, mortar joints, and floor-wall joints; spaces behind brick veneer walls that rest on uncapped hollow-block foundations; floor drains; footing drains; and exposed soil in the bottom of drainage sumps. Radon-contaminated water, when agitated, aerated, or splashed as in dishwashing, clothes washing, showering, toilet flushing, and opened faucets or when water is heated, permits the release of radon. In addition to rock and soil underlying dwellings, construction materials (some stone masonry, concrete blocks, bricks, concrete), and some well and seepage waters and gas supplies may be the source of radium and radon. In the average dwelling, 10,000 pCi/l of radon in the water can be assumed to release

*Picocuries per liter: 4 pCi/l = 150 Bq/m³ (becquerels per cubic meter).

†Source: *Health Risks of Radon and Other Internally Deposited Alpha-Emitters: Bier IV*, National Academy Press, Washington, DC.

‡National Research Council estimate, 1988 (see ref. 26). Lung cancer may be causing 5000 to 10,000 lung cancer deaths per year in the United States based on an average annual dose of 2.4 rem.

§See W. W. Nazaroff and K. Teichman, “Indoor Radon,” *Environ. Sci. Technol.* (June 1990): 777.

1 pCi/l to the air, but the actual indoor concentration will be dependent primarily on the amount of radon entering from the soil and on the extent to which the indoor air is diluted by outside air.²⁸

The EPA is proposing a level of 200 to 500 pCi/l for drinking water, which might be increased to perhaps 1,000. A level of 20,000 pCi/l in water is considered a significant concentration. If the water is high in radon, it can be removed by filtering through a granular activated-carbon (GAC) filter, by storage until the radon has decayed, or by aeration before it enters the dwelling water system. But the carbon becomes radioactive and in decay releases gamma radiation, which can be a health hazard. Aeration appears to be the most cost-effective procedure for public water systems and a GAC filter for a private dwelling having its own well-water supply, if needed. Activated carbon concentrates the radon and decay products and, hence, poses a disposal problem. Consult with the equipment dealer, the state or local health department, and radiation protection office for the proper way to dispose of the used carbon.

Radon contamination in an existing dwelling, if it is a problem, can be reduced by preventing its entry or by removing the radon. It can be reduced by closing and caulking all cracks, joints, and openings of the structure in the basement or in contact with the ground, or in the flooring above the crawl space, and by tightly covering open drains and sumps as previously noted. Good insulation of water pipes and underflooring beneath living areas would be required in the crawl space in areas subjected to subfreezing temperatures²⁹ and to reduce heating or cooling costs. If this is not sufficient to reduce the indoor radon level, natural or mechanical forced-air ventilation into basement and crawl spaces can be provided, with openings to allow radon-laden air to exit. Exhaust ventilation would be needed for tightly covered sumps and footing drains. In Florida, a vent area of 1 ft² for each 150 ft² of floor area for wooden flooring or at least 1.5 ft² of opening for each 15 feet of linear perimeter wall for nonwooden flooring is required by the housing code. To reduce radon levels in basements and enclosed crawl spaces, bring in outside air to dilute and displace the inside air. Forced-air ventilation may be necessary; exhaust fans in living areas and combustion air for warm-air furnaces and fireplaces would depressurize the dwelling and draw in radon from the basement and should not be used. Provide outside air vent for furnace and hot-water gas heater and outside air duct for wood stove and fireplace.

In a new building, the gravel under the basement floor or floor slab could have perforated pipe embedded in it to intercept and vent radon gas above the roof using a mechanical exhaust fan. Wind turbines and natural convection are not effective. A polyethylene sheet would be placed under the basement concrete floor slab above the gravel before it is poured. The ventilation method used must not reduce the air pressure within the dwelling. Sealing major potential sources of radon entry, as already stated, and ventilation should greatly reduce radon concentrations to "safe" levels in most cases. The need for radon protection, such as built-in ventilation under the basement floor or floor slab, is best provided in new construction and required in building codes where needed. Local geological information and in-home radon measurements will give an indication of need.

Measurement for radon exposure is in working-level units, which include radon's first four daughter products that will result in MeV of potential alpha energy per liter of air. A working level of 1.0 is assumed to be equivalent to a one-month total of 200 pCi/l of radon in most indoor environments (at 50 percent equilibrium).³⁰ A working-level month (WLM) is equivalent to an average of 173 hour spent in a mine by a uranium worker. Exposure must not exceed 4 WLMs in any calendar year. The occupational limit for workers is 4.8 WLMs according to the 1985 recommendation of the International Commission on Radiological Protection.³¹ The National Council on Radiation, Protection, and Measurement says radon level should not exceed 2 WLMs per year, or 8 pCi/l.³² The U.S. Mine Safety and Health Administration has set a maximum exposure level of 8 pCi/l for miners.

State and local health departments or state radiation protection offices can usually provide a list of companies supplying radon testing services. Federal and state publications are available to assist the homeowner to understand the problem and take corrective action if indicated.³³ Seek professional advice if a significant problem exists.

Formaldehyde Formaldehyde, a colorless gas, may cause extreme discomfort and contact dermatitis indoors. The odor can be detected at less than 1 ppm. Exposure to 1.0 to 5.0 ppm or less can cause burning of the eyes, tearing, and general irritation of the upper respiratory passages. Levels of 0.3 to 2.7 ppm have been found to disturb sleep and to be irritating to some persons. Exposure to 10 to 20 ppm may produce coughing, tightening in the chest, a sense of pressure in the head, and palpitations. Exposures of 50 to 100 ppm and above can cause serious injury, including pulmonary edema and pneumonitis, and possibly death when above 100 ppm. Exposure to formaldehyde solutions, or urea-formaldehyde-containing resins, is a well-recognized problem.³⁴ However, a four-year study at the National Cancer Institute concluded that there is "little evidence that mortality from cancer is associated with formaldehyde exposure at levels experienced by workers in this study."³⁵

Sources of formaldehyde are resins and glues to bond particle board and plywood, urea-formaldehyde foam insulation, permanent press fabric, embalming fluid, drugs, disinfectants, and cosmetics as well as chemicals used in pathology and anatomy laboratories and in the manufacture of automobiles, furniture, paper, and electrical equipment.³⁶ Formaldehyde problems are also related to materials in mobile homes and prefabricated housing. Users of formaldehyde should wear protective clothing, use protective equipment, and apply engineering controls such as hoods and separate exhaust systems. The workplace should provide a minimum ventilation of five air changes per hour. Some ameliorative measures suggested, where urea-formaldehyde is a problem, are to remove the product; seal with a specially formulated coating, vinyl covering, latex paint, or varnish after two years; and increase ventilation. Sealing will prevent the penetration of moisture, contact with urea-formaldehyde, and release of formaldehyde gas. The gas release from materials tends to decline in time. Improper formulation of

urea–formaldehyde foam insulation is believed to exacerbate the problem. It is no longer used in the United States. Phenol–formaldehyde resins are generally used in outdoor materials and do not release significant quantities of formaldehyde; however, they cost more than urea–formaldehyde products.

The Occupational Safety and Health Administration (OSHA) 8-hr time-weighted average occupational exposure has been reduced from 3.0 to 1.0 ppm with a maximum short-term exposure level of 2.0 ppm for any 15-min period.^{37*} The National Research Council has established a limit of 0.1 ppm for space flights. The Department of Housing and Urban Development (HUD) has set a limit of 0.4 ppm for indoor air.

Polychlorinated Biphenyls (PCBs) PCBs are considered “probable” human carcinogens based on animal studies. Although manufacture was banned in 1979, many products containing PCBs remain in use. Possible major exposure routes to PCBs are inhalation when electrical transformers and other equipment containing PCBs are ruptured or burned, breathing PCB-contaminated air or skin contact in the work environment, the ingestion of food (fish) or drinking water containing PCBs, and spills or illegal dumping of fluids containing PCBs. Fluorescent light ballasts and vinyl-coated paper are also a common source of PCBs. It is best to use caution and seek advice immediately from your health or environmental protection department should there be an actual or potential exposure to PCBs.

The Occupational Safety and Health Administration has established an airborne exposure limit of from 0.5 mg/m³ (54 percent chlorine content) to 1 mg/m³ (42 percent chlorine content) as an 8-hr time-weighted average (skin).[†] The National Institute of Occupational Safety and Health (NIOSH) recommends that the airborne exposure to PCBs in the workplace be 1 µg/m³ or less.[‡] The EPA has proposed a limit of 100 µg/m² in areas where frequent and regular skin contact with surfaces is possible.

Tobacco Smoke Environmental tobacco smoke consists of a suspension of 0.01 to 1 µm particles leaving the burning tobacco condensate. Also produced are numerous hazardous gases including carbon monoxide. The involuntary chronic exposure to cigarette smoke, also referred to as passive smoking, is associated with an increased risk of lung cancer, according to a 1986 report of the National Academy of Science (NAS).³⁸ In addition, children of smoking parents have increased respiratory illnesses compared with children whose parents do not smoke; however, data on other diseases such as other cancers and cardiovascular diseases are insufficient. According to the NAS report, passive smoking causes irritation of the eyes, nose, and throat of many nonsmokers. Ventilation rates

*Average level is proposed to be reduced to 0.75 ppm.

†Potential contribution to overall exposure by the cutaneous route, including mucous membranes and eyes.

‡See “NIOSH, CDC, Recommendations for Occupational Safety and Health Standards, 1988,” DHHS, PHS, NIOSH, CDC, *MMWR*. Supplement, August 26, 1988, pp. 23 and 24.

of up to five times higher in smoking areas are suggested to achieve acceptable indoor air quality. Office spaces should provide at least 20 ft³/min per occupant of clean outside air where smoking is permitted and at least 5 ft³/min per occupant in nonsmoking areas.³⁹ Effort should be directed to the prohibition of smoking in enclosed spaces and the discouragement of smoking.

Volatile Organic Compounds (VOCs) VOCs are a broad range of chemical compounds, with boiling points in the range of approximately 120 to 480°F (50° to 260°C) and vapor pressures greater than about 4×10^{-5} to 4×10^{-6} in. Hg.⁴⁰ Several hundred VOCs have been identified in the indoor environment.⁴¹ The Large Buildings Study by the EPA developed a VOC sample target list that includes aliphatic hydrocarbons, halogenated hydrocarbons, and oxygenated hydrocarbons such as aldehydes, alcohols, ketones, esters, ethers, and acids.⁴² Sources of VOCs in nonindustrial environments include building materials, furniture, furnishings, ventilation systems, household and consumer products, office equipment, and outdoor-related activities (e.g., traffic, neighborhood industry).

Little is known about the symptoms of overexposure to VOCs, but some are suspected of causing adverse health effects such as sensory irritation, odor, and the more complex set of symptoms of sick-building syndrome. Also researchers have found that neurotoxic effects may follow from low-level exposures to gaseous air pollutants.⁴³ Reactions include runny eyes and nose, high frequency of airway infections, asthmalike symptoms among nonasthmatics, along with odor or taste complaints. There is also a possible link between the increase in allergies throughout the industrialized areas of the world and exposure to elevated concentrations of VOCs.

Emission source control, gas-phase air filtration using activated-carbon filters or photocatalytic reactors, and ventilation are common ways of controlling indoor VOCs.⁴⁴ Sophisticated models have been developed to simulate the VOC emission, sorption, and transport in the built environment.⁴⁵ These models can help explain the physics of VOC transport process, and can be used to guide the building design.⁴⁶

Other Emissions Unvented kerosene, fuel oil, and wood stove space heaters, gas cooking and heating appliances, power equipment including automobiles, and gas clothes dryers lead to the emission of particulates, in addition to hazardous gases. Portable heaters also present risks of burns, injuries, fires, and explosions. Their use should be prohibited. Unvented kerosene space heaters can emit organic compounds, in addition to nitrogen dioxide, carbon dioxide, carbon monoxide, and sulfur dioxide. The concentrations can exceed the EPA ambient air standards, particularly in small spaces and where ventilation is inadequate. Poor-quality kerosene exacerbates the problem. Gas cooking appliances are also sources of carbon dioxide, nitrogen dioxide, formaldehyde, and other organic compounds, in addition to carbon monoxide. Carbon monoxide, nitrogen oxides, and particulates from automobile exhaust in garages can produce increased and

hazardous concentrations in office buildings above the garage and in public areas. Gasoline-powered ice resurfacing machinery can cause the same effect in indoor ice-skating rinks and forklifts in enclosed spaces.

The smoke from cooking and heating with open fires in houses in some under-developed countries is the cause of serious respiratory illness in infants. Pregnant women exposed to the smoke produce lower-birthweight children.⁴⁷

Thermal and Moisture Requirements

Good ventilation requires that the air contain a suitable amount of moisture and that it be in gentle motion, cool, and free from offensive body and other odors, poisonous and offensive fumes, and large amounts of dust. Comfort zones for certain conditions of temperature, humidity, and air movement are given by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).⁴⁸ Air movement, radiant heat, the individual, and the tasks being performed must also be taken into consideration.

There is no one temperature and humidity at which everyone is comfortable. People's sensations, health, sex, activity, and age all enter into the comfort standard. McNall⁴⁹ recommends a temperature range between 73 and 77°F (23 and 25°C) and humidity between 20 and 60 percent for lightly clothed adults engaging in sedentary activities in residences. Lubart⁵⁰ suggests a comfort level within the range of 68°F (20°C) at inside relative humidity of 50 percent to 76°F (24°C) with 10 percent relative humidity. The EPA recommends a relative humidity of 30 to 50 percent for homes.⁵¹ Indoor relative humidity of 60 percent or higher would cause excessive condensation and greater mildew, corrosion, and decay. Excessive moisture can cause condensation and increasing deterioration of building materials. Humidities above 70 percent promote germination and growth of fungal spores. Ordinarily, however, only temperature and ventilation control is used in the home, with no attempt made to measure or control the relative humidity. Humidity control becomes more important with reduced ventilation because the products of respiratory and metabolic processes and certain indoor operations and activities contribute moisture vapor. In a confined space, this can lead to the accumulation of contaminants and moisture and discomfort or illness.

Ventilation

Indoor air should be free of objectionable odors, unhealthy levels of microorganisms, allergens, and chemical contaminants. The design of a ventilation system should avoid uncomfortable drafts and large temperature variations. National, state,⁵² and local building and energy conservation codes specify ventilation requirements for various space uses and should be consulted. It has been proposed that the generally accepted minimum supply of fresh air per occupant be 15 or 20 ft³/min.⁵³ Much higher fresh air supply is needed in rooms where smoking is permitted or where other polluting activities are permitted. The OSHA requirements must be met in the workplace. In true air conditioning, air is treated to simultaneously control its temperature, humidity, cleanliness, and distribution to

meet requirements of the conditioned space. Room air inlets and returns should be arranged to ensure proper air mixing and ventilation of the space and to avoid drafts.

The tendency to reduce air infiltration and fresh air makeup in ventilation has increased the buildup of air contamination, with resultant occupant complaints. To alleviate the problem, minimum ventilation standards, including fresh air intakes, have been established or proposed in building codes and other publications.⁵³ In addition, the use of certain indoor products such as urea-formaldehyde insulation and unvented kerosene space heaters has been banned in some jurisdictions. However, owner- or occupant-provided equipment, materials, and furnishings not under regulatory control and ambient air quality may nevertheless contribute to indoor air pollution. Ventilation may be provided by natural or mechanical means. Investigation of an indoor air pollution problem could well start with carbon dioxide tests and interrogation of management, employees, and custodial and union people. If carbon dioxide concentrations are below 600 ppm, with comfortable temperature and humidity levels, complaints about air quality should be minimal.

Natural Ventilation A minimum of one or two air changes per hour can often be secured by normal traffic and leakage through walls, floors, and ceilings and through or around doors and windows, but previously mentioned energy conservation measures may reduce air infiltration and air change by 50 percent or more. Under ordinary circumstances, adequate ventilation can be obtained in residences by natural means with properly designed windows. Openable windows, louvers, or doors are needed to ventilate and keep attics, basement rooms, pipe spaces, and cellars relatively dry. The tops of windows should extend as close to the ceiling as possible, with consideration to roof overhang, to permit a greater portion of the room to be exposed to controlled sunlight. The minimum total window or skylight area, measured between stops, for a habitable room should be at least 8 percent of the floor area and the openable area at least 45 percent of the window or skylight area.⁵⁴ The ventilation of modern buildings is usually dependent on mechanical air conditioning and air recirculation, including controlled fresh air intake. Some examples and design criteria are discussed next.

Schools Separate venting of each classroom to the outside is preferred. Good standards specify that the mechanical ventilating system provide a minimum air change of 15 to 20 ft³/min per student to remove carbon monoxide and odors, without drafts. The air movement should not exceed 25 ft/min, and the vertical temperature gradient should not vary more than 5°F (3°C) in the space within 5 feet of the floor and 2 feet or more from exterior walls. Temperature should be automatically controlled.

Public Areas In recreation halls, theaters, churches, meeting rooms, and other places of temporary assembly, a system of mechanical or induced ventilation is usually needed to meet the requirement of at least 15 ft³ of clean air per minute per person. Any system of ventilation used should prevent short circuiting,

uncomfortable drafts, and the buildup of unhealthy levels of air contaminants. Approximately one-third of the recirculated air should be clean outside air.

Correctional Institutions Where dependence is on natural ventilation, windows or other openings should provide an area of at least 12.5 percent of the floor space of the sleeping, living, educational, and work areas and be located to provide cross-ventilation. Gyms and swimming pools require special temperature, humidity, and ventilation controls. If dependence is on mechanical ventilation, 15 to 20 ft³/min per person is recommended. Where air is recirculated, approximately one-third should be fresh, clean outside air.⁵⁵

Toilets and Bathrooms Bathroom and toilet room ventilation is usually accomplished by means of windows or ventilating ducts. The common specification for natural ventilation is that the window or skylight area be at least 8 or 10 percent of the floor area and not less than 3 ft², of which 45 percent is openable. For gravity exhaust ventilation, vents or ducts at least 72 in.² in area per water closet or urinal and a minimum of 2 ft³/min of fresh air per square foot of floor area should be provided. A system of mechanical exhaust ventilation providing at least five air changes per hour of the air volume of the bathroom or toilet room during hours of probable use is usually specified for ventilation where windows, ducts, or vents are not relied on or are not available for ventilation. ASHRAE⁵³ recommends 50 ft³/min per water closet and per urinal for a public restroom. Exhaust fans activated by the opening and closing of doors or by a light switch do not provide satisfactory ventilation. The recirculation of air supplied to toilets, lavatories, toilet rooms, bathrooms, and restrooms (also kitchens, laboratories, and garages) is generally not permitted.⁵⁶

Air Change Measurement Air in an enclosed space normally diffuses out and outdoor air filters in at a rate dependent on the tightness of the space or building and wind direction and velocity. The air change can be determined by dividing the volume of air entering an enclosed space or room by the volume of the space or room. For example, if 100 ft³/min enters a room having a volume of 1,000 ft³ occupied by five people, there would be six air changes per hour ($100 \times 60 \div 1,000$) and 20 ft³/min per occupant.

The air change may be measured by use of tracers. Desirable qualities of a tracer gas are detectability, nonreactivity, nontoxicity, neutral buoyancy, relatively low concentration in ambient air, and low cost.⁵⁷ The commonly used tracers include nitrous oxide (N₂O), carbon dioxide (CO₂), helium (He), and sulfur hexafluoride (SF₆). Several tracer gas measurement procedures exist, including an American Society for Testing and Materials (ASTM) standard.⁵⁸ In the measurement, the tracer is released into the building in a specific manner, and the concentration of the tracer within the building is monitored and related to the building's air change rate. Standardization of devices is necessary.

Monitoring The monitoring and measurement of the quality of indoor air can be accomplished by modification, as needed, of equipment used to sample

ambient air and occupational exposure and by adapting laboratory equipment and procedures. Passive measuring devices for carbon monoxide, radon, formaldehyde, and asbestos, although not accurate, are acceptable. The Anderson impactor sampler may be used to collect indoor airborne fungi supplemented by plate incubation for colony count and identification. Psychrometers for measuring temperature and humidity and smoke tubes for determining air movement are also generally used. Samplers for volatile organic compounds and continuous samplers are also available. Standardized methods for the determination of air pollutants in indoor air are listed in Table 2.11.

Respiratory Illness Control

The NIOSH suggests seven steps to minimize respiratory illness:

1. Promptly and permanently repair all external and internal leaks in the heating, ventilation, and air-conditioning system (HVAC).
2. Maintain relative humidity below 70 percent in occupied spaces and in low-air-velocity plenums. (At a higher level of humidity, the germination and proliferation of fungal spores are enhanced.)
3. Prevent the accumulation of stagnant water in cooling-deck coils of air-handling units through proper inclination and continuous drainage of drain pans.
4. Use steam rather than recirculated water as a water source for humidifiers in HVAC systems; however, such steam sources should not be contaminated with volatile amines.
5. Replace filters in air-handling units at regular intervals. (These should have at least a moderate efficiency rating—50 percent or more—as measured by the atmospheric-dust spot test and should be of the extended-surface type; prefilters (e.g., roll type) should be used before passage over the higher efficiency filters.)
6. Discard, rather than disinfect carpets, upholstery, ceiling tiles, and other porous furnishings that are grossly contaminated.
7. Provide outdoor air into ventilation systems at minimum rates per occupant of at least 20 ft³/min in areas where occupants are smoking and at least 5 ft³/min in nonsmoking areas. (ASHRAE Recommended Standard 62 specifies a minimum of 15 or 20 ft³/min per person.⁵³)

These activities should be considered in ongoing preventive maintenance programs.⁵⁹

The usual method of air purification by washing and filtration is relatively inefficient in removing bacteria or viruses from used air, although it can be effective in removing dust and other airborne particles. Electrostatic air precipitator units and special air filters effectively reduce indoor particulates. See also *Biological Contaminants and Health Effects*, this chapter. Central vacuum cleaning

TABLE 2.11 Method for Determination of Air Pollutants in Indoor Air

Method Number	Description	Types of Compounds Determined
IP-1A	Stainless steel canister	Volatile organic compounds (VOCs) (e.g., aromatic hydrocarbons, chlorinated hydrocarbons) having boiling points in the range of 176–392°F (80–200°C)
IP-1B	Solid adsorbent tubes	—
IP-2A	XAD-4 (styrene-divinylbenzene) sorbent tube	Nicotine (gaseous and particulate)
IP-2B	Treated filter cassette	—
IP-3A	Nondispersive infrared (NDIR)	Carbon monoxide and/or carbon dioxide
IP-3B	Gas filter correlation (GFC)	—
IP-3C	Electrochemical oxidation	—
IP-4A	Perfluorocarbon tracer (PTF)	Air exchange rate
IP-4B	Tracer gas	—
IP-5A	Continuous luminol monitor	Nitrogen oxides
IP-5B	Palmer diffusion tube	—
IP-5C	Passive sampling device	—
IP-6A	Solid adsorbent cartridge	Formaldehyde (CH ₂ O) and other aldehydes/ketones
IP-6B	Continuous colorimetric analyzer	—
IP-6C	Passive sampling device	—
IP-7	Medium-volume polyurethane foam (PUF)/XAD-2 sampler	Polynuclear aromatic hydrocarbons
IP-8	Low-volume PUF sampler followed by gas chromatography/electron capture detection	Pesticides (e.g., organochlorine, organophosphorus, urea, pyrethrin, carbamate, and triazine)
IP-9	Annular denuder system	Acid gases/aerosols/particles (e.g., nitrates, sulfates, and ammonia)
IP-10A	Size-specific impaction	Particulate matter
IP-10B	Continuous particulate monitor	—

Source: W. T. Winberry et al., “EPA Project Summary Compendium of Methods for the Determination of Air Pollutants in Indoor Air,” EPA/600/S4–90/010, U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC, May 1990.

systems are very effective for the removal of dust and other particulates without resuspending the finer particles indoors.

Venting of Heating Units

Proper venting is the removal of all the products of combustion through a designated channel or flue to the outside air with maximum efficiency and safety.

Gravity-type venting relies largely on having the vent gases inside the vent hotter (thus lighter) than the surrounding air. The hotter the vent gases, the lighter they are and the greater their movement up through the vent. Thus, in order to keep the vent gases hot so that they may work at maximum efficiency, proper installation and insulation are necessary.

Factors that prevent proper venting are abrupt turns; downhill runs; common vents to small, uninsulated vent pipes; conditions that cause backdrafts; obstructions in the flue or chimney to which a furnace, heater, or stove is connected such as birds nests, soot and debris, broken mortar and chimney lining, and old rags; and unlined masonry chimneys. Stained and loose paper or falling plaster around a chimney is due to poor construction. A masonry chimney will absorb a great deal of the heat given off by the vent gases, thus causing the temperature in the chimney to fall below the dew point. The high moisture in vent gases condenses inside the chimney, forming sulfuric acid. This acid attacks the lime in the mortar, leaching it out and creating leaks and eventual destruction of the chimney. Therefore, it is necessary to line a masonry chimney with an insulating pipe, preferably terracotta flue lining.

Figure 2.16 shows chimney conditions apt to result in backdrafts. The flue or vent should extend high enough above the building or other neighboring obstructions so that the wind from any direction will not strike the flue or vent from an angle above the horizontal. Unless the obstruction is within 30 feet or is unusually large, a flue or vent extended at least 3 feet above flat roofs or 2 feet above the highest part of wall parapets and peaked roof ridges will be reasonably free from downdrafts.

To ensure proper venting as well as proper combustion, sufficient amounts of fresh air are required, as shown in Figure 2.16. An opening of 100 to 200 in.² will usually provide sufficient fresh air under ordinary household conditions; this opening is needed to float the flue gases upward and ensure proper combustion in the fire box. Proper venting and an adequate supply of fresh air are also necessary for the prevention of carbon monoxide poisoning or asphyxiation.

The connection (breeching) between the furnace or stove and chimney should be tight fitting and slope up to the chimney at least 1/4 in./ft. Chimneys are usually constructed of masonry with a clay tile flue liner or of prefabricated metal with concentric walls with air space or insulation in between and should be Underwriter's Laboratories approved. All furnaces and stoves should be equipped with a draft hood, either in the breeching or built into the furnace or stove, as required, for proper draft. See Figure 2.16.

Before making any vent installations or installing any gas- or oil-fired appliances, consult the building code and the local gas or utility company. Standards for chimneys, fireplaces, and venting systems, including heating appliances and incinerators, are given by the National Fire Protection Association,⁶⁰ building codes, and other publications.

Portable kerosene heaters are a fire hazard and, since they are not vented, emit dangerous gases into a room. Their sale and use should be prohibited. The

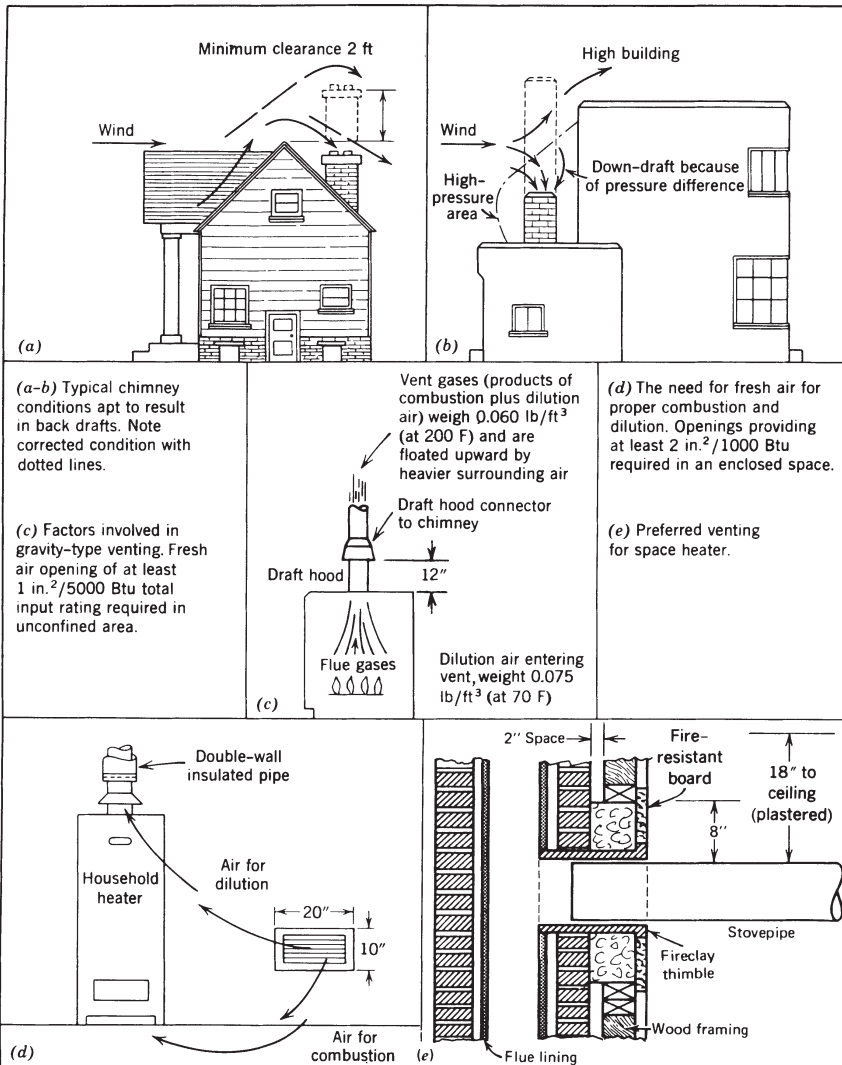


FIGURE 2.16 Some venting details. (Drawings are typical and not necessarily in full accordance with any code.) See state and local building and fire prevention codes.

concentrations of carbon dioxide, nitrogen dioxide, and sulfur dioxide emitted into a room usually greatly exceed ambient air standards.

Wood stoves require special fire protection and venting. See Cooperative Extension Service recommendations and local building code requirements.

Chimneys, vents, and ducts can become blocked by bird nests, squirrel nests, soot, grease, leaves, and other debris. Such conditions can develop during the

nonheating season, which will prevent proper venting of the heating unit. Dangerous levels of carbon monoxide can accumulate if chimneys, vents, and ducts are not kept clear.

MOBILE HOME PARKS

Mobile homes are defined as “transportable, single-family dwelling units suitable for year-round occupancy and containing the same water supply, waste disposal, and electrical conveniences as immobile housing.”⁶¹ A mobile home is also defined as a “manufactured relocatable living unit.”⁶² Mobile homes produced since 1954 are 10, 12, and 14 feet wide and up to 60 or 70 feet long. Wider units are assembled at the home site by combining sections to form double- and triple-wide units.

The Bureau of the Census identified 5.267 million mobile home units in the United States in 1987 as year-round housing occupied by over 13 million residents. There were 3.9 million homes in 1980 and 2.1 million in 1970. In 1987, 99 percent had complete plumbing, 46 percent were connected to a public sewer, 68 percent used public water, 81 percent had central heating, and 34 percent had central air conditioning. Annual sales dropped to 212,000 units in 1975 and increased to 300,000 units in 1977. Between 1980 and 1984, 1,129,000 units were added. Sales peaked in 1973 with 625,000 units. The typical mobile home is 14 feet wide and 65 feet long. Many are double units; some are triple. In 1974, about one-third of the buyers were married couples under 35 years of age and one-third were retired and over 65. In 1987, about 86 percent of the mobile homes were owner occupied. Modern mobile home parks may have all utilities, swimming pool and other recreational facilities, laundry, community buildings, paved streets with curbs or gutters, trees and landscaping, and patio slab, and may look like an established housing development. Lots are typically 5000 ft². Lots larger than 5000 ft² permit more flexibility in exposure and siting the mobile home. *It must be kept in mind that, unless the plot is owned by the mobile home owner, continued occupancy is dependent on the desire and future plans of the park owner;* hence, a mobile home park cannot be considered a permanent realty subdivision. Because of the risk of property sale and resultant hardships, consideration has been given to protective laws, cooperative ownership, and contractual arrangements.

The parks established have all of the potential environmental sanitation and safety problems of a small community. Because of this, standards have been prepared to guide mobile home manufacturers, operators, owners, and regulatory agencies to help promote safe and sound manufacture, site preparation, and sanitary practices. Compliance with these standards is facilitated by reference to the pertinent chapters in this text; to the guides cited in the footnotes, which include recommended ordinances; and to the guides published by HUD.^{63 – 65*}

*The American National Standards Institute, National Fire Protection Association, and Building Officials & Code Administrators International also have suggested standards for adoption by local governments.

Other precautions include stable stands, tiedowns to minimize overturning during windstorms, smoke detectors and fire extinguishers in homes, with two exits from each unit, a minimum spacing of 10 feet, minimum site size, protection of water connections against freezing, sufficient electric power for all electrical equipment including approved-type inside wiring, and interior materials that do not cause the release of hazardous pollutants.

INSTITUTION SANITATION

An institution is a complete property with building, facilities, and services having a social, education, or religious purpose. This includes schools, colleges and universities, hospitals, nursing homes, homes for the aged, day-care centers, jails and prisons, reformatories, and the various types of federal, state, city, and county welfare, mental, and detention homes or facilities.

Institutions as Small Communities

Most institutions are communities unto themselves. They have certain basic characteristics in common that require careful planning, design, construction, operation, and maintenance. These include site selection, planning, and development for the proposed use, including subsoil investigation, accessibility, and proximity to sources of noise and air pollution; a safe, adequate, and suitable water supply for fire protection as well as for institutional use; sewers and a wastewater disposal system; roads and a stormwater drainage system; facilities for the storage, collection, and disposal of all solid wastes generated by the institution; boilers and incinerators with equipment and devices to control air pollution; food preparation and service facilities; fire-resistant housing and facilities for the resident population; laundry facilities; and insect, rodent, and noxious weed control. In addition, depending on the particular institution, they might have recreational facilities, such as a swimming pool or bathing beach. A hospital or educational institution often has its own laundry. A state training school or institution might have a dairy farm or produce farm, pasteurization plant, industrial operation, and food-processing plant. The environmental, health, engineering, and sanitation concerns at all these places are, in many instances, quite extensive and complex.

The possibilities for the transmission of illnesses associated with air, water, food, and contact are increased at institutions. Scrupulous cleanliness, hygiene (handwashing), and sanitation are essential at all times. Certain institution advisory committees can be helpful. These might include radiation safety, infection and biohazard control, emergency preparedness, occupational and environmental health and safety, laboratory safety, animal care and research, diving safety, and accident prevention. Institutions provide an ideal environment for the spread of communicable diseases. They require careful surveillance and preventive measures adapted to the particular use and population. The reader is referred to the appropriate subject matter throughout this text for details.

The material that follows will highlight environmental, health, engineering, and sanitation factors at various types of institutions. The institutions have many environmental factors in common.

Hospitals and Nursing Homes

Hospital-acquired, or nosocomial, infections result in additional morbidity, mortality, and costs pointing to the need for greater infection surveillance and control.⁶⁶ The majority of nosocomial infections are endemic. They may affect not only the patient who develops the infection but also other patients, the hospital staff, and the community as well. Data accumulated over past years indicate that under certain conditions as much as half of all nosocomial infections may be preventable.⁶⁷ Most infections are probably medically or nursing related.

The hospital is expected to provide an environment that will expedite the recovery and speedy release of the patient. Carelessness can introduce contaminants and infections that delay recovery and may overburden the weakened patient, thereby endangering the patient's survival. It has been estimated that 1.5 million patients, out of some 300 million, or about 5 percent, incur infections in hospitals annually.⁶⁸

The hospital-acquired infection rate in 1983 was highest in large teaching hospitals and lowest in nonteaching hospitals, 41.2 and 24.4 per 1000 cases discharged, respectively. Another study found a nosocomial infection rate between 5 and 6 percent. The infection rate was highest on the surgical service, followed generally by medicine, gynecology, and obstetrics. The urinary tract was the most frequent site of infection, followed by surgical wounds and lower respiratory tract, accounting for 70 percent of all infections. *Escherichia coli*, *Staphylococcus aureus* (coagulase negative), enterococci, and *Pseudomonas aeruginosa* were the most frequently reported pathogens—also *Klebsiella* spp., *Enterobacter* spp., *Proteus* spp., and *Candida* spp.⁶⁹ The experience was very similar in 1984.⁷⁰

It is unlikely that the air (or surfaces) in an operating room will be sterile in the strict sense of the word, but it must be maintained at an extremely low bacterial level. Ultraviolet radiation has great potential for reducing the microbial flora of the air, where the patient may be especially vulnerable, but to be effective, particles carrying organisms must make direct contact with the radiation. Chemicals used include aerosols of triethylene glycol, lactic acid, resorcinol, and hypochlorous acid.

Numerous reasons have been offered for hospital-acquired infections: an increase in the number of older patients with chronic diseases; an increase in high-risk patients and surgical procedures such as open-heart surgery and organ transplants; innovations in diagnostic and therapeutic procedures, including widespread use of antibiotics, indwelling catheters, and artificial kidneys; inadequate disinfection or sterilization of respiratory therapy and other equipment; prevalence of *S. aureus* and group A streptococci; and the increasing identification of gram-negative organisms such as *P. aeruginosa*, proteus, *E. Klebsiella*, and *A. aerogenes*; as well as the gram-positive, toxin-producing *Clostridium difficile*.⁷¹⁻⁷³

Basic to the prevention of nosocomial infections are hygienic medical, nursing, and staff practices, including frequent handwashing; equipment sterilization; food, water, plumbing, air, laundering, linen handling, and housekeeping sanitation, including floor cleaning to suppress dust; the prevention of overcrowding, minimization of movement of patients and hospital personnel from point to point; and avoidance of antibiotics use when possible. A major control mechanism is the establishment of a representative infection control committee, which should include appointment of a full-time environmental control officer with comprehensive responsibility and authority to coordinate and ensure that medical, nursing, housekeeping, maintenance, and ancillary staffs are following good practices and procedures, including nosocomial infection surveillance and control, proper waste handling, food sanitation, safety including radiation, and occupational health protection. This officer would also have the responsibility of being the liaison between the institution and federal, state, and local regulatory agencies, including fire, health, building, and environmental protection.

The duties of the environmental control officer would include assurance of “satisfactory” responses to all of the items listed in Figure 2.17. Since the survey form is merely suggestive of the broad scope of each subject and far from complete, it is apparent that the environmental control officer must be broadly trained through education and experience to recognize and appreciate the full impact of conditions observed and their possible risk to patients, staff, visitors, and community and the promptness with which unsatisfactory conditions must be corrected. Suggested preparation would include a graduate degree from a recognized institution in environmental health science or a related degree with an internship or training in institutional health management, administrative techniques, and environmental control.

A major concern in hospitals, nursing homes, and other institutions is fire safety. Basic elements include construction, detection and alarm, containment, extinguishment, evacuation, and staff training. The Department of Health and Human Services has a survey report form⁷⁴ that is used in Medicare–Medicaid and state programs. The survey report is comprehensive and applicable to a hospital, skilled nursing facility, intermediate-care facility, and facilities with 15 beds or less.

Construction is required to comply with state and local building codes, which usually include extensive fire protection regulations. Requirements relate to such factors as construction materials, exits and exit access, corridors, protection and enclosure of vertical openings, protection of hazardous areas, smoke detection, automatic sprinkler systems, and much more.

Special precautions must be taken with kidney dialysis machines. Water for kidney dialysis machines must be very soft, low in minerals and dissolved solids, and of good physical and microbiological quality. Distillation, deionization or reverse-osmosis treatment, and granular activated-carbon treatment are usually required, as ordinary potable water may be toxic for the dialysis patient. Chloramines in water are harmful to the patient. Chloramines pass through semipermeable membranes.⁷⁵ Synthetic resins in softening ion exchange

Name _____		Address _____		T.V.C. _____	
Operator _____		Persons interviewed _____			
Inst. No. _____		No. Cert. Beds _____		Inspected by _____ Date _____	

Item	S	U	Item	S	U
<i>Structure and grounds</i>			<i>Insect and rodent control</i>		
1. Location			36. Physical controls		
2. Buildings and grounds			37. Chemical controls		
3. Accessible by emergency vehicles			<i>Infant formula and nursery</i>		
4. Service entrances			38. Equipment, supplies, technicians, records, practices, isolation		
5. Elevators			39. Approved source and handling		
<i>Water supply</i>			<i>Space provisions</i>		
6. Supply and pressure, hospital and fire			40. Patient rooms		
7. Treatment, physical, biological, chemicals			41. Isolation rooms		
8. Quality—hospital, protect, and surveillance; incl. water carafes			42. Bath and toilet rooms		
9. Quality—special, medical, and lab.			43. Nursing service areas		
10. Hot water			44. Other services—rooms, spaces		
<i>Liquid and solid wastes</i>			45. Central and general storage		
11. Sewage piping and disposal			<i>Fire safety</i>		
12. Biological wastes collection, storage, disposal			46. Fire-resistive construction		
13. Solid wastes collection, storage, disposal; hazardous per RCRA			47. Interior finishes		
<i>Plumbing</i>			48. Smoke and fire doors, open		
14. Toilets, lavatories, tubs, showers, sinks			49. Fire-resistant enclosures—chutes, shafts, stairs, kitchen, boiler, and incinerator rooms		
15. Cross-connection and backflow control			50. Exit doors, access, stair, hall, signs		
16. Drinking fountains			51. Flame-retardant fabrics, drapes		
<i>Emergency power and light</i>			52. Flammable liquids		
17. Power to vital services			53. Flammable anesthetics		
18. Lighting to vital areas			54. Oxygen and nitrous oxides		
<i>Ventilation, heat, and air conditioning</i>			55. Fire hydrants, hoses, standpipes		
19. Air flows, rates, pressure, differential			56. Fire extinguishers, portable		
20. Air filtration			57. Automatic sprinklers in chutes, soiled linen, trash, and storage rooms		
21. Air temperature			58. Kitchen hoods and grease removal		
22. Air humidity			59. Fire-detection systems in boiler, kitchen, labs, laundry, pantry, garage		
23. Intake and exhaust locations			60. Fire-alarm system, internal		
<i>Laundry</i>			61. Alarms connected to fire department or station		
24. Soiled linen handling and transportation			62. Electrical hazards controlled		
25. Laundering			63. Anesthesia areas—electrical safeguards		
26. Clean linen handling and transportation			64. No smoking—signs, supervision		
<i>Food protection and quality</i>			65. Fire plans—posting, drills, training		
27. Food sources			<i>Accident safety</i>		
28. Refrigerated food storage			66. Handrails and grab bars—corridors, stairs, ramps, toilets, bath		
29. Dry food storage			67. No obstacles—corridors, ramps, stairs		
30. Food preparation			68. Floors—nonslip and nontrip		
31. Food serving, hot and cold					
32. HACCP plan					
33. Food equipment and utensils					
34. Ice making and handling					
35. Vending machines					

FIGURE 2.17 Hospital environmental health survey form. Use federal or state form where available.

Item	S	U	Item	S	U
69. Burn protection—heaters, hot water			<i>Supporting services</i>		
70. Patient furnishings and equipment			81. Housekeeping		
71. Electrical safety hazards			82. Plant maintenance		
72. Accident reporting, records			<i>Refrigeration (nondietary)</i>		
73. Lighting levels			83. Pharmaceutical and blood storage		
<i>Infection Control</i>			84. Morgue		
74. Infection control committee			<i>Pools (therapy or swimming)</i>		
75. Sterilization facilities			85. Recirculation and filtration		
76. Sterilization—procedure, surveillance, records			86. Disinfection		
77. Sterilization of medical apparatus			<i>Radiations and hazardous wastes</i>		
78. Disinfection of patient-used articles			87. Diagnostic X-ray units		
79. Cleanliness of operating, delivery, isolation rooms, and nursery			88. Therapeutic X-ray units		
80. Disinfection of inhalation therapy apparatus			89. Teletherapy units		
			90. Radioact. materials—storage, use		
			91. Microwave ovens		
NOTE: S means satisfactory equipment, construction, operation, maintenance. U means unsatisfactory. Contract Services _____ Housekeeping _____ Laundry _____ Dietary _____ Other _____ Give name.					

FIGURE 2.17 (continued)

units are damaged by dioxide, chlorites, chlorates, and chlorine and, hence, are unsuitable for this purpose. Granular activated-carbon and reverse-osmosis treatment remove chlorite and free chlorine, but the removal of chlorine dioxide and chlorate is unknown.⁷⁶ Peracetic acid at 700 ppm for the cleaning and disinfection of reverse-osmosis equipment and system is reported as a promising, nontoxic substitute for certain water treatment systems.⁷⁷ The physician involved should determine the water quality standards for water used in kidney dialysis. European Pharmacopeia specifies that the water must be free of pyrogens and made exclusively by distillation for hospital use.

Wash-water temperatures in the hospital laundry have been studied by numerous investigators. A minimum temperature of 160° to 167°F (71°–75°C) for 25 minutes is generally specified. It appears that the temperature can be reduced to 140°F (60°C) for lightly soiled hospital linens from nonisolation areas, but more investigation is needed to ensure that this temperature is adequate for the laundering of *all* linens, including isolation linens. It appears that dilution, the use of bleach, and the drying cycle are more important than water temperature in the laundering of hospital linens. Cycles at 170°F (77°C) and 72°F (22°C) were compared.⁷⁸ In any case, proper handling of laundered linen to prevent cross-contamination and contamination in handling is essential.⁷⁹

Extensive infection surveillance and control program guidelines have been published by the Joint Commission on Accreditation of Hospitals and others.^{80–82} Guidelines for protecting health care workers have also been prepared.⁸³

Health care is provided in hospitals and nursing homes. A hospital usually provides acute care, including diagnosis and treatment. A nursing home provides long-term care, with limited rehabilitation. An adult home or old-age home

provides room and board but not health care. The nursing home levels of care vary from “heavy care” to “light care” and may bridge the gap between the hospital and adult home.

A great deal of special emphasis has been placed on hospital and nursing home construction, equipment, and inspection or survey of operations and services. Federal and state standards must be met with respect to fitness and adequacy of the premises, equipment, personnel, rules and bylaws, standards of medical care, and hospital services. Plans for new structures and for additions or modifications of existing facilities are also reviewed for compliance with federal and state requirements to help ensure the best possible facilities for medical care.

The survey or inspection of hospitals and nursing homes takes into consideration the administration, fire prevention, medical, nursing, environmental sanitation, nutrition, accident prevention and safety, operational, and related matters. A proper initial survey of these diverse matters calls for a professionally trained team consisting of a physician, sanitarian, engineer, nurse, nutritionist, and hospital administrator. Figures 2.17 and 2.18 show suggested hospital and nursing home environmental survey items. Of course, they can be greatly amplified.⁷⁴ The proper interpretation of the environmental health survey form items requires a well-rounded educational background and specialized training, as previously noted, including thorough knowledge of applicable federal and state laws, with support from consultants when indicated. It is good procedure to coordinate the inspection program with the work of other agencies and to develop continuing liaison with the health department, county medical society, accreditation groups, local nursing home association, local hospitals, fire departments, building departments, social welfare services, and others involved. This can strengthen compliance and avoid embarrassment resulting from conflicting recommendations.

Special attention should be given to non-fire-resistive hospitals and nursing homes, if permitted. Until such places can be replaced with fire-resistive structures, they should be protected against possible fire. This would include automatic sprinklers and alarms; horizontal and vertical fire stopping of partitions; enclosure and protection of the boiler room; outside fire escapes; fire doors in passageways, vertical openings, and stairways; fire detectors, smoke detectors, and fire extinguishers; a fire evacuation plan and drills; 24-hour surveillance; and the housing of nonambulatory patients on the ground floor. These comments are also generally applicable to other health care facilities. Building and fire protection codes must be followed.

Surveillance by official agencies, voluntary organizations, and individuals should ensure that fire protection, safety, and medical care are not compromised in spite of increased costs or lack of funds.

Hospital and Related Wastes

Hospital wastes may include pathological, infectious, hazardous chemical, and radioactive wastes as well as cultures and stocks, blood and blood products, animal carcasses, pharmaceutical wastes, pressurized containers, batteries, plastics,

Name _____		Address _____		T.V.C. _____	
Operator _____		Person interviewed _____			
Capacity _____		Bed patients _____		Amb. patients _____	
nurses _____		Other _____		Personnel: RN _____ Pract. _____	

	Yes	No	CM		Yes	No	CM
<i>Housing and fire safety</i>							
1. Building, floors, stairs structurally sound				29. Slop sink—each floor, and 1 for 24 beds			
2. Rooms, kitchen, cellar, attic, yard clean				30. Bedpan sterilizer—1 for 24 bed patients			
3. Rooms, including kitchen, well lighted				31. Toilet room on each floor			
4. Rooms, including kitchen, well ventilated				32. Separate toilet and shower for help convenient, washbasin with sanitary towels			
5. Rooms, basement, closets free of debris				<i>Food protection and quality</i>			
6. Beds 4-ft apart and 1 ft from walls				33. Equipment and facilities sanitary and adequate for food storage, preparation, and serving			
7. Windows, doors, openings screened				34. Dishes, trays, utensils clean and disinfected			
8. Free of rat and vermin infestation				35. Foodhandlers clean, have lockers			
9. Bedding clean, storage satisfactory				36. Refrigeration adequate			
10. Heating suitable and adequate				37. Food service, hot and cold. HACCP plan			
11. Fire-resistive construction				38. Pasteurized milk served in indiv. carton			
12. Smoke and fire doors provided				39. Refuse storage and disposal satisfactory			
13. Boiler rm. and incin. fire-resistant				40. No poisons stored in kitchen			
14. Exit door signs posted				41. Menu planned week in advance			
15. Flame-retard. drapes, fabrics				42. Meals nutritionally balanced			
16. Fire alarm system connec. to fire dept.				43. Food service attractive			
17. Fire plans posted; drills				44. Leftovers used promptly			
18. Flammables secured				<i>Medical and nursing service</i>			
19. Elec. hazards controlled				45. Mental and TB cases prohibited			
<i>Water supply</i>				46. Patient accidents and CD reported			
20. Water supply approved; fire hydrant within 500 ft				47. RN always in attendance			
21. Adequate supply hot and cold				48. Adequate competent help available			
22. Sanitary drinking fountain or paper cups				49. Employees free of CD			
23. Cross-connection and interconnection prohibited				50. Helpless patients get special attention			
24. Backflow preventers on WC, flushers—bedpan				51. Records kept giving:			
<i>Sewage and toilet facilities</i>				(a) Name of MD for patient			
25. Sewage disposal satisfactory				(b) Name and address of patient, sex, color, age, marital status, occupation, place of birth, admission, diagnosis, discharge, relative			
26. Waterclosets—1 for 8 beds							
27. Washbasins—1 for 8 beds							
28. Shower or tub—1 for 12 beds							

FIGURE 2.18 Nursing home inspection form. Use federal or state form where available.

	Yes	No	CM		Yes	No	CM
(c) Clinical history and treatment, medications, signed MD's orders				53. Drugs properly labeled in cabinet			
(d) Qualification of nurses and attendants				54. Adequate dressings and supplies			
(e) Narcotics on hand, dispensed				55. Recreation facilities for patients			
52. Narcotics stored in locked cabinet				56. Occupational therapy			
				57. Infectious wastes segregated			
Explain "No" items, use back NOTE: CM indicates correction made.							
REMARKS _____							

Date inspected _____ By _____							

FIGURE 2.18 (continued)

low-level radioactive wastes, disposable needles, syringes, scalpels, and other sharp items. These are in addition to food service, laboratory, bandage, cleaning, and miscellaneous wastes. Proper handling, segregation, packaging, marking, storage, transport, treatment, and disposal of all hospital wastes are necessary to minimize the potential risks to the health of the patient, health care worker, visitor, refuse handler, and community.^{84,85} Only about 15 percent of all hospital wastes are infectious. Although of public health and aesthetic concerns, they do not pose a health risk for the general public.

Infectious and pathological wastes, including packaging, disposable needles, syringes, and scalpels, are best disposed of by incineration providing proper temperature, oxygen, and residence time and by autoclaving followed by compaction or shredding. Chemotherapy and pathological wastes are incinerated. Autoclaved wastes are disposed of in a landfill or incinerator. Older hospital incinerator emissions can be expected to be high in particulates, chlorinated toxins, hydrochloric acid, and chlorine (in view of the burning of large quantities of plastic wastes), if the waste is not well mixed and if proper design and operation, including air pollution control devices, are not provided. Most, if not all, old hospital incinerators require upgrading.

Recommendations to equal or exceed air quality standards include temperature of 2,000°F (1,093°C) with 2 seconds residence time and secondary chamber exit temperature of 1,800°F (982°C); 97 percent acid gas removal or 30 ppm; particulates 0.010 gram/ft³; CO emissions 100 ppm hourly average; and opacity less than 10 percent.⁸⁶ A controlled starved air incinerator with flue gas scrubbers has been found satisfactory to control emissions.⁸⁷

General hospital and kitchen wastes can usually be disposed of through the community waste collection system. Centralized regional incinerators and autoclaving with compaction or shredding for hospital wastes are usually recommended over individual plants. Other alternatives include chemical disinfection of macerated wastes with discharge to the sewer system (if permitted by the

regulatory agency) and microwave disinfection of shredded wastes. Liquid infectious wastes may be carefully poured to a drain connected to a sanitary sewer.⁸⁸

The usual method for the disposal of *low-level* radioactive solid waste is by storage until decayed, followed by disposal with the general waste. Low-level liquid waste, including body wastes, can be diluted and disposed of to the sanitary sewer. Gaseous radioactive wastes are dispersed directly to the outside air, away from any indoor air intakes or occupied areas. The entire process requires responsible regulatory and institutional surveillance.

The EPA regulates the handling of hazardous wastes and OSHA has jurisdiction over chemical carcinogens and other hazardous chemicals in work areas. Hospital wastes are also controlled by the Nuclear Regulatory Commission, the Toxic Substances Control Act, and the Resource Conservation and Recovery Act. State and local regulations must also be followed. It is incumbent upon hospitals and other generators, including clinics, medical laboratories, nursing homes, doctors, dentists, and veterinarians, to identify infectious and hazardous materials. They must protect workers, patients, and visitors from any hazard within the institution, clinic, or office and the community from any discharges or releases to the air, water, and land.⁸⁹

Schools, Colleges, and Universities

Schools, colleges, and universities may incorporate a full spectrum of facilities and services not unlike a community. Involved—in addition to basic facilities such as water supply, sewage, and other wastewater disposal, plumbing, solid waste management, and air quality—are control of food preparation and service, on-site and off-site housing, hospital or dispensary, swimming pool, radiation installations and radioisotopes, insect and rodent infestations, and safety and occupational health in structures, laboratories, and work areas, including fire safety, electrical hazards, noise, and hazardous materials. In view of their complexity and their effect on life and health, all institutions should have a professionally trained environmental health and safety officer and staff responsible for the enforcement of standards, such as in a sanitary code, encompassing the areas of concern already noted. Such personnel can work closely with federal, state, and local health and safety regulatory officials and thus provide maximum protection for the student population and teaching, research, and custodial staffs.⁹⁰ Figures 2.19 and 2.20 suggest the broad areas to be considered when making an inspection. Guidance as to what is considered satisfactory compliance can be found in this text under the appropriate headings and also in federal, state, and local publications.

Correctional Institutions

Correctional institutions include short-term jails, long-term prisons, and various types of detention facilities. The health care services may include primary health care services, secondary care services, health care services for women offenders, mental health care, dental care, environmental concerns, nutrition and food

Name _____ Location _____ T.V.C. _____			
Principal _____ Supt. of Schools _____ Date _____			
Grades _____ No. classrooms _____ No. boys _____ No. girls _____ Public _____			
Private _____ Parochial _____ Boarding _____			

Item	Yes	No	CM	Item	Yes	No	CM
1. Water system approved by health department				17. Natural and artificial light provided			
2. One sanitary drinking fountain for every 75 children, or				(a) 50-ft-c in classrooms, libraries, offices, shops, laboratories, gymnasium, pool			
3. One sanitary paper-cup dispenser for every 75 children, where needed				(b) 75-ft-c in sewing, drafting, and arts and crafts rooms			
4. One washbasin with warm and cold water for every 30 students				(c) 50-ft-c in sightsavings classrooms			
5. Soap, paper towels, and mirrors provided				(d) 10-ft-c in auditorium, assembly rooms, cafeterias			
6. One toilet including tissue and partition for every 35-45 girls, and one toilet including tissue and one urinal for every 30-40 boys; separate.				(e) 10-ft-c in locker rooms, corridors, stairs, toilet rooms			
7. Toilet and lavatory rooms convenient, clean, free of odors, ventilated; floors impervious and drained				(f) 70-ft-c in kitchen			
8. Shower and locker room clean, drained; adeq. warm water				18. Thermometer at seat level, provided, which reads in winter at			
9. Sewage and excreta disposal satisfactory				(a) 68-72°F in classrooms, auditoriums, offices, cafeterias			
10. Buildings of fire-resistive construction				(b) 66-70°F in corridors, stairways, shops, laboratories, kitchen			
11. Corridors, stairs, exits, doors marked and provide safe and ready escape from building in case of fire				(c) 60-70°F in gymnasium			
12. Flammables stored in metal cans				(d) 76-80°F in locker and shower room			
13. Fire extinguishers, sprinkler heads, fire hydrants, fire hose, fire alarm, fire escapes, panic bolts operable and tested every 6 months.				(e) 80-86°F in swimming pool			
14. Fire drills conducted, each floor emptied in 2 min.				19. In nonheating season, when outdoor temperature reads 80°, 90°, 95°F, inside temperature reads 75°, 78°, 80°F, respectively.			
15. Poisons, etc., labeled and secured				20. Ventilation and heating satisfactory (10-30 ft ³ per min per person); drafts and excessive heat prevented			
16. Seats in classrooms face away from window or light sources; no glare				21. Place provided to store clothes, lunch boxes, rubbers			
				22. A separate adjustable and movable seat and desk available for each child			
				23. Class room provides 25-30 ft ² ; per pupil			

FIGURE 2.19 School sanitation inspection form.

	Yes	No	CM		Yes	No	CM
24. Buildings, windows, rooms, chalkboards, lights, fixtures, corridors, walls, ceilings, etc., clean; grounds free of litter, insects, rodents, weeds, pools of water				28. Solid wastes properly stored and disposal satisfactory			
25. Swimming pool operated and maintained in conformance with sanitary code requirements*				29. Air pollution prevented			
26. Dining room or cafeteria operated and maintained in conformance with sanitary code requirements*				30. A competent person assigned responsibility to see that all environmental hygiene precautions are observed by teachers and students. (Incorporate in curricula.)			
27. Safety precautions taken in shops, laboratories, play area				31. Floors, walls, ceilings in good repair			
				32. No hazardous asbestos			
				NOTE: CM indicates correction made.			
*Use separate inspection form. Explain "No" items.							
REMARKS _____							

Date inspected _____ By _____							

FIGURE 2.19 (continued)

services, pharmacy services, health records, evaluation services, and staffing. Environmental health concerns are discussed next.

Incarceration may result in or intensify the need for health care services. The provision of a safe and healthy environment, services, and facilities would minimize the need. Food poisoning, poor and insufficient food, vermin infestations, inadequate work and recreational programs, and overcrowding are known causes of prison unrest and illness. Overcrowding and poor food quality and food service are major problems at many jails and prisons. Walker⁹¹ summarizes the problem very clearly in pointing out that overcrowded conditions often overtax the ventilation system and sanitary facilities, minimize privacy and personal space. Without privacy and personal space, the basic psychological and physiological needs of the residents are not met; tension and hostility grow; security requirements increase; and a negative cycle is put into play.

The elimination of overcrowding and improvement in the wholesomeness, quantity, and sanitation of food service can eliminate major causes of discontent.

The environmental aspects of correctional institutions are, in many respects, similar to those of other institutions and are concerned with many of the same basic environmental engineering and sanitation facets of a community.

Designs for new construction and major alterations should be reviewed and approved by the regulatory agencies having jurisdiction and, in any case, comply with nationally recognized standards. Regulatory agencies should make annual

Name _____ Address _____ T.V.C. _____	
Operator _____ Persons interviewed _____	
Capacity _____ Men _____ Women _____ Inspected by _____ Date _____	

Item	S	U	Item	S	U
<i>Water supply</i>			<i>Dietary</i>		
1. Quality meets drinking water standards			23. Food sources approved		
2. Quantity—yield storage, pressure adequate—hot and cold			24. Refrigerator storage temperature, space, clean		
3. Operation, maintenance, and reports satisfactory, no backflow			25. Dry storage clean, dry, space		
4. Qualified operator			26. Food preparation, handling, cooling proper		
5. On routine sampling schedule			27. Food service temperature and protection satisfactory		
<i>Sewage and toilet facilities</i>			28. Utensils and equipment type, condition, satisfactory		
6. Flush toilets adequate			29. Dishwashing—dishes, utensils		
7. Wash basins adequate			30. Handwashing facil. adequate, convenient		
8. Showers adequate			<i>Structure and grounds</i>		
9. Service sinks adequate			31. Location suitable		
10. Treatment meets stream standards			32. Buildings and grounds well drained		
11. Operation, maintenance, and reports satisfactory			33. Accessible by emergency vehicles		
12. Qualified operator			34. Service entrances convenient		
<i>Air pollution control</i>			35. Elevators serve all floors		
13. Incinerator emissions meet standards			<i>Radiation</i>		
14. Boiler emissions meet standards			36. Diagnostic X-ray units satisfactory		
15. Process emissions meet standards			37. Therapeutic X-ray units satisfactory		
16. Fuel composition and use acceptable			38. Teletherapy units satisfactory		
<i>Solid wastes</i>			39. Radioactive materials properly stored, used		
17. Garbage storage and collection satisfactory			40. Microwave units satisfactory		
18. Refuse storage and collection satisfactory			<i>Housing and safety</i>		
19. Disposal satisfactory			41. Rooms clean, lighted, ventilated		
<i>Swimming pool and bathing beach</i>			42. Fire escape from rooms		
20. Life-saving equipment and lifeguards adequate			43. Adequate space for occupancy		
21. Adequate clarity			44. Insect and rodent control effective		
22. Adequate treatment and reports			45. Clean bedding		
			46. Heating safe and adequate for intended use		
			47. Fire protection adequate		
			48. Fire-resistive construction		
			49. OSHA standards met		

S means substantially satisfactory equipment, construction, operation, maintenance.
 U means unsatisfactory. Use available codes, rules, and regulations for compliance. Mark items NA if not applicable.

Supplied services _____ Water Supply _____ Sewerage _____ Refuse Collection _____ Dietary _____ Other _____ Give name of contractor or supplier.

FIGURE 2.20 Abbreviated institution environmental health inspection form. (For comprehensive interpretations, see pertinent sections of this text.)

inspections and reports of the facilities and services in the same manner as is done for other state, municipal, and public facilities and establishments.

Environment Inspection and Report Outline

A comprehensive inspection and report would involve investigation of the following items:

A. Grounds and Structures

1. Location, accessibility, service entrances, cleanliness, noise
2. Protection from flooding; drainage
3. Construction materials and maintenance; dampness, drafts, leaks; sound and in good repair
4. Fire protection, municipal and on-site; adequacy; water supply; alarms
5. Safety, accident prevention, road signs, lighting

B. Utilities

1. Water supply: source, treatment, storage and distribution, quality, quantity, pressure; quality surveillance and compliance with federal and state standards; operation control
2. Wastewater collection and disposal: sewage and all other liquid waste collection, treatment, and disposal; compliance with federal and state standards; operation control
3. Solid wastes: storage, collection and disposal; storage areas or rooms, cans, bins; on-site processing and disposal; hazardous waste handling, storage, and disposal; compliance with federal and state standards
4. Heating, electricity and air conditioning; adequacy; safety
5. Air quality: power plant, incinerator, institution operations; compliance with federal and state standards
6. Emergency power and disaster planning; power to vital services and lighting to vital areas

C. Shelter

1. Temperature control: heat, ventilation, humidity control, cooling
2. Lighting: walkways, assembly areas, cells, kitchens, work areas, special uses, and facilities
3. Space requirements: cells, assembly areas, recreational areas, dining rooms, visiting areas
4. Fire safety: fire-resistive construction; compartmentation; interior finishes; enclosures, doors, stairs; extinguishers and extinguisher systems, sprinklers, detection and alarm systems; fire water supply; fire plans and drills

5. Accident prevention: physical design, working conditions, fire and electrical hazards; occupational exposures and recreational facilities; also, occupational health standards (OSHA) as applied to jails and prisons (Drugs, pesticides, flammables, and other hazardous materials stored in a secure place.)
6. Housekeeping: general cleanliness and maintenance; facility interior surfaces (walls, floors, ceilings, facilities, equipment); equipment and facilities maintenance; grounds and spaces; roster and cleaning schedule
7. Noise: interior, exterior; mechanical equipment, work areas comply with OSHA standards

D. Services and Facilities

1. Food and protection: wholesomeness, refrigeration, storage, preparation, transportation, service; processing; equipment; foodhandler inspection; ice; vending machines
2. Radiation protection: diagnostic, therapeutic, teletherapy, X-ray units; radioactive materials storage and use; microwave ovens; industrial uses
3. Vermin control: rodents, insects, and other arthropods; physical and chemical controls; pesticide storage secure and used as directed on label
4. Laundry facilities: soiled linen and clean linen separate storage, handling, and transportation; laundering process
5. Plumbing: water, soil, and waste lines, drains, toilets, washbasins; adequacy of hot and cold water for all purposes; service sinks; cross-connection and backflow control
6. Recreational facilities: bathing beach, swimming pool; other; life-saving equipment and life guards; water clarity and quality; accident control; maintenance, operation and sanitation facilities; safety
7. Institutional operations: canning, slaughtering, dairy, pasteurization; other farm operations; manufacturing; vocational training; hospital; laundry; bakery
8. Facilities available for public and staff: toilets; dressing rooms; visiting areas
9. Medical care facility area: storage of drugs; disinfection and sterilization; refrigeration of blood and drugs; morgue

E. Personal Hygiene

1. Personal hygiene: infestation and disinfestation; showers, towels, clothes, toiletries, etc.
2. Bedding: mattresses, pillows, sheets, blankets, beds
3. Toilet and bathing facilities: number and type of water closets, squatting plates, washbasins, showers; removable pail privies
4. Barber and beauty shops: room designated, equipped, staffed

F. Personnel and Supervision

1. In-service training: staff and inmates having environmental sanitation responsibilities

2. Self-inspection: qualified person designated, responsible to administrator
3. Regulatory agencies: inspection and approval of facilities and services annually

Because of the diverse facilities and services involved, it is essential that the regulatory person assigned to make inspections be broadly trained and have the experience and maturity to know when to call upon a specialist to investigate in greater detail and resolve complex problems. Many resources, including specially trained consultants, laboratory facilities, regulations, and inspection services, are available from various departments and agencies of the government (including federal) as well as national organizations. These should be utilized to identify and help resolve potential and actual deficiencies.

The basic principle involved, the public health rationale, and the basis for satisfactory compliance for each item just listed are given in *Standards for Health Services in Correctional Institutions*.⁵⁵

Day-Care Centers

Day-care centers provide an environment for children of an age conducive to the spread of respiratory, contact, and water- and foodborne diseases discussed in Chapter 1 and in this section. They can also lead to other disease complications. Diapering and food preparation and service are critical activities requiring scrupulous cleanliness and frequent handwashing. Enteric and respiratory disease transmission via the fecal–oral route and by intimate contact is more common among children in a day-care center. Multiple pathogen infection is not uncommon. *Cryptosporidium* spp., *Giardia lamblia*, *Salmonella*, *Shigella sonnei*, *E. coli* (toxic strain), and enteroviruses are some of the more commonly found enteric pathogens in reported outbreaks. The increased interest and private, federal, and state support of day-care centers and their consequent expansion make their regulation an important public health function. Here is an opportunity to apply known preventive measures, including frequent handwashing, hygiene, food sanitation, separation of ill children, and education of staff and management, in disease transmission and prevention.⁹²

REFERENCES

1. *WHO Tech. Rep. Ser.*, **225** (1961): 6.
2. *New York Times*, March 29, 1987, p. E5.
3. *Environmental Quality*, Eighth annual report of the Council on Environmental Quality, U.S. Government Printing Office, Washington, DC, December 1977, pp. 308–310.
4. *Environmental Trends*, Council on Environmental Quality, U.S. Government Printing Office, Washington, DC, 1989, p. 126.
5. *New York Times*, April 13, 1986, p. R7.
6. *Proceedings of the First Invitational Conference on Health Research in Housing and its Environment*, Airlie House, Warrenton, VA, March 17–19, 1970, PHS, DHEW, Environmental Health Service, Washington, DC.

7. R. Ranson, "Relating Housing Standards to Health Hazards," *J. R. Soc. Health*, December 1987, pp. 231–238.
8. R. Dubos, paper delivered at the Smithsonian Institution Annual Symposium, February 16–18, 1967; *The Fitness of Man's Environment*, Smithsonian Institution Press, Washington, DC, 1968.
9. "NEEDS, Neighborhood Environmental Evaluation and Decision System," Bureau of Community Environmental Management, PHS, DHEW, Washington, DC, 1970.
10. *Housing: Basic Health Principles & Recommended Ordinance*, APHA, Washington, DC, 1971.
11. M. Schaefer, "Health Principles of Housing," *World Health*, July 1987, pp. 17–19.
12. E.W. Mood, *Housing and Health APHA-CDC Recommended Minimum Housing Standards*, APHA, Washington, DC, 1986.
13. *Uniform Housing Code*, International Conference of Building Officials, Whittier, CA, 1997.
14. J.G. Molner and M.S. Hilbert, "Responsibilities of Public Health Administration in the Field of Housing," and C. L. Senn, "Planning of Housing Programmes," in *Housing Programmes: The Role of Public Health Agencies*, Public Health Papers 25, WHO, Geneva, 1964; "Expert Committee on the Public Health Aspects of Housing," *WHO Tech. Rep. Ser.*, **225** (1961); "Appraisal of the Hygienic Quality of Housing and its Environment," *WHO Tech. Rep. Ser.*, **353** (1967); Subcommittee of the Program Area Committee on Housing and Health, *Guide for Health Administrators in Housing Hygiene*, APHA, New York, 1967.
15. J.S. Salvat and M.R. Levin, *New Approaches to Housing Code Administration*, Research Rep. 17, National Commission on Urban Problems, Washington, DC, 1969.
16. *National Plumbing Code*, American Society of Mechanical Engineers, New York, 2006.
17. *Uniform Plumbing Code*, International Association of Plumbing and Mechanical Officials, Walnut, CA, 2006.
18. *Standard Plumbing Code*, Southern Building Code Congress International, Birmingham, AL, 2006.
19. *Report of Public Health Service Technical Committee on Plumbing Standards*, PHS Pub. 1038, DHEW, Washington, DC, September 1962.
20. *International Plumbing Code*, International Code Council, Falls Church, VA, 2006.
21. *Guidance for Indoor Air Quality Investigations (Draft)*, Hazard Evaluation and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies, NIOSH, Cincinnati, OH, January 1987, pp. 4 and 12.
22. H.L.S.C. Hens, "Fungal Defacement in Buildings: A Performance Related Approach," *Int. J. HVAC&R Res.* (July 1999): 265–280.
23. R. Brown, "Home and Office: Shelter or Threat?" *EPA J.* (December 1987): 2–5.
24. "New Indoor Air Standard Brings More of Outside," *Engineering News*, December 1989, p. 15; J.F. Brundage, R.M. Scott, W.M. Lednar, D.W. Smith, and R.N. Miller, "Building Associated Risk of Febrile Acute Respiratory Diseases in Army Trainees," *JAMA*, **259** (14), 2108–2112 (1988).
25. "Radon Linked to Major Increases in Lung Cancer Risk: NRC Report," *Nation's Health*, APHA, Washington, DC, March 1988, p. 12.
26. NCRP Report No. 103, September 1989, p. 1.

27. D. Prime, "Exposure to Radon Decay Products in Dwellings," *J. R. Soc. Health* (December 1987): 228–230.
28. H.M. Prichard, "The Transfer of Radon from Domestic Water to Indoor Air," *J. Am. Water Works Assoc.* (April 1987): 159–161.
29. M.C. Osborne, D.G. Moore, R.E. Southerlan, T. Brennan, and B.E. Pyle, "Radon Reduction in Crawl Space House," *J. Environ. Eng.* (June 1989): 574–589.
30. *Radon Reduction Techniques for Detached Houses*, EPA/625/5–86/019, EPA, Washington, DC, June 1986.
31. *Radon Reduction in New Construction, An Interim Guide*, EPA-87-009, Offices of Air and Radiation Research and Development, EPA, Washington, DC, August 1987.
32. "Formaldehyde Exposures in a Gross Anatomy Laboratory—Colorado," *MMWR*, CDC, January 7, 1983, p. 698.
33. K.B. Noble, "Study Slight Risk of Formaldehyde," *New York Times*, September 20, 1986.
34. "U.S. Stiffens Rule on Formaldehyde Exposure," *New York Times*, November 22, 1987, p. 45.
35. "NIOSH Recommendations for Occupational and Health Standards, 1988," *MMWR*, August 26, 1988, p. 15.
36. B. Hulka, "'Other People's Smoke': Round Two," *New York Times*, March 25, 1987, p. F12.
37. *MMWR*, September 14, 1984.
38. *Indoor Air Quality: Organic Pollutants*, WHO Regional Office for Europe (EURO Report and Studies I111), WHO, Copenhagen, 1989.
39. P. Wolkoff, "Volatile Organic Compounds: Sources, Measurements, Emissions, and the Impact on Indoor Air Quality," *Indoor Air*, **5** (Suppl. 3) (1995): 11.
40. H.S. Brightman, S.E. Womble, E.L. Ronca, and J.R. Girman, "Base-line Information on Indoor Air Quality in Large Buildings (BASE'95)," in *Proceedings of Indoor Air'96*, Vol. **3**, Nagoya, Japan, 1996, pp. 1033–1038.
41. L. Molhave, J.G. Jensen, and S. Larsen, "Acute and Sub-Acute Subjective Reaction to Volatile Organic Compounds," *Atmos. Envir.*, **25A** (1998): 1283–1293.
42. X. Yang, *Study of Building Material Emissions and Indoor Air Quality*, Ph.D. Dissertation, Building Technology Program, Massachusetts Institute of Technology, Cambridge, MA, 1999.
43. J. Zhao, J. and X. Yang, "Photocatalytic Oxidation for Indoor Air Purification: a Literature Review," *Building and Environment*, **38**, 645–654 (2003).
44. X. Yang, J. Srebric, X. Li, G. He, "Performance of Three Air Distribution Systems in VOC Removal from an Area Source," *Building and Environment*, **39** (11) (2004): 1289–1299.
45. X. Yang, and Q. Chen, "A Coupled Airflow and Source/Sink Model for Simulating Indoor VOC Exposures," *Indoor Air*, **11** (2001): 257–269.
46. X. Yang, Q. Chen, J. Zeng, J.S. Zhang, and C.Y. Shaw, "A Mass Transfer Model for Simulating Volatile Organic Compound Emissions from 'Wet' Coating Materials Applied to Absorptive Substrates," *International Journal of Heat and Mass Transfer*, **44** (9), (2001): 1803–1815.
47. H.W. de Koning, "Air Pollution in Africa," *World Health* (January/February 1990): 8–9.

48. *Handbook of Fundamentals*, ASHRAE, Atlanta, GA, 2001, p. 8.12.
49. P.E. McNall Jr., in *Proceedings of the First Invitational Conference on Health Research in Housing and its Environment*, Airlie House, Warrenton, VA, March 17–19, 1970, PHS, DHEW, Environmental Health Service, Washington, DC, p. 27.
50. J. Lubart, “Winter Heating an Enemy Within,” *Med. Sci.* (March 1967): 33–37.
51. *The Inside Story: A Guide to Indoor Air Quality*, EPA/402/K–93/007, EPA, CPSC, Washington, DC, April 1995.
52. *New York State Energy Conservation Construction Code*, New York State Energy Office, Albany, December 1986.
53. *Ventilation for Acceptable Indoor Air Quality*, ANSI/ASHRAE 62-1999, ASHRAE, Atlanta, GA, 1999.
54. E.W. Mood, *APHA-CDC Recommended Minimum Housing Standards*, APHA, Washington, DC, 1986, p. 27.
55. N.N. Dubler (Ed.), *Standards for Health Services in Correctional Institutions*, APHA, Washington, DC, 1986, pp. 65–67.
56. *The BOCA Basic Building Code—1975*, Building Officials & Code Administrators International, Chicago, IL.
57. *Handbook of Fundamentals*, ASHRAE, Atlanta, GA, 2001, pp. 26.26–26.27.
58. *Test Methods for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution*, Standard E741-93, American Society for Testing and Materials, Philadelphia, PA, 1993.
59. *MMWR*, September 14, 1984.
60. *Chimneys, Fireplaces, Venting Systems*, Pub. No. 211, National Fire Protection Association, Quincy, MA, 1970.
61. PHS, DHEW, *Environmental Health Guide for Mobile Home Parks*, Mobile Home Manufacturers Association, Chicago, IL, January 1966, p. 3.
62. PHS, DHEW, *Environmental Health Guide for Mobile Home Communities*, Mobile Home Manufacturers Association, Chicago, IL, January 1971.
63. *Mobile Home Court Development Guide*, HUD, Washington, DC, January 1970.
64. *Guidelines For Improving The Mobile Home Living Environment*, HUD, Washington, DC, August 1977.
65. *How to Buy A Manufactured Home*, Manufactured Housing Institute, Arlington, VA, December 1985.
66. “Infection Surveillance and Control Programs in U.S. Hospitals: An Assessment, 1976,” *MMWR*, CDC, Atlanta, GA, April 28, 1978, p. 139; *MMWR, CDC Surveillance Summaries*, **32**(4SS) (1984).
67. J.V. Bennett and P.S. Brachman, *Hospital Infections*, Little, Brown, and Co., Boston, MA, 1979.
68. R.L. Elston, “The Role of Hands in the Spread of Diseases,” *Am. J. Public Health*, November 1970, p. 2211.
69. “Nosocomial Infection Surveillance, 1983,” *MMWR, CDC Surveillance Summaries*, **33**(2SS) (1984).
70. “Nosocomial Infection Surveillance, 1984,” *MMWR*, **35** (1SS) (1986).
71. *Prevention of Hospital-acquired Infections: A Practical Guide*, 2nd ed., WHO, Geneva, Switzerland, 2002.

72. D.G. Brown, "Environmental Health and Safety Concerns in the Health Care Setting," *J. Environ. Health*, July/August 1980, pp. 11–13.
73. *MMWR*, **32** (4SS) (1983).
74. *Fire Safety Survey Report—1981 Code, Medicare—Medicaid*, Department of Health and Human Services, Health Care Financing Administration, Form OMB No. 0938-0242; *Health Care Facilities Handbook*, National Fire Protection Association, Quincy, MA, 1990.
75. J.D. Komorita and V.L. Snoeyink, "Technical Note: Monochloramine Removal from Water by Activated Carbon," *J. Am. Water Works Assoc.* (January 1985): 62–64.
76. C.Z. Steinbergs, "Removal of By-products of Chlorine and Chlorine Dioxide at a Hemodialysis Center," *J. Am. Water Works Assoc.* (June 1986): 94–98.
77. A.J. Streifel, "High Quality Water System Disinfection," in *Dairy and Food Sanitation*, University of Minnesota, Minneapolis, MN, October 1986, p. 471.
78. M. Blaser, VA Hospital, Denver, APHA, Environment Section, Committee on Institutional Environments, Annual Meeting, Dallas, TX, November 13, 1983.
79. D.R. Battles and D. Vesely, "Wash Water Temperatures and Sanitation in the Hospital Laundry," *J. Environ. Health*, March/April 1981, pp. 244–250.
80. *Joint Commission on Accreditation of Hospitals: Accreditation Manual for Hospitals*, 3rd ed., Chicago, IL, 1976.
81. *Infection Control in the Hospital*, *American Hospital*, American Hospital Association, Chicago, IL, 1970.
82. *Isolation Techniques for Use in Hospitals*, PHS, CDC, Atlanta, GA.
83. *Guidelines for Protecting the Safety and Health of Health Care Workers*, DHHS, PHS, CDC, NIOSH, U.S. Government Printing Office, Washington, DC, September 1988.
84. "Management of Waste from Hospitals," *EURO Reports and Studies* 97, WHO Regional Office for Europe, Copenhagen, 1985.
85. *Guide for Infectious Waste Management*, EPA, Washington, DC, 1986.
86. J.D. Lauber and D.A. Drum, "Best Controlled Technologies for Regional Biomedical Waste Incineration," paper presented at the Annual Meeting of the Air and Waste Management Association, Pittsburgh, PA, June 27, 1990.
87. F.C. Powell, "Air Pollutant Emissions from the Incineration of Hospital Wastes, the Alberta Experience," *JAPCA*, July 1987, pp. 836–839.
88. "Recommendations for Prevention of HIV Transmission in Health-Care Settings," *MMWR*, August 21, 1987, p. 125.
89. R. DeRoos, "Hospital Standards Stress Hazardous Materials," *J. Environ. Health*, March/April 1986, p. 268.
90. *Health and Safety in the School Environment*, Pub. No. 78–8368, DHEW, PHS, Atlanta, GA, September 1978; R. Bond et. al., "Environmental Health Needs in Colleges and Universities," *Am. J. Public Health* (April 1961): 523–530; R.L. DeRoos, "Environmental Health and Safety in the Academic Setting," *Am. J. Public Health*, September 1977, pp. 851–854; and R.E. Hunt, "A Campus Is a Total Community," *J. Environ. Health* (November/December, 1979): 108–118.
91. B. Walker and T.J. Gordon, "Administrative Aspects of Environmental Health in Correctional Institutions," *J Environ. Health* (November/December 1976): 192–195.
92. D.L. Archer, "Disease in Day Care: A Public Health Problem for the Entire Community," *J. Environ. Health* (January/February 1989): 143–147.

BIBLIOGRAPHY

- An Appraisal Method for Measuring the Quality of Housing*: Part I, "Nature and Uses of the Method," 1945; Part II, "Appraisal of Dwelling Conditions," Vols. A, B, C, 1946; Part III, "Appraisal of Neighborhood Environment," 1950; APHA, Washington, DC.
- Andrzejewski, A., K.G. Berjusov, P. Ganewatte, M.S. Hilbert, W.A. Karumaratne, J.G. Molner, A.S. Perockaja, and C.L. Senn, *Housing Programmes: The Role of Public Health Agencies*, Public Health Papers 25, WHO, Geneva, 1964.
- "Appraisal of the Hygienic Quality of Housing and Its Environment," *WHO Tech. Rep. Ser.*, **353** (1967).
- ASHRAE Handbook: HVAC Applications*, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Atlanta, GA, 2007.
- "Basic Health Principles of Housing and Its Environment," APHA Program Area Committee on Housing and Health, *Am. J. Public Health* (May 1969): 541–852.
- Basic Housing Inspection*, PHS, DHEW Pub. No. (CDC)80-8315, U.S. Government Printing Office, Washington, DC, 1976.
- Basic Principles of Healthful Housing*, APHA, Committee on the Hygiene of Housing, Washington, DC, 1946.
- The BOCA Basic Building Code/1981*, Building Officials and Code Administrators, Chicago, IL, 1981.
- Bond, R.G., G.S. Michaelson, and R.L. DeRoos (Eds.), *Environmental Health and Safety in Health-Care Facilities*, Macmillan, New York, 1973.
- Code for Safety to Life from Fire in Buildings and Structures*, National Fire Protection Association, Quincy, MA, 2000.
- Congress and American Housing*, U.S. Senate, Subcommittee on Housing and Urban Affairs, Committee on Banking and Currency, Washington, DC, 1968.
- Dubler, N. (Ed.), *Standards for Health Services in Correctional Institutions*, APHA, Washington, DC, 1986.
- Dubler, N. (Ed.), *Standards for Health Services in Correctional Institutions*, APHA, Washington, DC, 1986.
- Environmental Engineering for the School*, PHS Bull. 856 and Office of Education Pub. OE 21014, DHEW, Washington, DC, 1961.
- "Expert Committee on the Public Health Aspects of Housing," *WHO Tech. Rep. Ser.*, **225** (1961).
- Fire Protection Handbook*, 18th ed., National Fire Protection Association, Quincy, MA, 1997.
- General Standards of Construction and Equipment for Hospitals and Medical Facilities*, PHS Pub. 930-A-7, DHEW, Washington, DC, December 1967.
- Goromosov, M.S., *The Physiological Basis of Health Standards for Dwellings*, Public Health Papers No. 33, WHO, Geneva, 1968.
- Guidelines for Protecting the Safety and Health of Health Care Workers*, DHHS, PHS, CDC, NIOSH, U.S. Government Printing Office, Washington, DC, September 1988.
- Health Principles of Housing*, WHO, Geneva, 1989.
- Housing an Aging Population*, Committee on the Hygiene of Housing, APHA, Washington, DC, 1953.
- Indoor Air Quality*, Office of Environmental Health Programs, Department of Social and Health Services, State of Washington, January 1987.
- Infection Control in the Hospital*, American Hospital Association, Chicago, IL, 1970.
- The Inside Story: A Guide to Indoor Air Quality*, EPA 402/K-93/007, EPA, CPSC, Washington, DC, April 1995.

- Knittel, R.E., *Organization of Community Groups in Support of the Planning Process and Code Enforcement Administration*, PHS, DHEW, Washington, DC, 1970.
- Krasnowiecki, J., *Model State Housing Societies Law*, PHS Pub. 2025, DHEW, Washington, DC, 1970.
- La Duca, P.N., "Medical Facilities Environmental Concerns and the Role of the Hospital Sanitarian," *J. Environ. Health* (November/December 1987): 146–149.
- Life Safety Code*, NFPA 101, National Fire Protection Association, Quincy, MA, 2000.
- Litsky, B.Y., *Hospital Sanitation—An Administrative Problem*, Clessols Publishing, 1966.
- Mobile Home Court Development Guide*, HUD, Washington, DC, January 1970.
- Mood, E.W., *Housing and Health, APHA-CDC Recommended Minimum Housing Standards*, APHA, Washington, DC, 1986.
- National Electrical Code and Handbook*, National Fire Protection Association, Quincy, MA, 2005.
- National Plumbing Code*, American Society of Mechanical Engineers, New York, 2006.
- New Approaches to Housing Code Administration*, Research Rep. 17, National Commission on Urban Problems, Washington, DC, 1969.
- New York State Uniform Fire Prevention and Building Code*, New York State Division of Housing and Community Renewal, New York, January 1, 1984.
- Nursing Homes: Environmental Health Factors—A Syllabus*, PHS, DHEW, Washington, DC, March 1963.
- Parratt, S., *Housing Code Administration and Enforcement*, PHS, Pub. 1999, DHEW, Washington, DC, 1970.
- Principles for Healthful Rural Housing*, APHA, Committee on the Hygiene of Housing, Washington, DC, 1957.
- Proceedings of the First Invitational Conference on Health Research and Its Environment*, Airlie House, Warrenton, VA, March 17–19, 1970; sponsored by the American Public Health Association, and PHS, DHEW, Washington, DC.
- Public Health Service and Department of Health, Education, and Welfare, *Environmental Health Guide for Mobile Home Communities*, Mobile Homes Manufacturers Association, Chicago, IL, 1971.
- Ramsey, C.G., and H.R. Sleeper, in *Architectural Graphic Standards*, 8th ed., John R. Hoke (Ed.), Wiley, New York, 1988.
- Rehabilitation Guide for Residential Properties*, HUD, Washington, DC, January 1968.
- Subcommittee of the Program Area Committee on Housing and Health, *Guide for Health Administrators in Housing Hygiene*, APHA, Washington, DC, 1967.
- Tenants' Rights: Legal Tools for Better Housing*, HUD, Washington, DC, 1967.
- Uniform Building Code*, International Conference of Building Officials, Pasadena, CA, 2006.
- Uniform Housing Code*, International Conference of Building Officials, Whittier, CA, 2006.
- Uniform Plumbing Code*, International Association of Plumbing and Mechanical Officials, Walnut, CA, 2006.
- Congress and American Housing*, U.S. Senate, Subcommittee on Housing and Urban Affairs, Committee on Banking and Currency, Washington, DC, 1968.
- Walton, G., *Institutional Sanitation*, U.S. Bureau of Prisons, Washington, DC.

CHAPTER 3

SOLID WASTE MANAGEMENT

GEORGE TCHOBANOGLIOUS

Professor Emeritus of Civil and Environmental Engineering, University of California, Davis, California

Aesthetic, land-use, health, water pollution, air pollution, and economic considerations make proper solid waste management an ongoing concern for municipal, corporate, and individual functions that must be taken seriously by all. Indiscriminate dumping of solid waste and failure of the collection system in a populated community for two or three weeks would soon cause many problems. Odors, flies, rats, roaches, crickets, wandering dogs and cats, and fires would dispel any remaining doubts of the importance of proper solid waste management.

Solid waste management is a complex process because it involves many technologies and disciplines. These include technologies associated with the generation (including source reduction), on-site handling and storage, collection, transfer and transportation, processing, and disposal of solid wastes. All of these processes have to be carried out within existing legal, social, and environmental guidelines that protect the public health and the environment and are aesthetically and economically acceptable. To be responsive to public attitudes, the disciplines that must be considered in integrated solid waste management include administrative, financial, legal, architectural, planning, environmental, and engineering functions. For a successful integrated solid waste management plan, it is necessary that all these disciplines communicate and interact with each other in a positive interdisciplinary relationship.

In the material that follows, the major issues involved with the management of solid waste are presented and discussed. These issues include the elements of integrated solid waste management; the sources, characteristics, and quantities of solid waste; on-site storage and handling, solid waste collection; transfer and transport; waste reduction, recycling, and processing; composting; sanitary landfill planning design and operation; and incineration and hazardous waste. However, before discussing these topics, it will be useful to define the terminology used in the field of solid waste management. Additional details on solid waste management may be found in the U.S. Environmental Protection Agency.¹

DEFINITION OF TERMS

To understand the elements and technologies involved in integrated solid waste management it is useful to define some of the more commonly used terms.

Ash residue All the solid residue and any entrained liquids resulting from the combustion of solid waste or solid waste in combination with fossil fuel at a solid waste incinerator, including bottom ash, boiler ash, fly ash, and the solid residue of any air pollution control device used at a solid waste incinerator.

Biodegradable material Waste material capable of being converted, usually by bacteria and other microorganisms, into basic elements. Most organic wastes, such as food remains and paper, are biodegradable in a suitable environment.

Commercial waste Solid waste generated by stores, offices, institutions, restaurants, warehouses, and nonmanufacturing activities at industrial facilities.

Composting The controlled biological decomposition of organic solid waste under aerobic (in the presence of oxygen) conditions. Organic waste materials are transformed into soil amendments such as humus or mulch.

Fly ash The ash residue from the combustion of solid waste or solid waste in combination with fossil fuel that is entrained in the gas stream of the solid waste incinerator and removed by air pollution control equipment.

Food waste Putrescible solid material including animal and vegetable waste resulting from the handling, storage, sale, preparation, cooking, or serving of foods. Food waste originates primarily in home kitchens, stores, markets, restaurants, and other places where food is stored, prepared, or served.

Garbage An older term that is often used interchangeably with the newer term *food waste*.

Geomembrane An essentially impermeable membrane used in landfills to limit the movement of liquids and or gases resulting from the decomposition of waste materials.

Groundwater Water below the land surface in the saturated zone of the soil or rock. Groundwater includes perched water separated from the main body of groundwater by an unsaturated (vadose) zone.

Hazardous waste Defined later in this chapter.

Incinerator A facility designed to reduce the volume and weight of solid waste by a combustion process with or without a waste heat recovery system.

Industrial waste Solid waste generated by manufacturing or industrial processes, excluding wastes resulting from oil or gas drilling, production, and treatment operations (such as brines, oil, and frac fluids); overburden, spoil, or tailings resulting from mining; or solution mining brine and insoluble component wastes.

Integrated solid waste management The comprehensive management of solid waste involving several complementary activities and or process including source reduction, recycling, waste transformation, and landfilling.

Leachate A liquid resulting from precipitation percolating through landfills, which includes liquids resulting from the decomposed waste. With proper management, the amount of leachate can be minimized. Leachate that is collected is treated to prevent contamination of environment.

Municipal solid waste Includes nonhazardous waste generated in households, commercial establishments, institutions, and nonprocess-related industrial wastes (e.g., waste paper and paperboard); it excludes wastes from municipal services such as water and wastewater treatment sludges, industrial process wastes, agricultural wastes, and mining wastes.

Recycling A resource recovery method involving the collection and treatment of a waste product for use as raw material in the manufacture of the same or another produce (e.g., ground glass used in the manufacture of new glass).

Refuse A general term often used interchangeably with the term *solid waste*. To avoid confusion, the term *refuse* is not used in this chapter.

Residuals Water and wastewater sludges, septage, air pollution control facility waste, or any other such waste having similar characteristics or effects and solid waste remaining after the processing of solid waste by composting methods that was not made into compost suitable for use.

Resource recovery A term describing the extraction and utilization of materials that can be used as raw material in the manufacture of new products or as values that can be converted into some form of fuel or energy source. Resource recovery is a key element of an integrated solid waste management program.

Rubbish A general term for solid wastes, excluding food wastes and ashes, for materials collected from residences and commercial and institutional establishments.

Sanitary landfill A method of disposing of solid waste on land without creating nuisances or hazards to public health or safety. Modern sanitary landfills have leachate collection and treatment systems, landfill gas controls, and environmental monitoring systems.

Solid waste Any of a variety of solid materials, as well as some liquids in containers, which are discarded or rejected as being spent, useless, worthless or in excess. Usually the term does not include solid waste from certain community activities (e.g., catch basin cleanings, water and wastewater treatment sludges). Also excluded are solid, liquid, semisolid, or contained gaseous material resulting from industrial, mining, and agricultural operations.

Solid waste management The systematic administration of activities that provide for the collection, source separation, storage, transportation, transfer, processing (including recycling), treatment, and disposal of solid waste.

Source reduction Refers to reducing the amount of waste generated that must eventually be discarded, including minimizing toxic substances in products, minimizing volume of products, and extending the useful life of products. Requires manufacturers and consumers to take an active role in reducing the amount of waste produced.

Source separation The segregation of various materials from the waste stream at the point of generation for recycling. For example, householders separating paper, metal, and glass from the rest of their wastes.

Transfer station A facility with structures, machinery, or devices that receives deliveries of solid waste by local collection vehicles and provides for the transfer of the waste to larger vehicles that are used to deliver the waste to a recycling, treatment, or disposal site.

Waste-to-energy incineration (combustion) Disposal method in which municipal solid waste is brought to a plant where it is combusted either as received or after being processed to a more uniform fuel to generate steam or electricity. Waste-to-energy plants can decrease volume by 60 to 90 percent, while recovering energy from discarded products.

INTEGRATED WASTE MANAGEMENT

Integrated waste management (IWM) can be defined as the selection and application of suitable techniques, technologies, and management programs to achieve specific waste management objectives and goals. Because numerous state and federal laws have been adopted, IWM is also evolving in response to the regulations developed to implement the various laws. The EPA has identified four basic management options (strategies) for IWM: (1) source reduction, (2) recycling and composting, (3) combustion (waste-to-energy facilities), and (4) landfills. As proposed by the EPA, these strategies are meant to be interactive, as illustrated in Figure 3.1a. It should be noted that some states have chosen to consider the management options in a hierarchical order, as depicted in Figure 3.1b. For example, recycling can only be considered after all that can be done to reduce the quantity of waste at the source has been done. Similarly, waste transformation is only considered after the maximum amount of recycling has been achieved. Further, the combustion (waste-to-energy) option has been replaced with waste transformation in California and other states. Interpretation of the IWM hierarchy will, most likely, continue to vary by state. The management options that comprise the IWM are considered in the following discussion. The implementation of IWM options is considered in the remaining sections of this chapter.²

Source Reduction

The focus of source reduction is on reducing the volume and/or toxicity of generated waste. Source reduction includes the switch to reusable products and packaging, the most familiar example being returnable bottles. However, legislated

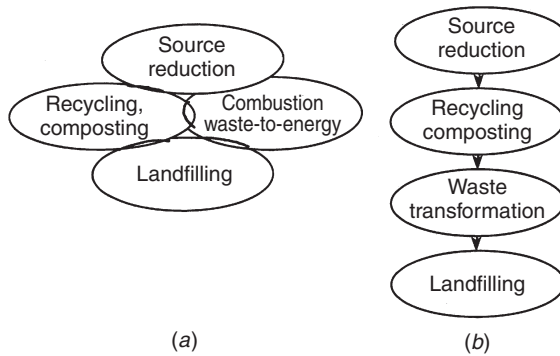


FIGURE 3.1 Definition sketch for integrated solid waste management: (a) interactive; (b) hierarchical.

bottle bills only result in source reduction if bottles are reused once they are returned. Other good examples of source reduction are grass clippings that are left on the lawn and never picked up and modified yard plantings that do not result in leaf and yard waste. The time to consider source reduction is at the product/process design phase.

Source reduction can be practiced by everybody. Consumers can participate by buying less or using products more efficiently. The public sector (government entities at all levels: local, state, and federal) and the private sector can also be more efficient consumers. They can reevaluate procedures that needlessly distribute paper (multiple copies of documents can be cut back), require the purchase of products with longer life spans, and cut down on the purchase of disposable products. The private sector can redesign its manufacturing processes to reduce the amount of waste generated in the manufacturing process. Reducing the amount of waste may require closed-loop manufacturing processes and the use of different raw materials and/or different production processes. Finally, the private sector can redesign products by increasing their durability, substituting less toxic materials, or increasing product effectiveness. However, while everybody can participate in source reduction, it affects how people go about their business, something that is difficult to mandate through regulation without getting mired in the tremendous complexity of commerce.

Source reduction is best encouraged by making sure that the cost of waste management is fully internalized. *Cost internalization* means pricing the service so that all of the costs are reflected. For waste management, the costs that need to be internalized include pickup and transport, site and construction, administrative and salary, and environmental controls and monitoring. It is important to note that these costs must be considered, whether the product is ultimately managed in a landfill, combustion, recycling facility, or composting facility. Regulation can aid cost internalization by requiring product manufacturers to provide public disclosure of the costs associated with these aspects of product use and development.²

Recycling and Composting

Recycling is perhaps the most positively perceived and doable of all the waste management practices. Recycling will return raw materials to market by separating reusable products from the rest of the municipal waste stream. The benefits of recycling are many. Recycling saves precious finite resources, lessens the need for mining of virgin materials—which lowers the environmental impact for mining and processing—and reduces the amount of energy consumed and the process carbon footprint. Moreover, recycling can help stretch landfill capacity. Recycling can also improve the efficiency and ash quality of incinerators and composting facilities by removing noncombustible materials, such as metals and glass.

Recycling can also cause problems if it is not done in an environmentally responsible manner. Many Superfund sites are what is left of poorly managed recycling operations. Examples include deinking operations for newsprint, waste oil recycling, solvent recycling, and metal recycling. In all of these processes, toxic contaminants that need to be properly managed are removed. Composting is another area of recycling that can cause problems without adequate location controls. For example, groundwater can be contaminated if grass clippings, leaves, or other yard wastes that contain pesticide or fertilizer residues are composted on sandy or other permeable soils. Air contamination by volatile substances can also result.

Recycling will flourish where economic conditions support it, not just because it is mandated. For this to happen, the cost of landfilling or resource recovery must reflect its true cost and must be at least \$40 to \$50 per ton or higher (2008 dollars). Successful recycling programs also require stable markets for recycled materials. Examples of problems in this area are not hard to come by; a glut of paper occurred in Germany in the 1984 to 1986 time frame due to a mismatch between the grades of paper collected and the grades required by the German papermills. Government had not worked with enough private industries to find out whether the mills had the capacity and equipment needed to deal with low-grade household newspaper. In the United States, a similar loss of markets has occurred for paper, especially during the period from 1994 through 1997. Prices have dropped to the point where it actually costs money to dispose of collected newspapers in some parts of the country.

Stable markets also require that stable supplies are generated. This supply-side problem has been problematic in certain areas of recycling, including metals and plastics. Government and industry must work together to address the market situation. It is critical to make sure that mandated recycling programs do not get too far ahead of the markets.

Even with a good market situation, recycling, and composting will flourish only if they are made convenient. Examples include curbside pickup for residences on a frequent schedule and easy drop-off centers with convenient hours for rural communities and for more specialized products. Product mail-back programs have also worked for certain appliances and electronic components.

Even with stable markets and convenient programs, public education is a critical component for increasing the amount of recycling. At this point, the United States must develop a conservation, rather than a throwaway, ethic, especially in light of the current energy crisis (2008). Recycling presents the next opportunity for cultural change. It will require us to move beyond a mere willingness to collect our discards for recycling. That cultural change will require consumers to purchase recyclable products and products made with recycled content. It will require businesses to utilize secondary materials in product manufacturing and to design new products for easy disassembly and separation of component materials.²

Combustion (Waste-to-Energy)

The third of the IWM options (see Figure 3.1) is combustion (waste-to-energy). Combustion facilities are attractive because they do one thing very well; they reduce the volume of waste noticeably, up to ninefold. Combustion facilities can also be used to recover useful energy, either in the form of steam or in the form of electricity. Volume reduction alone can make the high capital cost of incinerators attractive when landfill space is at a premium or when the landfill is distant from the point of generation. For many major metropolitan areas, new landfills must be located increasingly far away from the center of the population. Moreover, incinerator bottom ash has a promise for reuse as a building material. Those who make products from cement or concrete may be able to utilize incinerator ash.

The major constraints of incinerators are their cost, the relatively high degree of sophistication needed to operate them safely and economically, and the fact that the public is very skeptical concerning their safety. The public is concerned about both stack emissions from incinerators and the toxicity of ash produced by incinerators. The EPA has addressed both of these concerns through the development of new regulations for solid waste combustion (waste-to-energy) plants and improved landfill requirements for ash. These regulations will ensure that well-designed, well-built, and well-operated facilities will be fully protective from the health and environmental standpoints.²

Landfills

Landfills are the one form of waste management that nobody wants but everybody needs. There are simply no combinations of waste management techniques that do not require landfilling to make them work. Of the four basic management options, landfills are the only management technique that is both necessary and sufficient. Some wastes are simply not recyclable, because they eventually reach a point where their intrinsic value is dissipated completely so they no longer can be recovered, and recycling itself produces residuals, and is no longer cost-effective and or energy efficient.

The technology and operation of a modern landfill can assure protection of human health and the environment. The challenge is to ensure that all operating

landfills are designed properly and are monitored once they are closed. It is critical to recognize that today's modern landfills do not look like the old landfills that are on the current Superfund list. Today's operating landfills do not continue to take hazardous waste. In addition, they do not receive bulk liquids. They have gas control systems, liners, leachate collection systems, and extensive groundwater monitoring systems. Perhaps most importantly, they are better sited and located in the first place to take advantage of natural geological conditions.

Landfills can also turn into a resource. Methane gas recovery is occurring at many landfills today, and CO₂ recovery is being considered. After closure, landfills can be used for recreation areas such as parks, golf courses, or ski areas. Some agencies and entrepreneurs are looking at landfills as repositories of resources for the future; in other words, today's landfills might be able to be mined at some time in the future when economic conditions warrant. This situation could be particularly true of monofills, which focus on one kind of waste material like combustion ash or shredded tires.²

Implementing Integrated Solid Waste Management

The implementation of IWM for residential solid waste, as illustrated in Figure 3.2, typically involves the use of a several technologies and all of the

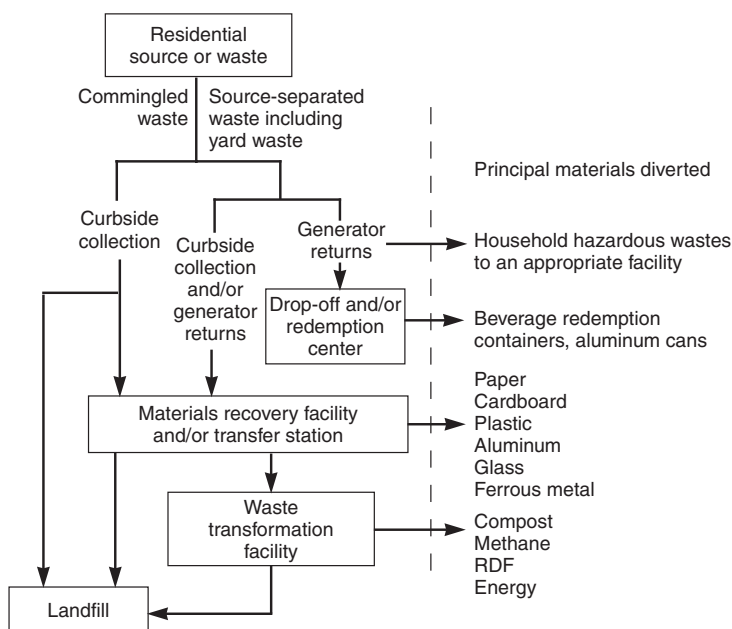


FIGURE 3.2 Implementation of IWM for management of residential solid wastes. Similar diagrams apply to commercial and institutional sources of solid waste. (Source: G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002.)

management options already discussed. At present, most communities use two or more of the municipal solid waste (MSW) management options to dispose of their waste, but there are only a few instances where a truly integrated and optimized waste management plan has been developed. To achieve an integrated strategy for handling municipal waste, an optimization analysis combining all of the available options should be conducted. However, at present, there is no proven methodology for performing such an optimization analysis.²

SOURCES, CHARACTERISTICS, AND QUANTITIES OF SOLID WASTE

In developing solid waste management programs, it is important to identify the sources, characteristics, and quantities of solid waste. Information on these subjects, as discussed in this section, is of fundamental importance in determining the types of collection service, the types of collection vehicles to be used, the type of processing facilities, and the disposal method to be used. Construction and demolition debris and special wastes that must be collected and processed separately are also considered.

Sources of Solid Waste

Sources of solid wastes in a community are, in general, related to land use and zoning. Although any number of source classifications can be developed, the following categories have been found useful: (1) residential, (2) commercial, (3) institutional, (4) construction and demolition, (5) municipal services, (6) treatment plant sites, (7) industrial, and (8) agricultural. Typical waste generation facilities, activities, or locations associated with each of these sources are reported in Table 3.1. As noted in Table 3.1, *municipal solid waste* is normally assumed to include all community wastes with the exception of wastes generated from municipal services, water and wastewater treatment plants, industrial processes, and agricultural operations. It is important to be aware that the definitions of solid waste terms and the classifications of solid waste vary greatly in the literature and in the profession. Consequently, the use of published data requires considerable care, judgment, and common sense.²

Characteristics of Solid Waste

Important characteristics of solid waste include the composition, quantities, and specific weight.

Composition Typical data on the percentage distribution for the wastes from the sources identified in Table 3.1 are reported in Table 3.2. As shown in Table 3.2, residential and commercial waste make up about 60 percent of the total municipal waste generated per person in the United States, excluding industrial and agricultural wastes. It is important to recognize that most surveys of solid

TABLE 3.1 Sources Where Solid Wastes Are Generated within a Community

Source	Typical Facilities, Activities, or Locations Where Wastes Are Generated	Types of Solid Wastes
Residential	Single-family and multifamily dwellings; low-, medium-, and high-rise apartments	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood glass, tin cans, aluminum other metal, ashes, street leaves, special wastes (including bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires), household hazardous wastes
Commercial	Stores, restaurants, markets, office buildings, hotels, motels, print shops, service stations, and auto repair shops	Paper, cardboard, plastics, wood, food wastes, glass, metal wastes, ashes, special wastes (see above), hazardous wastes
Institutional	Schools, hospitals, prisons, governmental centers	As above for commercial
Industrial (nonprocess wastes)	Construction, fabrication, light and heavy manufacturing, refineries chemical plants, power plants, demolition	Paper, cardboard, plastics, wood, food wastes, glass, metal wastes, ashes, special wastes (see above), hazardous wastes
Municipal solid waste	All of the above ^a	All of the above ^a
Construction and demolition	New construction sites, road repair renovation sites, razing of buildings, broken pavement	Wood, steel, concrete, dirt
Municipal services (excluding treatment facilities)	Street cleaning, landscaping, catch-basin cleaning, parks and beaches, other recreational areas	Special wastes, rubbish, street sweepings, landscape and tree trimmings, catch-basin debris; general wastes from parks, beaches and recreational areas
Treatment plant sites	Water, wastewater, and industrial treatment processes	Treatment plant wastes, principally composed of residual sludges and other residual materials
Industrial	Construction, fabrication, light and heavy manufacturing, refineries chemical plants, power plants, demolition	Industrial process wastes, scrap materials; nonindustrial waste, including food wastes, rubbish, ashes, demolition and construction wastes, special wastes, hazardous waste
Agricultural	Field and row crops, orchards, vineyards, dairies, feedlots, farms	Spoiled food wastes, agricultural wastes, rubbish, hazardous wastes

^aThe term *municipal solid waste (MSW)* normally is assumed to include all of the wastes generated in the community with the exception of waste generated from municipal services, treatment plants, industrial processes, and agriculture.

Source: G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.

TABLE 3.2 Estimated Percentage Distribution by Weight of All MSW Generated in a Typical Community in 2008, Excluding Industrial and Agricultural Wastes^a

Waste Category	Percent of Total	
	Range	Typical
Residential and commercial, excluding special and hazardous wastes	50–70	60
Special (bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires)	2–12	5
Hazardous ^b	0.01–1.0	0.1
Institutional	3–5	3.4
Construction and demolition	8–20	14
Municipal services		
Street and alley cleanings	2–5	3.8
Tree and landscaping	2–5	3
Parks and recreational areas	1.5–3	2
Catch basin	0.5–1.2	0.7
Treatment plant sludges	3–8	6
Total		100.0

^aAdapted in part from G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993; G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002; U.S. EPA, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006, Executive Summary*, Office of Solid Waste, EPA, Washington, DC, 2006a, <http://www.epa.gov/garbage/pubs/msw06.pdf>.

^bRange of reported values varies widely depending on method used to identify and classify hazardous wastes found in MSW.

waste generation do not consider the wastes from municipal services, industrial and agricultural sources. The estimate composition of residential and commercial solid waste along with the estimated quantities that are now recycled are reported in Table 3.3. The percentage data given in Table 3.3 are subject to adjustment depending on many factors: time of the year; habits, education, and economic status of the people; number and type of commercial and industrial operations; whether urban or rural area; and location. Each community should be studied and actual weighings made to obtain representative information for design purposes.

Quantities Various estimates have been made of the quantity of solid waste generated and collected per person per day. The amount of municipal and commercial solid waste generated per capita in the United States in 2006 (latest

TABLE 3.3 Estimated Physical Composition of Residential MSW Generated and Recycled in 2008, Excluding Food Wastes Discharged with Wastewater^a

Component	Percent by Weight			
	Generated		Recycled ^b	
	Range	Typical	Range	Typical
Organic Waste				
Food wastes	6–18	10	1–4	2.5
Paper and paperboard	25–40	34	45–55	52
Plastics	8–14	12	6–8	7
Textiles	2–6	4.5	12–18	15
Rubber	0.5–2	1	8–15	11
Leather	0.5–2	1	1.5–4	2.5
Yard wastes	5–20	13.0	50–65	60
Wood	4–8	5.5	8–12	10
Misc. organics	0.05–0.2	0.1	0.4–1.2	1
Inorganic Waste				
Glass	4–10	6.0	20–28	22
Tin cans	2–8	6.0	30–40	36
Aluminum	1–2	1.4	65–80	75
Other metal	1–4	3.0	5–10	67
Dirt, ash, etc	0–5	2.5		0.5
Total		100.0		

^aAdapted in part from G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993; G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002; U.S. EPA, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006, Executive Summary*, Office of Solid Waste, EPA, Washington, DC, 2006a, <http://www.epa.gov/garbage/pubs/msw06.pdf>. Reported percentage distributions are exclusive of special and hazardous wastes (see Table 3.2).

^bTwenty five percent of the households in the United States assumed to have food waste grinders and that the percentage of food waste ground up and discharged with wastewater is equal to 25 percent.

^cCurrent (2008) recycling rate for the United States assumed to be equal to about 50 to 54 percent.

available national data) is estimated to be 4.6 lb/capita•d (pounds of waste generated per capita per day).³ Additional details on the quantities and characteristics of the solid waste generated in the United States may be found in Franklin Associates and U.S. EPA.⁴ Based on the data given in Table 3.2, if hazardous, institutional, construction and demolition, and municipal wastes are considered, the total amount of waste generated per capita is about 7.7 lb/capita•d. Consideration of industrial and agricultural wastes would increase the total per capita generation rate significantly, more than double the amount (15 to 20 lb/capita•d) by some estimates. With the emphasis now placed on source reduction (such as less packaging) and waste recovery and recycling (such as of paper, metals, cans, and glass), the amount of solid waste requiring disposal has been reduced

markedly over the past 10 years. For example, the Board of Supervisors of the City of San Francisco has mandated a goal of 75 percent waste diversion by the year 2010. It is estimated that in 2008, about 50 to 54 percent by weight of the waste generated will be recovered for recycling and reprocessing. Recovery and recycling of hazardous wastes and toxicity reduction by substitution of less hazardous or nonhazardous materials is continuing to increase.

Typical data on the quantities of waste generated from specific sources are presented in Table 3.4. Typical data on the quantities of waste generated from miscellaneous nonresidential sources are presented in Table 3.5. Typical data on the quantities of waste generated from industrial sources are presented in Table 3.6, respectively. The data presented in Tables 5.4 through 5.6 are meant to be used as a general guide to expected quantities for the purpose of preliminary planning and feasibility assessment. In all cases the quantity information in these table must be verified locally before final design.

Specific Weight The volume occupied by solid waste under a given set of conditions is of importance, as are the number and size or type of solid waste containers, collection vehicles, and transfer stations. Transportation systems and land requirements for disposal are also affected. For example, the specific weight of loose solid waste will vary from about 100 to 175 lb/yd³. Specific weights of various solid waste materials are given in Table 3.7. The variabilities in the reported data are due to variations in moisture content.

Commercial and Household Hazardous Waste

The “contamination” of ordinary municipal waste by commercial and household hazardous wastes has exacerbated the potential problems associated with the disposal of municipal waste by landfill, incineration, and composting. Based on a number of past studies, the quantity of hazardous waste typically represents less than about 0.5 percent of the total waste generated by households. Typically, batteries and electrical items and certain cosmetics accounted for the largest amount. The EPA discusses the impact of toxic wastes on solid waste management.⁵

From a practical standpoint, it would appear that more can be accomplished by identifying and prohibiting disposal of commercial hazardous waste with municipal solid waste. The minimal household hazardous wastes could, with education and municipal cooperation, be disposed of by voluntary actions. These could include periodic community collections and provision of central guarded depositories. Many communities have established ongoing programs for the collection of household hazardous waste. The amount of waste can be expected to decrease as old stockpiles are discarded. Restricting sales and promoting development and substitution of nonhazardous household products would also be indicated. It should also be remembered that a large fraction of the household hazardous waste ends up in the sewer.

TABLE 3.4 Approximate Solid Waste Generation Rates from Various Sources in the United States

Source of Waste	Unit	lb/unit · day
Municipal	Capita	4.0
Household	Capita	3.5
Apartment building	Capita per sleeping room	4.0
Seasonal home	Capita	2.5
Resort	Capita	3.5
Camp	Capita	1.5
School		
With cafeteria	Capita	1.0
Without cafeteria	Capita	0.5
University	Student	0.86 to 1.0
Institution, general	Bed	2.5
Hospital	Bed	12–15
	Occupied bed and 3.7 if staff added	9.5
Nurses' or interns' home	Bed	3.0
Home for aged	Bed	3.0
Rest home	Bed	3.0
Nursing home, retirement	Bed	5.0
Infectious waste		
Hospital	Bed	4.0
Residential health care facility	Bed	0.5
Diagnostic and treatment center	Patient per week	0–6.5
Hotel		
First class	Room	3.0
Medium class	Room	1.5
Motels	Room	2.0
Day use facility, resort	Capita	0.5
Trailer camp	trailer	6–10
Commercial building, office	100 ft ²	1.0
Office building	Worker	1.5
Department store	100 ft ²	40
Shopping center	Survey required	Survey required
Supermarket	100 ft ²	9.0
Supermarket	Person	2.4
Restaurant	Meal	2.0
Cafeteria	Capita	1
Fast food	Capita	0.5
Drugstore	100 ft ²	5.0
Airport	Passenger	0.5
Prison	Inmate	4.5
Retail and service facility	1000 ft ²	13.0
Wholesale and retail facility	1000 ft ²	1.2
Industrial building, factory	400–3000 employees	7
	100–400 employees	3
Warehouse	Per 100 ft ²	2.0

(continues)

TABLE 3.4 (continued)

Source of Waste	Unit	lb/unit · day
National Forest recreational area		
Campground	Camper	1.2–1.4
Family picnic area	Picnicker	8.0–1.2
Organized camps	Occupant	1.4–2.2
Rented cabin, with kitchen	Occupant	1.2–1.8
Lodge, without kitchen	Occupant	0.2–0.8
Restaurant	Meal served	0.5–1.2
Overnight lodge, winter sports area	Visitor	1.5–2.1
Day lodge, winter sports area	Visitor	2.4–3.4
Swimming beach	Swimmer	0.02–0.05
Concession stand	Per patron	0.10–0.16
Job Corps, Civilian Conservation		
Corps camp, kitchen waste	Per corpsman	1.8–3.0
Administrative and dormitory	Per corpsman	0.5–1.2

Source: Adapted from J. A. Salvato, *Environmental Engineering and Sanitation*, 4th ed., Wiley, New York, 1992.

TABLE 3.5 Miscellaneous Solid Waste Generation

Type	Solid Waste Generation Rate	
	Unit	Range of Values
Tires	Tires discarded per capita per year	0.6–1.0
Waste oil	5 gal per vehicle per year	2.0–3.0
Wastewater sludge, raw	Tons per day per 1,000 people, dewatered to 25% solids, with no garbage grinders	0.3–0.5
	Tons per day per 1,000 people, dewatered to 25% solids, with 100% garbage grinders	0.7–0.9
Wastewater sludge, digested	Tons per day per 1,000 people, dewatered to 25% solids, or 3 lb per capita per day dry solids	0.20–0.30
Water supply sludge	Pounds per million gallons of raw water, on a dry-weight basis, with conventional rapid-sand filtration using alum; raw water with 10 Jackson turbidity units (JTU)	200–220
Scavenger wastes	Gallons per capita per day	0.25–0.35
Pathological wastes	Pounds per bed per day—hospital	0.6–0.8
	Pounds per bed per day—nursing home	0.4–0.6
Junked vehicles	Number per 1000 population—2002	40–80

Source: Adapted in part from Malcolm Pirnie Engineers, *Comprehensive Solid Waste Planning Study—1969*, Herkimer-Oneida Counties, State of New York Department of Health, Albany, 1969.

TABLE 3.6 Typical Solid Waste Generation Rates for Industrial Sources by SIC Code^a

SIC Code	Industry	Waste Production Rate (tons/employee·yr)
201	Meat processing	6.2
2033	Cannery	55.6
2037	Frozen foods	18.3
Other 203	Preserved foods	12.9
Other 20	Food processing	5.8
22	Textile mill products	0.26
23	Apparel	0.31
2421	Sawmills and planing mills	162.0
Other 24	Wood products	10.3
25	Furniture	0.52
26	Paper and allied products	2.00
27	Printing and publishing	0.49
281	Basic chemicals	10.0
Other 28	Chemical and allied products	0.63
29	Petroleum	14.8
30	Rubber and plastic	2.6
31	Leather	0.17
32	Stone, clay	2.4
33	Primary metals	24
34	Fabricated metals	1.7
35	Nonelectrical machinery	2.6
36	Electrical machinery	1.7
37	Transportation equipment	1.3
38	Professional and scientific institutions	0.12
39	Miscellaneous manufacturing	0.14

^aStandard Industrial Classification (SIC) Code.

Source: R. F. Weston, *A Statewide Comprehensive Solid Waste Management Study*, New York State Department of Health, Albany, 1970.

Construction and Demolition Debris

Construction and demolition debris consists of uncontaminated solid waste resulting from the construction, remodeling, repair, and demolition of structures and roads and uncontaminated solid waste consisting of vegetation from land clearing and grubbing, utility line maintenance, and seasonal and storm-related cleanup. Such waste includes, but is not limited to, bricks, concrete and other masonry materials, soil, wood, wall coverings, plaster, drywall, plumbing fixtures, nonasbestos insulation, roofing shingles, asphaltic pavement, glass, plastics that are not sealed in a manner that conceals other wastes, electrical wiring and components containing no hazardous liquids, and metals that are incidental to any of the above.⁶

Solid waste that is not construction and demolition debris (even if resulting from the construction, remodeling, repair, and demolition of structures, roads, and

TABLE 3.7 Weight of Solid Waste for Given Conditions

Condition of Solid Waste	Weight (lb/yd ³)
Loose solid waste at curb	125–240
As received from compactor truck at sanitary landfill	300–700
Normal compacted solid waste in a sanitary landfill ^a	750–850
Well-compacted solid waste in a sanitary landfill ^a	1000–1250
In compactor truck	300–600
Shredded solid waste, uncompacted	500–600
Shredded solid waste, compacted	1400–1600
Compacted and baled	1600–3200
Apartment house compactor	600–750
In incinerator pit	300–550
Brush and dry leaves, loose and dry	80–120
Leaves, loose and dry	200–260
Leaves, shredded and dry	250–450
Green grass, compacted	500–1100
Green grass, loose and moist	350–500
Yard waste, as collected	350–930
Yard waste, shredded	450–600

^aInitial value.

Source: J. A. Salvato, *Environmental Engineering and Sanitation*, 4th ed., Wiley, New York, 1992. and G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993. Reproduced with permission from Cornell Waste Management Institute, Center for the Environment.

land clearing) includes, but is not limited to, asbestos waste, garbage, corrugated container board, electrical fixtures containing hazardous liquids such as fluorescent light ballasts or transformers, carpeting, furniture, appliances, tires, drums and containers, and fuel tanks. Specifically excluded from the definition of construction and demolition debris is solid waste (including what otherwise would be construction and demolition debris) resulting from any processing technique, other than that employed at a construction and demolition processing facility, that renders individual waste components unrecognizable, such as pulverizing or shredding.

Some of this material, such as bricks, rocks, wood, and plumbing fixtures, can be recycled. However, care must be taken to ensure (by monitoring each load) that hazardous materials such as those mentioned above are excluded and that fire, odor, and groundwater pollution is prevented. Engineering plans and reports, hydrogeologic report, operation and maintenance reports, and permits from the regulatory agency are usually required.

Special Wastes Collected Separately

In every community a number of waste materials are collected separately from residential and commercial solid waste. Special wastes include (1) medical

wastes, (2) animal wastes, (3) waste oil, and (4) old tires. These wastes are considered in the following discussion.

Medical Wastes — Infectious and Pathological The Solid Waste Disposal Act, commonly referred to as the Resource Conservation and Recovery Act (RCRA), defines medical waste as “any solid waste which is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals. The term does not include any hazardous waste identified or listed under Subtitle C (mixtures with medical wastes are not excluded) or any household waste as defined in regulations under Code of Federal Regulations, Title 40, Subtitle C (materials found in waste generated by consumers).”⁷

Infectious waste usually comes from a medical care or related facility. It includes all waste materials resulting from the treatment of a patient on isolation (other than patients on reverse or protective isolation), renal dialysis, discarded serums and vaccines, pathogen-contaminated laboratory waste and animal carcasses used in research (including bedding and other waste), and other articles that are potentially infectious, such as hypodermic and intravenous needles.

Regulated medical waste under the act includes the following waste categories: cultures and stock of infectious agents and associated biologicals; human blood and blood products; pathological waste; used sharps (needles, syringes, surgical blades, pointed and broken glass); and contaminated animal carcasses. The EPA is authorized to exclude, if there is no substantial threat to human health or the environment, surgery or autopsy waste, miscellaneous microbiology laboratory waste, dialysis waste, discarded medical equipment, and isolation wastes. Other waste categories may be added if they pose a substantial threat. Potential hazards associated with the handling of infectious waste necessitate certain precautions. Infectious waste needs to be segregated at the source and clearly color (red) coded and marked. The packaging is expected to maintain its integrity during handling, storage, and transportation with consideration of the types of materials packaged. The storage time should be minimal (treated within 24 hours); the packaging should be moisture proof, puncture resistant, and rodent and insect proof; and the storage places and containers clearly marked with the universal biological hazard symbol and secured. Packaged waste is placed in rigid or semirigid containers and transported in closed, leak-proof trucks or dumpsters. It must at all times be kept separate from regular trash and other solid waste. Health care workers and solid waste handlers must be cautious.

Most infectious waste can be treated for disposal by incineration or autoclaving. The residue can be disposed of in an approved landfill. Liquids may be chemically disinfected; pathological wastes may also be buried, if permitted, or cremated; and blood wastes may, under controlled conditions, be discharged to a municipal sanitary sewer, provided secondary treatment is employed. Infectious waste may also be rendered innocuous by shredding–disinfection (sodium hypochlorite), thermal inactivation, and gas–vapor treatment. Infectious waste is only one component of medical waste.

In all cases, local, state, and federal regulations should be followed closely. Public concerns and fears associated with the possible spread of the viruses causing acquired immunodeficiency syndrome (AIDS) and hepatitis B, as well as other infections, have accelerated legislative and regulatory action, tighter management practices, and provision of specialized treatment and disposal services. Complete records (medical waste tracking form) must be kept by the generator and hauler of infectious waste to the point of final disposal as part of a four-part manifest system.

Animal Wastes Animal wastes may contain disease organisms causing salmonellosis, leptospirosis, tularemia, foot-and-mouth disease, hog cholera, and other illnesses. Manure contaminated with the foot-and-mouth disease virus must be buried in a controlled manner or otherwise properly treated. The excreta from sick animals should be stored 7 to 100 days, or as long as is necessary to ensure destruction of the pathogen, depending on temperature and moisture. Dead animals are best disposed of at an incinerator or rendering plant or in a separate area of a sanitary landfill. Large numbers might be buried in a special trench with due consideration to protection of groundwaters and surface waters if approved by the regulatory authority.

Waste Oil Large quantities of waste motor and industrial oil find their way into the environment as a result of accidental spills, oiled roads, oil dumped in sewers and on the land, and oil deposited by motor vehicles. Used oils contain many toxic metals and additives that add to the pollution received by sources of drinking water, aquatic life, and terrestrial organisms. The lead content of oil is of particular concern. It has been estimated that industrial facilities, service stations, and motorists produce 1.2 billion gallons of used oil, of which about 60 percent is used motor oil. Approximately 60 percent of the waste oil is reprocessed and used for fuel. About 25 to 30 percent is rerefined and reused as a lubricant. The remainder is used for road oil, dirt road dust control and stabilization, and other unacceptable uses. Rerefined oil is so classified when it has had physical and chemical impurities removed and, when by itself or blended with new oil or additives, is substantially equivalent or superior to new oil intended for the same purposes, as specified by the American Petroleum Institute.

Used Tires Tire dumps can cause major fires and release many hazardous chemicals, including oil, contributing to air and groundwater pollution. Tires collect rain water in which mosquitoes breed and provide harborage for rats and other vermin. Tires are not suitable for disposal by landfill but may be acceptable if shredded or split, although recycling is preferred and may be required.

ON-SITE HANDLING AND STORAGE

Where solid waste is temporarily stored on the premises, between collections, an adequate number of suitable containers should be provided.

Low-Rise Residential Areas

To a large extent, the type of container used for the collection of residential solid waste will depend on the type of collection service provided, and whether source

TABLE 3.8 Typical Collection Services for Commingled and Source Separated Solid Waste^a

Preparation Method for Waste Collected	Type of Service
Commingled wastes	Single collection service of large container for commingled household and yard waste Separate collection service for (1) commingled household waste and (2) containerized yard waste Separate collection service for (1) commingled household waste and (2) noncontainerized yard waste
Source-separated and commingled waste	Single collection service for a single container with source-separated waste placed in plastic bag along with commingled household and yard wastes Separate collection service for (1) source-separated waste placed in a plastic bag and commingled household waste in same container and (2) noncontainerized yard wastes Single collection service for source-separated and commingled household and yard wastes using a two-compartment container Separate collection service for (1) source-separated and commingled household wastes using a two-compartment container and (2) containerized or noncontainerized yard waste Separate collection service for (1) source-separated waste and (2) containerized commingled household and yard wastes Separate collection service for (1) source-separated waste, (2) commingled household waste, and (3) containerized yard wastes Separate collection service for (1) source-separated waste, (2) commingled household waste, and (3) noncontainerized yard wastes Separate collection service for (1) source-separated recyclable materials, (2) source-separated compostable materials (i.e., food and yard waste), and (3) nonrecyclable solid waste

^aThe method of waste preparation for collection is often selected for convenience and efficiency of collection services and subsequent materials processing activities.

Source: H. Theisen, "Solid Waste Collection," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 7.



(a)



(b)

FIGURE 3.3 Typical containers used for collection of residential solid waste: (a) source-separated recyclable materials are placed in three separate containers (one for paper, one for glass, and one for cans and plastics), residual nonrecyclable wastes are placed in separate containers, and yard wastes are place in the street for collection with specialized collection equipment; (b) commingled mixed wastes in a single large (90-gal) container.

separation of wastes is employed (see Table 3.8). The various types of containers used for residential service are illustrated in Figure 3.3.

Low- and Medium-Rise Apartments

Large containers located in enclosed areas are used most commonly for low and medium-rise apartments. In most applications, separate containers are provided for recyclable and commingled nonrecyclable materials. A typical example is shown in Figure 3.4.

Curbside collection service is common for most low- and medium-rise apartments. Typically, the maintenance staff is responsible for transporting the containers to the street for curbside collection by manual or mechanical means. In many communities, the collector is responsible for transporting containers from a storage location to the collection vehicle. Where large containers are used, the contents of the containers are emptied mechanically using collection vehicles equipped with unloading mechanisms.

High-Rise Apartments

In high-rise apartment buildings (higher than seven stories), the most common methods of handling commingled wastes involve one or more of the following: (1) wastes are picked up by building maintenance personnel from the various floors and taken to the basement or service area; (2) wastes are taken to the basement or service area by tenants; or (3) wastes, usually bagged, are placed by the tenants in a waste chute system used for the collection of commingled waste



FIGURE 3.4 Typical example of containers used for low- and medium-rise apartments. Large containers are used for solid waste to be disposed of in a landfill. The smaller containers in front of the enclosure are used for: (1) glass, tin can, aluminum cans, and plastic containers (type 1 and 2) and (2) recyclable paper and paperboard products.

at a centralized service location. Typically, large storage containers are located in the basements of high-rise apartments. In some locations, enclosed ground-level storage facilities will be provided. In some of the more recent apartment building developments, especially in Europe, underground pneumatic transport systems have been used in conjunction with the individual apartments chutes.

Commercial and Institution

Bulk containers or solid waste bins are recommended where large volumes of solid waste are generated, such as at hotels, restaurants, motels, apartment houses, shopping centers, and commercial places. They can be combined to advantage with compactors in many instances (see Figure 3.5). Containers should be placed on a level, hard, cleanable surface in a lighted, open area. The container and surrounding area must be kept clean, for the reasons previously stated. A concrete platform provided with a drain to an approved sewer with a hot-water faucet at the site to facilitate cleaning is generally satisfactory.

SOLID WASTE COLLECTION

Collection cost has been estimated to represent about 60 to 75 percent of the total cost of solid waste management, depending on the disposal method. Because the cost of collection represents such a large percentage of the total cost, the design of collection systems must be considered carefully. The type of service provided, the frequency of service, and the equipment used for collection are considered in the following discussion.

Type of Service

The type of collection service provided will depend on the community solid waste management program. Typical examples of the types of collection service provided for the collection of (1) commingled and (2) source-separated and commingled wastes, as reported in Table 3.8. It should be noted that numerous other variations in the service provided have been developed to meet local conditions. In addition to routine collection services, presented in Table 3.8, annual or semi-annual special collections for appliances, tires, batteries, paints, oils, pesticides, yard wastes, glass and plastic bottles, and “spring cleaning” have proven to be an appreciated community service while at the same time providing environmental protection.

Collection Frequency

The frequency of collection will depend on the quantity of solid waste, time of year, socioeconomic status of the area served, and municipal or contractor responsibility. In residential areas, twice-a-week solid waste collection during warm months of the year and once a week at other times should be the maximum



(a)



(b)

FIGURE 3.5 Typical containers used for collection of large amounts of waste from commercial establishments: (a) open top with lids; (b) closed container coupled to stationary compactor.



FIGURE 3.6 Commercial waste placed on sidewalk in New York City for manual collection at night or in very early morning hours.

permissible interval. In business districts, solid waste, including garbage from hotels and restaurants, should be collected daily except Sundays (see Figure 3.6). Depending on the type of collection system, the containers used for the on-site storage of solid waste should be either emptied directly into the collection vehicle or hauled away emptied and returned or replaced with a clean container. Solid waste transferred from on-site storage containers will invariably cause spilling, with resultant pollution of the ground and attraction of flies. If other than curb pickup is provided, such as backyard service, the cost of collection will be high. Nevertheless, some property owners are willing to pay for this extra service. Bulky wastes should be collected every three months. Most cities have also instituted ongoing programs for the collection of household hazardous wastes, typically every three months.

Types of Collection Systems

Solid waste collection systems may be classified from several points of view, such as the mode of operation, the equipment used, and the types of wastes collected. Collection systems can be classified, according to their mode of operation, into two categories: (1) hauled container systems and (2) stationary container systems. The individual systems included in each category lend themselves to the same method of engineering and economic analysis.⁸ The principal operational features of these two systems are delineated as follows.

Hauled Container Systems (HCSs) These are collection systems in which the containers used for the storage of wastes are hauled to a materials recovery facility (MRF), transfer station, or disposal site, emptied, and returned to either their original location or some other location. There are two main types of vehicles used in hauled container systems: (1) hoist truck for containers in the size range from 2 to 12 yd³ and (2) tilt-frame vehicles for containers in the size range from 10 to 50 yd³ (see Figure 3.7). Typical data on the containers and container capacities used with these vehicles are reported in Table 3.9. In addition trash-trailers are used in some locations for construction and demolition wastes.

Hauled container systems are ideally suited for the removal of wastes from sources where the rate of generation is high because relatively large containers are used (see Table 3.9). The use of large containers eliminates handling time as well as the unsightly accumulations and unsanitary conditions associated with the use of numerous smaller containers. Another advantage of hauled container systems is their flexibility: Containers of many different sizes and shapes are available for the collection of all types of wastes.

Stationary Container Systems (SCSs) In the stationary container system, the containers used for the storage of wastes remain at the point of generation, except when they are moved to the curb or other location to be emptied. Stationary container systems may be used for the collection of all types of wastes. The systems vary according to the type and quantity of wastes to be handled, as well as



(a)



(b)

FIGURE 3.7 Typical examples of collection vehicles and containers used in hauled container system: (a) hoist truck; (b) tilt frame unloading a drop box; and (c) drop boxes used at commercial discount store.



(c)

FIGURE 3.7 (continued)

the number of generation points. There are two main types: (1) systems in which manually loaded collection vehicles are used (see Figure 3.8) and (2) systems in which mechanically loaded collection vehicles are used (see Figure 3.9).

The major application of manual loading collection vehicles is in the collection of residential source-separated and commingled wastes and litter. Manual loading is used in residential areas where the quantity picked up at each location is small and the loading time is short. In addition, manual methods are used for residential collection because many individual pick-up points are inaccessible to mechanized mechanically loaded collection vehicles. Special attention must be given to the design of the collection vehicle intended for use with a single collector. At present, it appears that a side-loaded compactor, such as the one shown in Figure 3.8*a*, equipped with standup right-hand drive, is best suited for curb and alley collection.

Personnel Requirements

In most hauled container systems, a single collector-driver is used. The collector-driver is responsible for driving the vehicle, loading full containers onto the collection vehicle, emptying the contents of the containers at the disposal site (or transfer point), and redepositing (unloading) the empty containers. In some cases, for safety reasons, both a driver and helper are used. The helper usually is responsible for attaching and detaching any chains or cables used in loading and unloading containers on and off the collection vehicle; the driver is responsible for the operation of the vehicle. A driver and helper should always be used where hazardous wastes are to be handled. Labor

TABLE 3.9 Typical Data on Container Types and Capacities Available for Use with Various Collection Systems

Collection System	Container Type	Typical Range of Container Capacities
Hauled container system		
Hoist truck	Used with stationary compactor	6–12 yd ³
Tilt-frame	Open top, also called debris boxes or roll-off	12–50 yd ³
	Used with stationary compactor	15–40 yd ³
	Equipped with self-contained compaction mechanism	20–40 yd ³
Truck-tractor	Open-top trash-trailers	15–40 yd ³
	Enclosed trailer-mounted containers equipped with self-contained compaction mechanism	30–40 yd ³
Stationary container systems (compacting type)	Open top and closed top with side loading	1–10 yd ³
Compactor, mechanically loaded		
	Special containers used for collection of residential wastes from individual residences	90–120 gal
Compactor, mechanically loaded with divided hopper	Special split cart containers used for collection of recyclables and other nonrecyclable commingled waste	92–120 gal
Compactor trailer with mechanical lift assembly on semitractor	Special split cart containers used for collection of recyclables and other nonrecyclable commingled waste	90–120 gal
Compactor, manually loaded	Small plastic or galvanized metal containers, disposable paper and plastic bags	20–55 gal
Stationary container systems (noncompacting type)		
Collection vehicle with manually loaded side dump containers	All types of containers used for temporary storage of recyclable materials	32 gal
Collection vehicle with semiautomatic manually loaded side troughs	All types of containers used for temporary storage of recyclable materials	32 gal
Collection vehicle with semiautomatic manually loaded side troughs capable of unloading wheeled containers	All types of containers used for temporary storage of recyclable materials plus wheeled containers	60–120 gal
Collection vehicle with mechanical lift assembly	Special containers used for collection of source separated wastes from individual residences	60–120 gal

Note: $\text{yd}^3 \times 0.7646 = \text{m}^3$; $\text{gal} \times 0.003785 = \text{m}^3$.

Source: H. Theisen, "Solid Waste Collection," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 7, and G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.



(a)



(b)

FIGURE 3.8 Typical examples of manually loaded collection vehicles used in stationary container system: (a) side-loaded right-hand standup drive collection vehicle for commingled solid waste; (b) rear-loaded collection vehicle for commingled solid waste; (c) side-loading vehicle used for collection of source-separated materials.



(c)

FIGURE 3.8 *(continued)*

requirements for curbside collection with manually and mechanically loaded vehicles with a one-person crew are reported in Table 3.10.

Labor requirements for mechanically loaded stationary container systems are essentially the same as for hauled container systems. Where a helper is used, the driver often assists the helper in bringing loaded containers mounted on rollers to the collection vehicle and returning the empty containers. Occasionally, a driver and two helpers are used where the containers to be emptied must be rolled (transferred) to the collection vehicle from inaccessible locations, such as in congested downtown commercial areas. In stationary container systems, where the collection vehicle is loaded manually, the number of collectors varies from one to four, in most cases, depending on the type of service and the collection equipment. While the aforementioned crew sizes are representative of current practices, there are many exceptions. In many cities, multiperson crews are used for curb service as well as for backyard carry service.

Health Issues

The frequency and severity of injuries in the solid waste management industry are very high. The National Safety Council reported that solid waste collection workers have an injury frequency approximately 10 times the national average for all industries, higher than police work and underground mining. Workmen's compensation rates account for about 9 to 10 percent of payroll for all solid waste collectors.



(a)



(b)

FIGURE 3.9 Typical examples of mechanically loaded collection vehicles used in stationary container system: (a) side-loading vehicle with dual compartment; (b) front-loaded collection vehicle. (Source: Courtesy of Heil Environmental Industries; reproduced with permission.)

TABLE 3.10 Typical Labor Requirements for Curbside Collection with Manually and Mechanically Loaded Collection Vehicle Using One-Person Crew^a

Average Number of Containers and/or Boxes per Pickup Location	Time (min/location)	
	Manual Pickup	Mechanical Pickup
1 (60–90 gal)	—	0.5–0.6
1 or 2	0.5–0.6	
3 or 4	0.6–0.9	
Unlimited service ^b	1.0–1.2	

^aValues given are for typical residential area with lot sizes varying from 1/4 to 1/3 acre.

^bNot all residents take advantage of unlimited service each collection day.

Source: H. Theisen, “Solid Waste Collection,” in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 7.

TRANSFER AND TRANSPORT

The urban areas around cities have been spreading, leaving fewer nearby acceptable solid waste disposal sites. The lack of acceptable sites has led to the construction of incinerators, resource recovery facilities, or processing facilities in cities or their outskirts or the transportation of wastes longer distances to new landfill disposal sites. However, as the distance from the centers of solid waste generation increases, the cost of direct haul to a site increases. A “distance” is reached (in terms of cost and time) when it becomes less expensive to construct a transfer station or incinerator at or near the center of solid waste generation where wastes from collection vehicles can be transferred to large tractor-trailers for haul to more distant disposal sites. Ideally, the transfer station should be located at the centroid of the collection service area.

Economic Analysis of Transfer Operations

A comparison of direct haul versus the use of a transfer station and haul for various distances is useful in making an economic analysis of potential landfill sites. The transfer station site development, transportation system, and social factors involved in site selection should also be considered in making the comparison.

If the cost of disposal by sanitary landfill is added to the cost comparison, the total relative cost of solid waste transfer, transportation, and disposal by sanitary landfill can be compared to the corresponding cost for incineration, if incineration is an option. The relative cost of incineration with the cost of landfill for various haul distances and a given population is illustrated in Figure 3.10. Based on past experience, a direct-haul distance (one-way) of 25 to 30 miles is about the maximum economical distances although longer distances are common, where other options are unacceptable or cannot be implemented for a variety of reasons, including cost. A similar comparison in which distance is shown in terms of times of travel to the disposal site is presented in Figure 3.11.

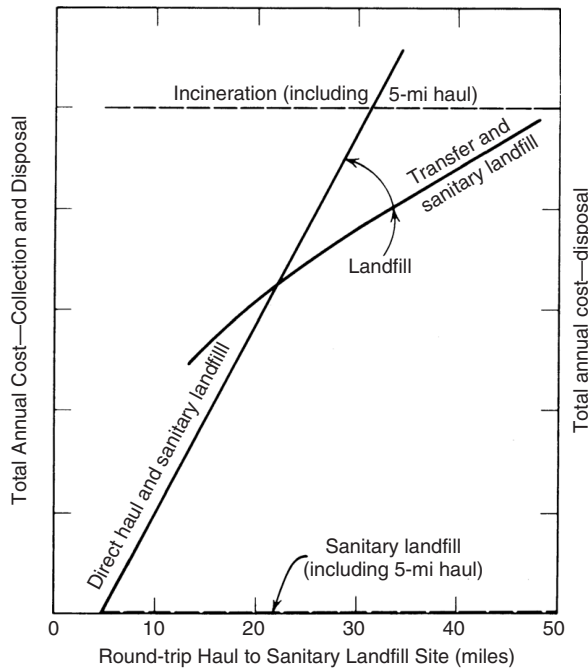


FIGURE 3.10 Effect of haul distances to site on cost of disposal by sanitary landfill compared to cost of disposal by incineration.

Types of Transfer Stations

Transfer stations are used to accomplish transfer of solid wastes from collection and other small vehicles to larger transport equipment. Depending on the method used to load the transport vehicles, transfer stations, as reported in Table 3.11 may be classified into two general types: (1) direct load and (2) storage load (see Figure 3.12). Combined direct-load and discharge-load transfer stations have also been developed transfer stations may also be classified with respect to throughput capacity (the amount of material that can be transferred and hauled) as follows: small, less than 100 tons/day; medium, between 100 and 500 tons/day; and large, more than 500 tons/day.

Direct-Load Transfer Stations At direct-load transfer stations, the wastes in the collection vehicles are emptied directly into the vehicle to be used to transport them to a place of final disposition or into facilities used to compact the wastes into transport vehicles (see Figure 3.13) or into waste bales that are transported to the disposal site. In some cases, the wastes may be emptied onto an unloading platform and then pushed into the transfer vehicles, after recyclable materials have been removed. The volume of waste that can be stored temporarily on the unloading platform is often defined as the *surge capacity* or the *emergency storage*

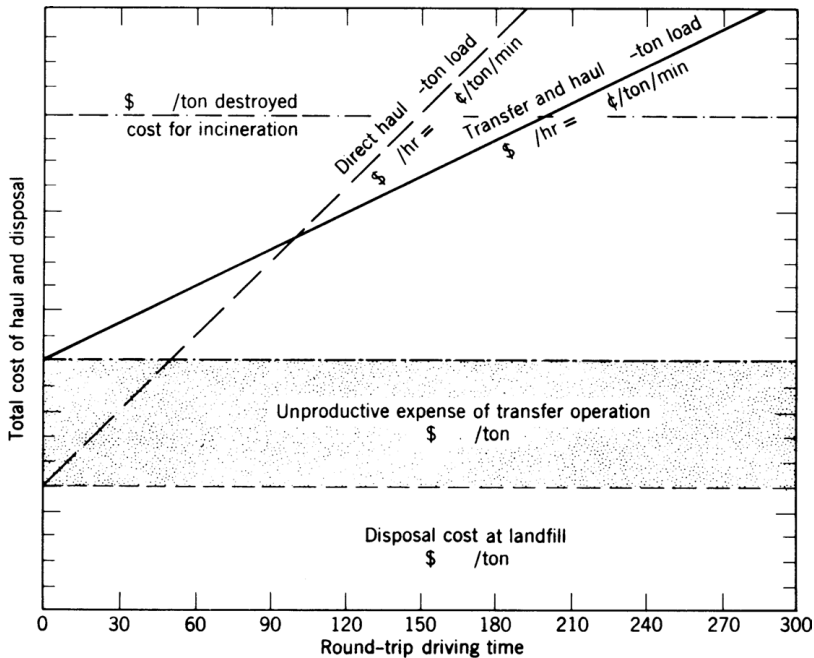


FIGURE 3.11 Cost comparison—incineration versus transfer and haul to landfill.

capacity of the station. Small direct-load transfer stations used to serve industrial parks, rural areas, and entrances to landfills are illustrated in Figure 3.14.

Storage-Load Transfer Station In the storage-load transfer station, wastes are emptied directly into a storage pit from which they are loaded into transport vehicles by various types of auxiliary equipment (see Figure 3.1*b*). The difference between a direct-load and a storage-load transfer station is that the latter is designed with a capacity to store waste (typically one to three days).

Vehicles for Uncompacted Wastes

Motor vehicles, railroads, and ocean-going vessels are the principal means now used to transport solid wastes. Pneumatic and hydraulic systems have also been used. However, in recent years, because of their simplicity and dependability, open-top semitrailers have found wide acceptance for the hauling of uncompacted wastes from direct-load transfer stations (see Figure 3.15*a*). Another combination that has proven to be very effective for uncompacted wastes is the truck-trailer combination (see Figure 3.15*b*). Transport trailers used for hauling solid waste over great distances are all of monoque construction, where the bed of the trailer also serves as the frame of the trailer. Using monoque construction allows greater waste volumes and weights to be hauled.

TABLE 3.11 Types of Transfer Stations Used for Municipal Solid Waste

Type	Description
Direct-Load Transfer Stations	
Large- and medium-capacity direct-load transfer station without compaction	Wastes to be transported to landfill are loaded directly into large open-top transfer trailers for transport to landfill.
Large- and medium-capacity direct-load transfer stations with compactors	Wastes to be transported to landfill are loaded directly into large compactors and compacted into specially designed transport trailers or into bales, which are then transported to landfill.
Small-capacity direct-load transfer stations	Small-capacity transfer stations are used in remote and rural areas. Small-capacity transfer station are also used at landfills as a convenience for residents who wish to haul wastes directly to landfill.
Storage-Load Transfer Station	
Large-capacity storage-load transfer station without compaction	Wastes to be transported to a landfill are discharged into a storage pit where they are pulverized before being loaded into open trailers. Waste is pulverized to reduce the size of the individual waste constituents to achieve more effective utilization of the transfer trailers.
Medium-capacity storage-load transfer station with processing and compaction facilities	Wastes to be transported to a landfill are discharged into a pit where they are further pulverized before being baled for transport to a landfill.
Other Types of Transfer Stations	
Combined discharge-load and direct-load transfer station	Waste to be transported to a landfill can either be discharged on a platform or discharged directly into a transfer trailer. Wastes discharged onto a platform are typically sorted to recover recyclable materials.
Transfer and transport operations at MRFs	Depending on the type of collection service provided, materials recovery and transfer operations are often combined in one facility. Depending on the operation of the MRF, wastes to be landfilled can be discharged directly into open trailers or into a storage pit to be loaded later into open-top trailers or baled for transport to a landfill.

Source: Adapted from G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.

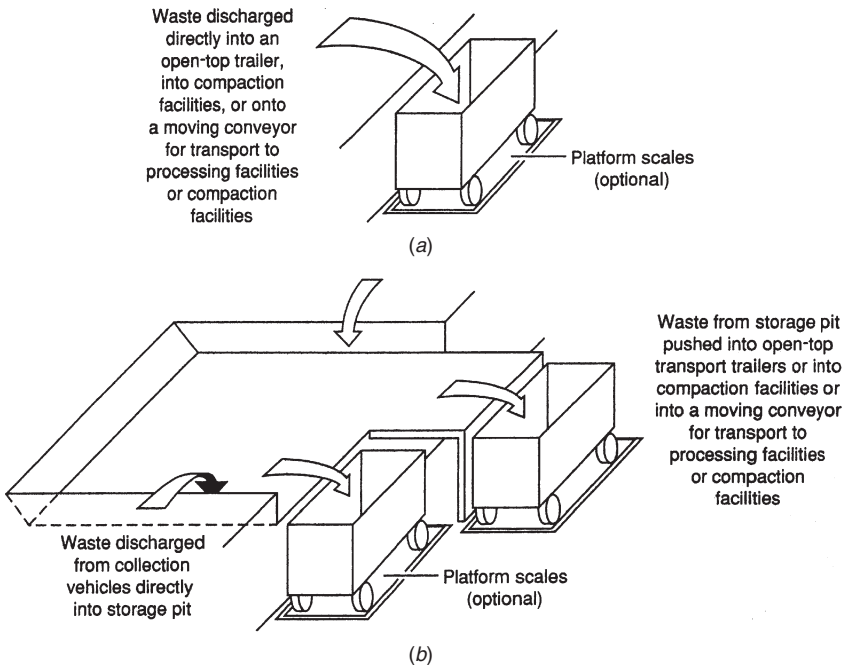


FIGURE 3.12 Definition sketch for two most common types of transfer stations: (a) direct discharge; (b) storage-discharge. (Source: LaGrega, M. D., P. L. Buckingham, and J. C. Evans, *Hazardous Waste Management*, 2nd ed., McGraw-Hill, New York, 2001.)

Transfer Station Siting Issues

A transfer station, resource recovery facility, or processing facility should be located and designed with the same care as described for an incinerator. Drainage of paved areas and adequate water hydrants for maintenance of cleanliness and fire control are equally important. Other concerns are landscaping, weigh scales, and traffic, odor, dust, litter, and noise control. Rail haul and barging to sea also involve the use of transfer stations. They may include one or a combination of grinding, baling, or compaction to increase densities, thereby improving transportation efficiency.

WASTE REDUCTION AND MATERIALS RECOVERY

Proper solid waste management should first prevent and reduce the generation of solid wastes, reduce their hazardous characteristics, and recover and recycle waste to the extent practicable and then dispose of the remaining wastes in a manner that does not endanger public health or the environment. The focus of this section is on waste reduction and the recovery and recycling of materials.

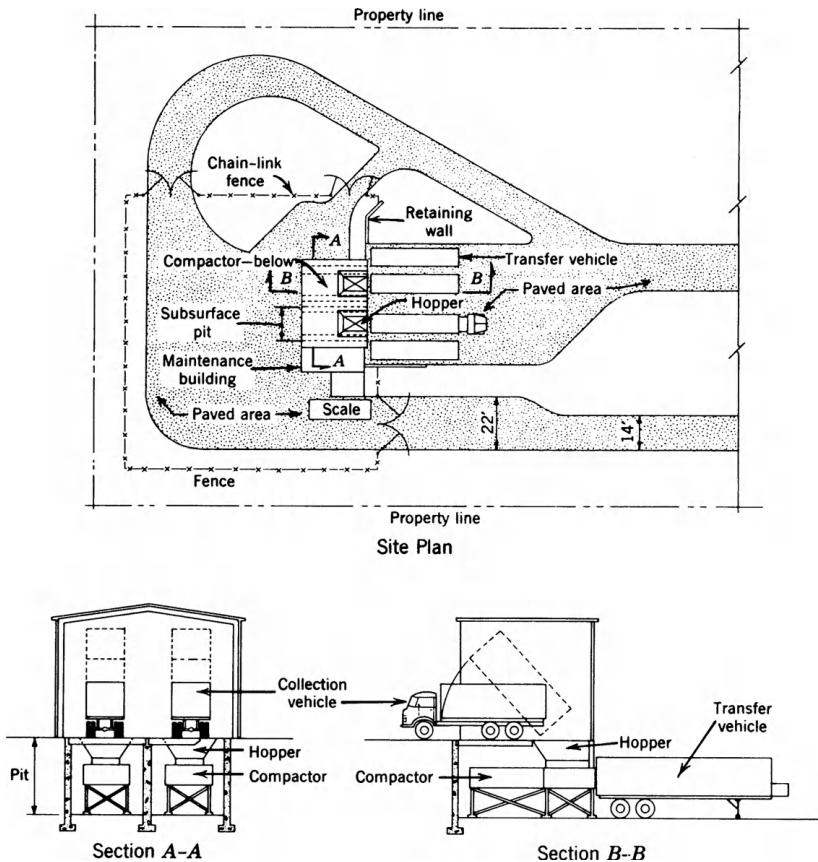


FIGURE 3.13 Direct-discharge transfer station equipped with stationary compactors. (Courtesy of Malcolm Pirnie, Inc. Reproduced with permission.)

Waste Reduction

The extent to which solid wastes can be reduced, recovered, and recycled should be an integral part of every solid waste management system study, whether involving composting, a sanitary landfill, or an incinerator. Composting is also considered a form of recycling. The first step, however, should be waste reduction at the point of generation or product formulation. Industrial material, process, and packaging changes can minimize the waste or substitute a less toxic or objectionable material. The amount of waste can then be reduced, and what waste is produced can be recovered, reused, or recycled to the extent feasible, thereby reducing the amount for final disposal. Additional details on source reduction may be found elsewhere.⁹

There has been considerable interest in a returnable bottle deposit law in some states to reduce highway litter, conserve resources, and reduce the volume



(a)



(b)

FIGURE 3.14 Small direct-discharge transfer stations: (a) convenience type located in rural areas at entrance of landfill disposal sites. (b) individuals unloading waste materials into a convenience type transfer station located at the entrance to a landfill.



(a)



(b)

FIGURE 3.15 Typical examples of transfer trailers used to transport waste over large distances to (a) single large trailer with drop bottom and (b) tractor trailer combination in process of being unloaded at landfill.

of solid wastes for disposal. The bottle law is usually applicable to all types of beverage containers, including glass, metal, and plastic, but not to other types of containers such as food jars, plastic and paper cups, wine and liquor bottles, and the like. The effectiveness of the bottle deposit law has been debated by some considering its limited application, the handling involved, and total cost, tangible and intangible. A substantial number of deposit containers are not returned by the consumer. This results in an unintended income to the supermarket or other retailer and what amounts to an additional cost to the consumer. Other alternatives should be considered. The reduction of *all* types of litter and insults to the landscape, including spillage from uncovered vehicles, elimination of junked cars, debris, and illegal dumps, and education of the public to promote a clean environment such as through Keep America Beautiful, requires greater support. Some returnable bottle laws are being amended to include liquor, wine, and wine cooler bottles and possibly other containers.

Materials Recovery and Recycling

Recovery of materials and energy from solid wastes is not new. Scavengers have salvaged newsprint and cardboard, rags, copper, lead, and iron for years. These materials, together with aluminum, glass, plastics, and wood, are being reclaimed at central collection and processing stations to a greater or lesser extent, depending on the available market, tax policies, and public interest. Energy recovery, where feasible, has been an important consideration in which unsorted solid waste and shredded solid waste, referred to as refuse (solid-waste) derived fuel (RDF), is burned to produce steam or electricity.

Recycling can effect savings in landfill space and in energy. One ton of newspapers can save 3.0 to 3.3 yd³ of landfill space. It is estimated that 95 percent less energy is required to produce aluminum from recycled aluminum than from bauxite. Crushed recycled glass melts at a lower temperature than virgin raw material, thereby conserving energy. Unfortunately, the recycling of glass has essentially ceased because of a glut of material available, the high cost of handling and processing recycled glass, and the cost associated with pollution control.

Resource recovery is not a municipal operation to be entered into just because it seems like the logical or proper thing to do. It is a complex economic and technical system with social and political implications, all of which require competent analysis and evaluation before a commitment is made. Included are the capital and operating costs, market value of reclaimed materials and material quality, potential minimum reliable energy sales, assured quantity of solid wastes, continued need for a sanitary landfill for the disposal of excess and remaining unwanted materials and incinerator residue, and a site location close to the centroid of the generators of solid wastes. Not all concepts are viable. Incentives and monetary support may be required to obtain an acceptable site.

Resource recovery is a partial waste disposal and reclamation process. Materials not recovered may amount to 40 to 55 percent of the original waste by weight, although a resource recovery system can theoretically be used to separate up to 90 percent of the municipal waste stream into possibly marketable

components. It has been estimated that under the best conditions only about 50 to 60 percent of the solid waste will be recovered. In 1979, 7 percent was being recycled for materials or energy. In 1990, the national average was estimated to be 11 percent. In the year 2000, the average was about 26 percent. In 2008, the average is close to 50 percent. As noted previously, the Board of Supervisors of the City of San Francisco has mandated a goal of 75 percent waste diversion by the year 2010. In general, it has been found that the recovery of materials from municipal solid waste is not a paying proposition. Most materials recovery operations are subsidized, in part, by the collection fees or by added monthly charges. In most communities, materials recovery facilities are used to help meet mandated diversion (from landfill disposal) requirements.

Processing Technologies for the Recovery of Materials

In the not-so-distant past, solid-waste processing and disposal methods have included the open dumping, hog feeding, incineration, grinding and discharge to a sewer, milling, compaction, sanitary landfill, dumping and burial at sea (prohibited in the United States), incineration, reduction, composting, pyrolyzation, wet oxidation, and anaerobic digestion. Currently, the most commonly accepted processing technologies involve the recovery of materials at materials recovery facilities and composting. Materials recovery facilities are considered next; composting is considered in the following section.

Implementation of Materials Recovery Facilities

Because the EPA has mandated diversion goals, most communities have developed a variety of materials recovery facilities. The purpose of this section is to define the type of materials recovery facilities now in use, to review the principal unit operations and processes used for the recovery of materials, and to highlight the planning issues associated with the implementation of a materials recovery facility. Additional details on materials recovery facilities may be found in Ref. 10.

Types of Materials Recovery Facilities (MRFs) The separation of household and commercial waste can be done at the source, at the point of collection by collection crews or at centralized *materials recovery facilities* or large integrated *materials recovery/transfer facilities* (MR/TFs). The type of MRF will depend on the type of collection service provided and the degree of source separation the waste has undergone before reaching the MRF. The two general types of MRFs are (1) for source-separated material and (2) for commingled solid waste. The functions of each of these types of MRFs are reviewed in Table 3.12. As reported in Table 3.12, many different types of MRFs have been developed, depending on the specific objective. Further, as reported in Table 3.13, materials recovery facilities can also be classified in terms of size and the degree of mechanization. Small MRFs associated with the further processing of source-separated materials tend to be less highly mechanized.

TABLE 3.12 Typical Examples of Materials and Functions/Operations of MRFs Used for Processing of Source-Separated Recyclable Materials and Commingled Solid Waste

Materials	Function/Operation
MRFs for Source-Separated Recyclable Materials	
Mixed paper and cardboard	Manual separation of high-value paper and cardboard or contaminants from commingled paper types; baling of separated materials for shipping; storage of baled materials Manual separation of cardboard and mixed paper; baling of separated materials for shipping; storage of baled materials Manual separation of old newspaper, old corrugated cardboard, and mixed paper from commingled mixture; baling of separated materials for shipping; storage of baled materials
PETE and HDPE plastics	Manual separation of PETE and HDPE from commingled plastics; baling of separated materials for shipping; storage of baled materials
Mixed plastics	Manual separation of PETE, HDPE, and other plastics from commingled mixed plastics; baling of separated materials for shipping; storage of baled materials
Mixed plastics and glass	Manual separation of PETE, HDPE, and glass by color from commingled mixture; baling of separated materials for shipping; storage of baled materials
Mixed glass With sorting	Manual separation of clear, green, and amber glass; storage of separated materials
Without sorting	Storage of separated mixed glass
Aluminum and tin cans	Magnetic separation of tin cans from commingled mixture of aluminum and tin cans; baling of separated materials for shipping; storage of baled materials
Plastic, aluminum cans, tin cans, and glass	Manual or pneumatic separation of polyethylene terephthalate (PETE), high-density polyethylene (HDPE), and other plastics; manual separation of glass by color, if separated; magnetic separation of tin cans from commingled mixture of aluminum and tin cans; magnetic separation may occur before or after the separation of plastic; baling of plastic (typically two types), aluminum cans and tin cans, and crushing of glass and shipping; storage of baled and crushed materials
Yard wastes	Manual separation of plastic bags and other contaminants from commingled yard wastes, grinding of clean yard waste, size separation of waste that has been ground up, storage of oversized waste for shipment to biomass facility, and composting of undersized material Manual separation of plastic bags and other contaminants from commingled yard wastes followed by grinding and size separation to produce landscape mulch; storage of mulch and composting of undersized materials Grinding of yard waste to produce biomass fuel; storage of ground material

(continues)

TABLE 3.12 (continued)

Materials	Function/Operation
MRFs for Commingled Solid Waste	
Recovery of recyclable materials to meet mandated first-stage diversion goals	Bulky items, cardboard, paper, plastics (PETE, HDPE, and other mixed plastic), glass (clear and mixed), aluminum cans, tin cans, other ferrous materials
Recovery of recyclable materials and further processing of source-separated materials to meet second-stage diversion goals	Bulky items, cardboard, paper, plastics (PETE, HDPE, and other mixed plastic), glass (clear and mixed), aluminum cans, tin cans, other ferrous materials; additional separation of source-separated materials, including paper, cardboard, plastic (PETE, HDPE, other), glass (clear and mixed), aluminum cans, tin cans
Preparation of MSW for use as fuel for combustion	Bulky items, cardboard (depending on market value), glass (clear and mixed), aluminum cans, tin cans, other ferrous materials
Preparation of MSW for use as feedstock for composting	Bulky items, cardboard (depending on market value), plastics (PETE, HDPE, and other mixed plastic), glass (clear and mixed), aluminum cans, tin cans, other ferrous materials
Selective recovery of recyclable materials	Bulky items, office paper, old telephone books, aluminum cans, PETE and HDPE, and ferrous materials; other materials, depending on local markets

Source: Adapted from H. Leverenz, G. Tchobanoglous, and D. B. Spencer, “Recycling,” in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.

Methods and Equipment for the Separation and Recovery of Materials

Methods and processes used singly and in various combinations to recover and prepare wastes for reuse and/or disposal are summarized in Table 3.14. Of the methods reported in Table 3.14, manual sorting is by far the most commonly used method for processing waste materials (see Figure 3.16). It is interesting to note that no machine has been developed to date that can match the eye–hand coordination of humans. The particulate grouping of unit processes and operations will depend on the characteristics of the material to be separated.

MRF Process Flow Diagrams Once a decision has been made on how and what recyclable materials are to be recovered, MRF process flow diagrams must

TABLE 3.13 Typical Types of Materials Recovery Facilities, Capacity Ranges, and Major Functions and System Components Based on Degree of Mechanization

System Type	Capacity (tons/day)	Major System Components
Materials recovery Low	5–20	Processing of source-separated materials only; enclosed building, concrete floors, elevated hand-sorting conveyor, baler (optional), storage for separated and prepared materials for one month, support facilities for workers
Intermediate	20–100	Processing of source-separated commingled materials and mixed paper; enclosed building, concrete floors, elevated hand-sorting conveyor, conveyors, baler, storage for separated and baled materials for two weeks, support facilities for workers, buy-back center
High	>100	Processing of commingled materials or MSW; same facilities as intermediate system plus mechanical bag breakers, magnets, shredders, screens, and storage for baled materials for up to two months
Composting Low end system	5–20	Source-separated yard waste feedstock only; grinding equipment, cleared level ground with equipment to form and turn windrows, screening equipment (optional)
High-end system	>20	Feedstock derived from source-separated yard waste or processing of commingled wastes; facilities include enclosed building with concrete floors, in vessel composting reactors; enclosed building for curing of compost product; equipment for processing (e.g. screening and bagging); and marketing compost product

Source: H. Leverenz, G. Tchobanoglous, and D. B. Spencer, "Recycling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.

be developed. In developing MRF process flow diagrams, the following factors must be considered: (1) identification of the characteristics of the waste materials to be processed, (2) consideration of the specifications for recovered materials now and in the future, and (3) the available types of equipment and facilities. For example, specific waste materials cannot be separated effectively from commingled MSW unless bulky items such as lumber and white goods and large pieces of cardboard are first removed and the plastic bags in which waste materials are placed are broken open and the contents exposed. The specifications for the recovered material will affect the degree of separation to which the waste

TABLE 3.14 Typical Methods and Equipment Used for Processing and Recovery of Individual Waste Components from MSW

Processing Options	Description
Manual sorting	Unit operation in which personnel physically remove items from the waste stream. Typical examples include (1) removal of bulky items that would interfere with other processes and (2) sorting material off an elevated conveyor into large bins located below the conveyor.
Size reduction	Unit operation used for the reduction of both commingled MSW and recovered materials. Typical applications include (1) hammermills for shredding commingled MSW, (2) shear shredders for use with commingled MSW and recycled materials such as aluminum, tires, and plastics, and (3) tub grinders used to process yard wastes.
Size separation	Unit operation in which materials are separated by size and shape characteristics, most commonly by the use of screens. Several types of screens are in common use, including (1) reciprocating screens for sizing shredded yard wastes, (2) trommel screens used for preparing commingled MSW prior to shredding, and (3) disc screens used for removing glass from shredded MSW.
Magnetic field separation	Unit operations in which ferrous (magnetic) materials are separated from nonmagnetic materials. A typical application is the separation of ferrous from nonferrous materials (e.g., tin from aluminum cans).
Densification (compaction)	Densification and compaction are unit operations used to increase the density of recovered materials to reduce transportation costs and simplify storage. Typical applications include (1) the use of baling for cardboard, paper, plastics, and aluminum cans and (2) the use of cubing and pelletizing for the production of densified RDF.
Materials handling	Unit operations used for the transport and storage of MSW and recovered materials. Typical applications include (1) conveyors for the transport of MSW and recovered materials, (2) storage bins for recovered materials, and (3) rolling stock such as fork lifts, front-end loaders, and various types of trucks for the movement of MSW and recovered materials.
Automated sorting	Unit operation in which materials are separated by material characteristics. Typical examples include (1) optical sorting of glass by color, (2) X-ray detection of polyvinyl chloride (PVC), and (3) infrared sorting of mixed resins.

Source: G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.



(a)



(b)

FIGURE 3.16 Typical manual separation of waste components at a materials recovery facility: (a) separating cardboard, paper, plastic, film plastic, glass, tin cans, and aluminum cans from mixed municipal solid waste at a facility with a current capacity of 400 tons/day with room to expand to 1200 ton/day by adding two more sorting lines and (b) separating contaminants from source separated compostable wastes before preprocessing (size reduction) and placement in piles in long rows (windrows) for composting. (See Figure 3.20(b).) (Courtesy H. Leverenz.)

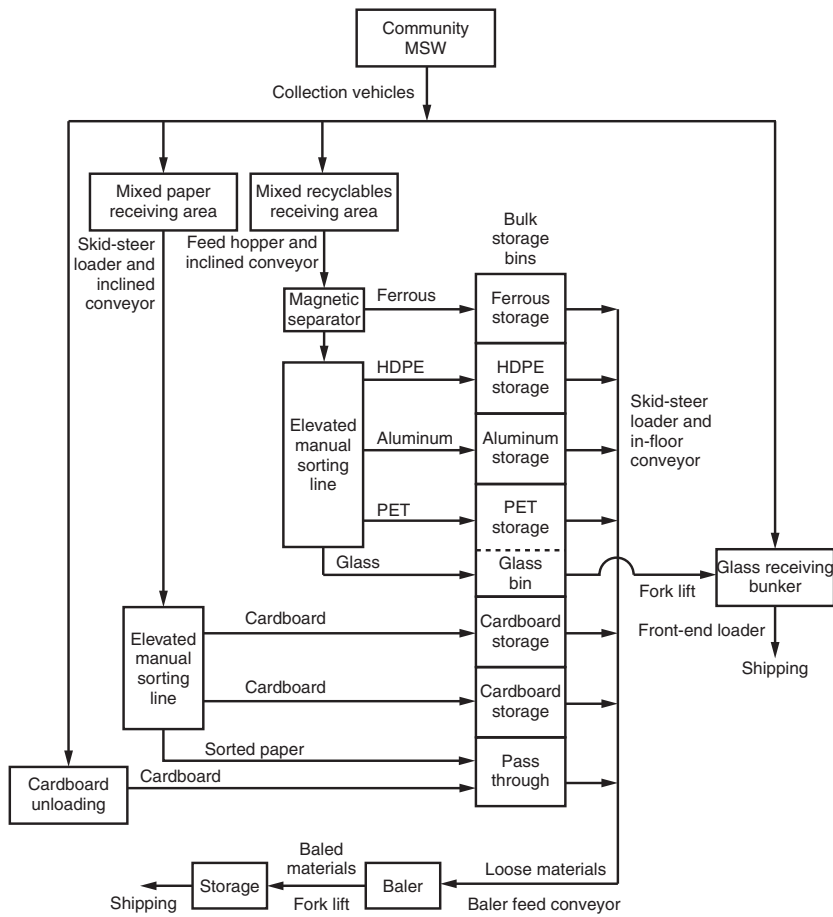


FIGURE 3.17 Process flow diagram for MRF used to further process source-separated waste. (Source: H. Leverenz, G. Tchobanoglous, and D. B. Spencer, “Recycling,” in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.)

material is subjected. Three typical MRF process flow diagrams are presented in Figures 3.17, 3.18, and 3.19 for source-separated recyclable material, for mixed paper and cardboard, and commingled solid waste, respectively.¹¹

Technical Considerations in the Planning and Design of MRFs

Technical consideration in the planning and design of MRFs involves three basic steps: (1) feasibility analysis, (2) preliminary design, and (3) final design. These planning and design steps are common to all major public works projects such as landfills or wastewater treatment plants. In some cases, the feasibility analysis has

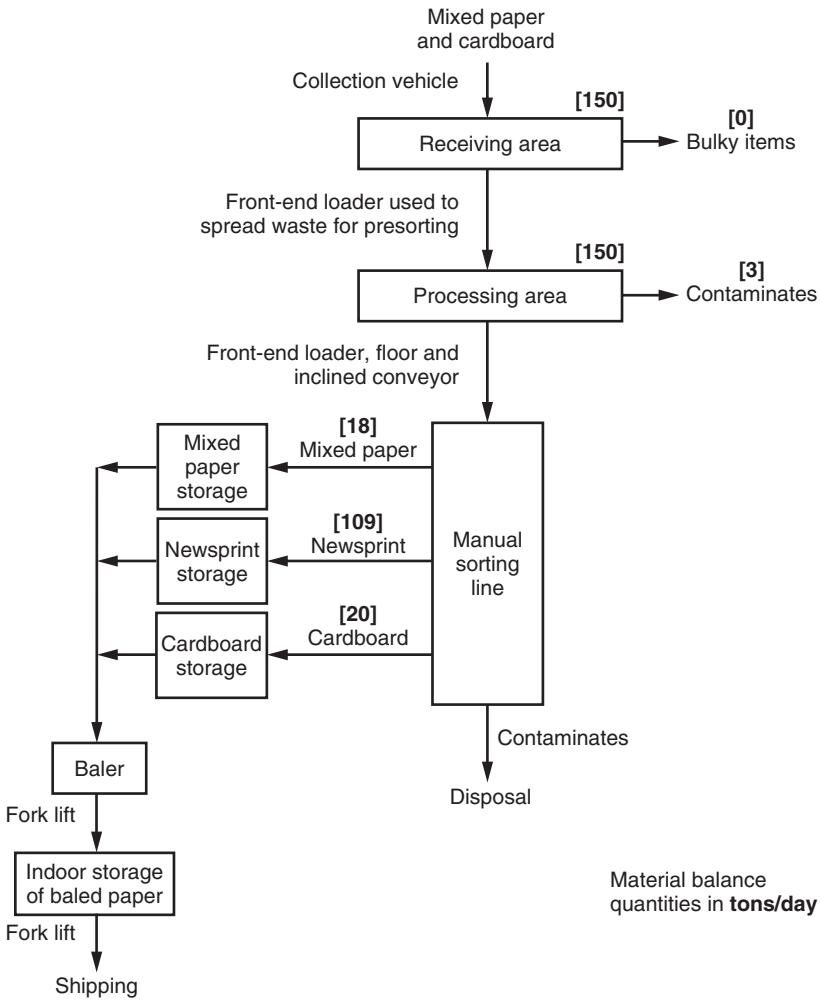


FIGURE 3.18 Process flow diagram for MRF used to separate mixed paper and cardboard. (Source: H. Leverenz, G. Tchobanoglous, and D. B. Spencer, “Recycling,” in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.)

already been accomplished as part of the integrated waste management planning process. These topics are considered further in Table 3.15.¹¹

COMPOSTING

Composting is the controlled decay of organic matter in a warm, moist environment by the action of bacteria, fungi, and other organisms. The organic matter

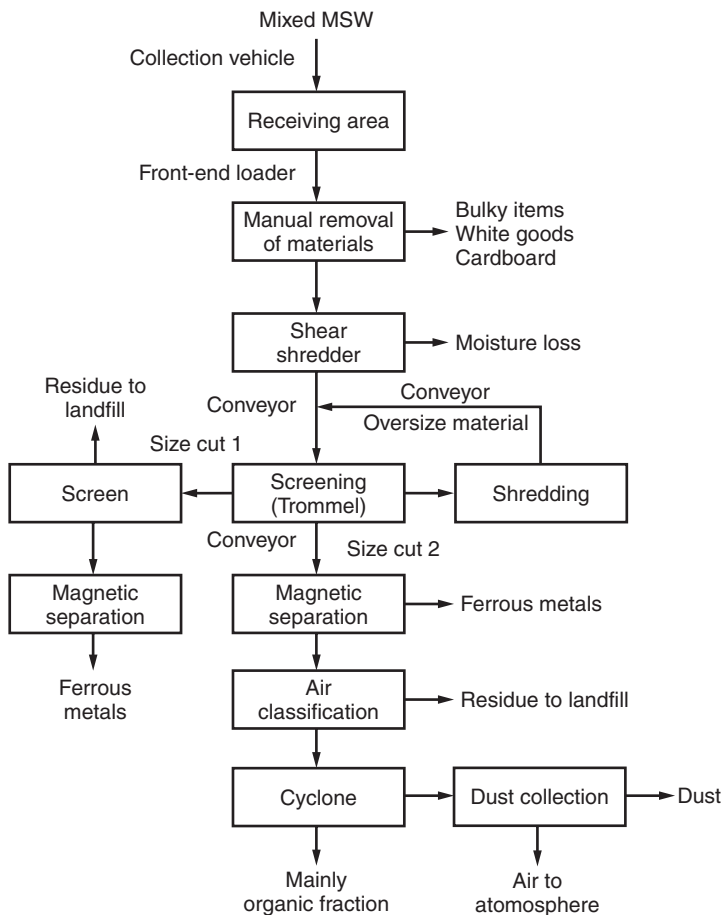


FIGURE 3.19 Process flow diagram for MRF used to process commingled waste for recovery of recyclable materials. (Source: H. Leverenz, G. Tchobanoglous, and D. B. Spencer, "Recycling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.)

may be in municipal solid waste, wastewater sludge, septage, agricultural waste, manure, leaves and other yard waste, or combinations of these materials and other organic wastes. Composting is becoming an increasingly popular waste management option as communities look for ways to divert portions of the local waste stream from landfills. The principal applications of composting are for (1) yard wastes, (2) the organic fraction of MSW, (3) partially processed commingled MSW, and (4) co-composting the organic fraction of MSW with wastewater sludge. Because of the importance of composting in meeting mandated waste diversion goals, the number of composting facilities has increased significantly over the past 10 years. The uses of compost and constraints to its uses; a

TABLE 3.15 Important Technical Considerations in the Planning and Design of MRFs**Step 1: Feasibility Analysis**

Function of MRF	The coordination of the MRF with the integrated waste management plan for the community. A clear explanation of the role and function of the MRF in achieving landfill waste diversion, and recycling goals is a key element.
Conceptual design, including types of wastes to be sorted	What type of MRF should be built, which materials will be processed now and in the future, and what should be the design capacity of the MRF? Plan views and renderings of what the final MRF might look like are often prepared.
Siting	While it has been possible to build and operate MRFs in close proximity to both residential and industrial developments, extreme care must be taken in their operation if they are to be environmentally and aesthetically acceptable. Ideally, to minimize the impact of the operation of MRFs, they should be sited in more remote locations where adequate buffer zones surrounding the facility can be maintained. In many communities, MRFs are located at the landfill site.
Economic analysis	Preliminary capital and operating costs are delineated. Estimates of revenues available to finance the MRF (sales of recyclables, avoided tipping fees, subsidies) are evaluated. A sensitivity analysis must be performed to assess the effects of fluctuating prices for recyclables and the impacts of changes in the composition of the waste.
Ownership and operation	Typical ownership and operation options include public ownership, private ownership, or public ownership with contract operation.
Procurement	What approach is to be used in the design and construction of the MRF? Several options exist, including (1) the traditional architect-engineer and contractor process, (2) the turn-key contracting process in which design and construction are performed by a single firm, and (3) a full-service contract in which a single contractor designs, builds, and operates the MRF

(continues)

TABLE 3.15 *(continued)***Step 2: Preliminary Design**

Process flow diagrams	One or more process flow diagrams are developed to define how recyclable materials are to be recovered from MSW (e.g., source separation or separation from commingled MSW). Important factors that must be considered in the development of process flow diagrams include (1) characteristics of the waste materials to be processed, (2) specifications for recovered materials now and in the future, and (3) the available types of equipment and facilities.
Materials recovery rates	Prediction of the materials flow to the MRF is necessary to estimate the effectiveness or performance of the recycling program. The performance of a recycling program, the overall component recovery rate, is generally reported as a materials recovery rate or recycling rate, which is the product of three factors: (1) participation factor, (2) composition factor, and (3) source recovery factor. Component capture rates for the recyclable materials most commonly collected in source separation recycling programs must be estimated. Composition factors are measured in waste composition studies. ^a
Materials balances and loading rates	One of the most critical elements in the design and selection of equipment for MRFs is the preparation of a materials balance analysis to determine the quantities of materials that can be recovered and the appropriate loading rates for the unit operations and processes used in the MRF.
Selection of processing equipment	Factors that should be considered in evaluating processing equipment include: capabilities, reliability, service requirements, efficiency, safety of operation, health hazard, environment impact, and economics.
Facility layout and design	The overall MRF layout includes (1) sizing of the unloading areas for commingled MSW and source-separated materials; (2) sizing of presorting areas where oversize or undesirable materials are removed; (3) placement of conveyor lines, screens, magnets, shredders, and other unit operations; (4) sizing of storage and out-loading areas for recovered materials; and (5) sizing and design of parking areas and traffic flow patterns in and out of the MRF. Many of these layout steps are also common to the layout and design of transfer stations.

(continues)

TABLE 3.15 (continued)

Staffing	Depends on type of MRF (i.e., degree of mechanization).
Economic analysis	Refine preliminary cost estimate prepared in feasibility study.
Environmental issues	Important environmental issues include groundwater contamination, dust emissions, noise, vector impacts, odor emissions, vehicular emissions, and other environmental emissions.
Health and safety issues	Important health and safety issues are related to worker and public access issues.
Step 3: Final Design	
Preparation of final plans and specifications	Plans and specifications will be used for bid estimates and construction.
Preparation of environmental documents	The necessary environmental documents (e.g., Environmental Impact Report) are prepared.
Preparation of detailed cost estimate	A detailed engineer's cost estimate is made based on materials take-offs and vendor quotes. The cost estimate will be used for the evaluation of contractor bids if the traditional procurement process is used.
Preparation of procurement documents	A bidding process is used to obtain supplies, equipment, and services related to the construction, operation, and maintenance of the facility.

^aTypical component recovery rates may be found in Leverenz et al. (2002).

Source: H. Leverenz, G. Tchobanoglous, and D. B. Spencer, "Recycling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.

description of the compost process; descriptions of some of the more common composting processes, important design and operational considerations, and the implementation of the compost process are considered in the following discussion. Additional details on the compost process can be found in Refs. 12–15.

Uses of Compost and Constraints to Its Use

Compost improves soil moisture retention; it is a good soil conditioner but a poor fertilizer. Compost, depending on the waste source and its composition, may be used as a soil amendment for agricultural soil and landscaping in municipal parks, golf courses, gardens, and green belts; sod growing; home gardens; and nursery and greenhouse use. Compost may also be used as landfill cover, land reclamation, animal litter, and possibly animal feed. It may also be used as an additive to fertilizer, as a fuel, or in building materials.

The presence of toxic levels of pesticides, heavy metals, and pathogens should be determined and evaluated to ensure the levels are compatible with the intended

TABLE 3.16 Maximum Allowable Metal Concentrations for Class I and II Compost and Allowable Usage

Parameter	Concentration (ppm dry weight)	
	Class I ^a	Class II ^b
Mercury	10	10
Cadmium	10	25
Nickel	200	200
Lead	250	1000
Chromium, total	1000	1000
Copper	1000	1000
Zinc	1000	2500
Polychlorinated biphenyls (PCBs) total	1	10

^aMust not be used on crops grown for direct human consumption (i.e., crops consumed without processing to minimize pathogens). Can be used on food chain crops and other agricultural and horticultural uses. Must not exceed 10 mm (0.39 in.) particle size.

^bMust be restricted to use on nonfood chain crops. Must not exceed 25 mm (0.98 in.) particle size.

Source: New York State, *Municipal Energy Recovery Facilities Handbook*, New York State Environmental Facilities Corporation, Albany, 1988.

use of the compost. A typical listing of permissible metal concentrations in compost is presented in Table 3.16. For pathogen reduction purposes, the temperature of the mixture must be maintained at or above 131 °F (55 °C) for at least three consecutive days.

The total composting time, including curing, is determined by the material, process used, and exposure to the elements. Two weeks to as much as 18 months may be required for complete stabilization and curing of the compost. Thus, a plant location distant from habitation is recommended, as odors may become a problem. Also, because the demand for compost may be seasonal, provision must be made for compost storage.

Composting Process

Composting involves the biological decomposition of organic materials (substrates) under controlled conditions that allow for the development of an end product that is biologically stable and free of viable pathogens and plant seeds and can be applied to land beneficially. The key concepts and objectives contained in the definition of compost are as follows:

- Composting is a biological process (e.g., aerobic anaerobic).
- Composting results in the production of a biologically stable end product.
- The end products free of viable pathogens.
- The end product is free of viable plant seeds.
- The end product can be applied to land beneficially.



(a)



(b)

FIGURE 3.20 Overview of windrow composting operation: (a) preparation (size reduction) of yard waste for composting and (b) processed waste placed in windrows to undergo the composting process (see also Figure 3.21).

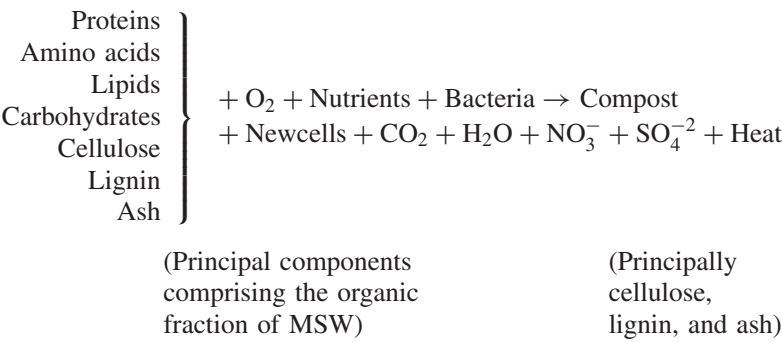
To meet the above objectives, the composting process, as illustrated in Figure 3.20, usually involves the following three basic steps:

1. Preprocessing (e.g., size reduction, seeding, nutrient addition, and addition of bulking agent)
2. Decomposition and stabilization of organic material (two-stage process comprised of a first-stage high-rate phase followed by second-stage curing phase)

3. Postprocessing (e.g., grinding, screening, bagging, and marketing of compost product)

Composting of mixed solid waste should be preceded by a separation and recycling program, including glass, plastic, and metal separation; then usually shredding or grinding; and a program for the periodic collection of household hazardous waste. Industrial and other hazardous waste must be excluded.

The two-stage decomposition and stabilization of organic solid waste to a compost process can be described by the following reaction:



As shown by this reaction, essentially all of the organic matter with the exception of cellulose and lignin are converted during the compost process. It should be noted that, in time, both the cellulose and lignin will undergo further biological decomposition, primarily through the action of fungi and actinomycetes.

Postprocessing will typically include screening and nutrient and other amendment additions, depending on the application. Many municipalities make the compost available to the residents for a nominal price.

Composting Technologies

The three composting methods used most commonly in the United States are (1) windrow, (2) aerated static pile, and (3) in-vessel methods. It should be noted that over the past 100 years more than 50 individual compost processes have been developed. The more important of these processes based on function and/or the type of reactor used for the process are summarized in Table 3.17. Some of the processes are described next.

Although many process variations are in use, odor control is a major concern in all processes. Aeration and controlled enclosed processing facilities can be used to minimize the problem. Provision must also be made for vector control, leachate collection, and the prevention of groundwater and surfacewater pollution. The stabilized and cured compost may be ground but is usually screened before sale. Storage space is required.

TABLE 3.17 Municipal Composting Systems Grouped by Function or Reactor Configuration

Function or Configuration	Commercial Process
Heaps and windrows, natural aeration, batch operation	Indore/Bangalore Artsiely Baden-Baden (hazemag) Buhler Disposals Associates Dorr-Oliver Spohn Tollemache Vuilafoer Maatschappij (VAM)
Cells with natural or forced aeration, batch operation	Beccari Biotank (Degremont) Boggiano-Pico Kirkconnel (Dumfriesshire) Metro-Waste Prat (Sofranie) Spohn Verdier Westinghouse/Naturizer
Horizontal rotating and inclined drums, continuous operation	Dano Biostabilizer Dun Fix Fermascreen (batch) Head Wrightson Vickers Seerdrum
Vertical flow reactors, continuous operation, agitated bed, natural or forced aeration	Earp-Thomas Fairfield-Hardy Frazer-Eweson Jersey (John Thompson) Multibacto Nusoil Snell Triga
Agitated bed	Fairfield-Hardy

Source: G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002.

Windrow Composting In the windrow process, after processing the material to be composted is placed in long windrows (see Figure 3.20). The windrows are 3 to 6 feet high (1–2 m) and 6 to 15 feet wide (2–5 m) at the base. The windrow process is conducted normally in uncovered pads and relies on natural ventilation

with frequent mechanical mixing of the piles to maintain aerobic conditions. The windrow process can be accelerated if the compost is turned over every four or five days, until the temperature drops from about 150° or 140°F (66° or 60°C) to about 100°F (38°C) or less. Under typical operating conditions, the windrows are turned every other day. The turning is accomplished with specialized equipment (see Figure 3.21) and serves to aerate the pile and allow moisture to escape. To meet the EPA pathogen reduction requirements, the windrows have to be turned five times in 15 days, maintaining a temperature of 55°C. The complete compost process may require two to six months.

Because anaerobic conditions can develop within the windrow between turnings, putrescible compounds can be formed that can cause offensive odors, especially when the windrows are turned. In many locations, negative aeration is provided to limit the formation of odorous compounds. Where air is provided mechanically, the process is known as aerated windrow composting.¹² Odors will result if the compost is not kept aerobic. It may be necessary to enclose the operation and provide fans and collectors of the odorous air, forcing it through a scrubber or other treatment device for discharge up a stack to the atmosphere.

Aerated Static Pile Composting In the aerated static pile process, the material to be composted is placed in a pile and oxygen is provided by mechanical aeration systems. Most states require paved surfaces for the pile construction areas to permit capture and control runoff and allow operation during wet weather. The most common aeration system involves the use of a grid of subsurface piping (see Figure 3.22). Aeration piping often consists of flexible plastic drainage tubing assembled on the composting pad. Because the drainage-type aeration piping



FIGURE 3.21 View of machine used to aerate compost placed in windrows (Courtesy H. Leverenz.)

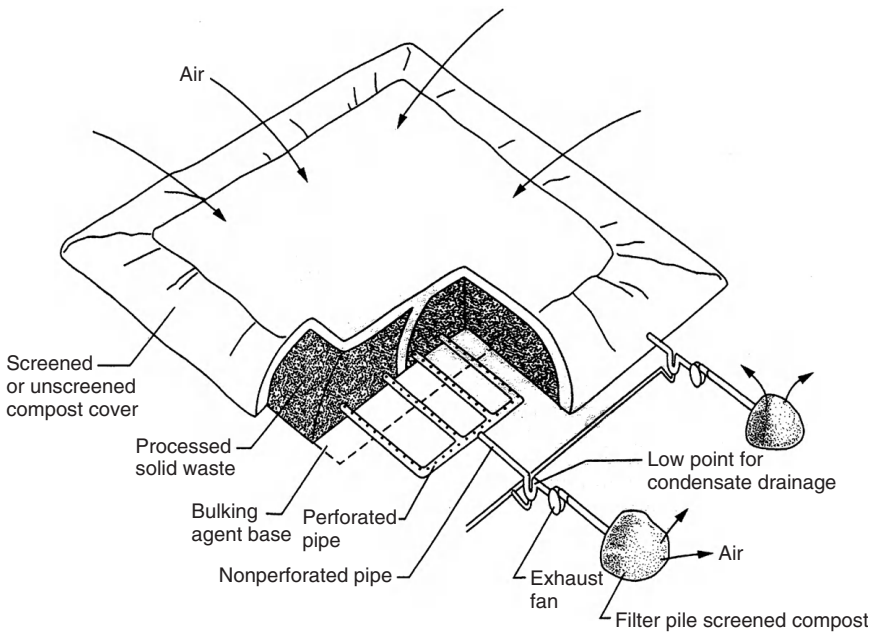


FIGURE 3.22 Schematic of static aerated compost pile.

is inexpensive, it is often used only once. Before constructing the static pile, a layer of wood chips is placed over the aeration pipes or grid to provide uniform air distribution. The static pile is then built up to 8 to 12 feet (2.6–3.9 m) using a front-end loader. A cover layer of screened or unscreened compost is placed over the sludge to be composted. Typically, oxygen is provided by pulling air through the pile with an exhaust fan. Air that has passed through the compost pile is vented to the atmosphere through a compost filter for odor control.

In-Vessel Composting Systems In-vessel composting is accomplished inside an enclosed container or vessel. Every imaginable type of vessel has been used as a reactor in these systems, including vertical towers, horizontal rectangular and circular tanks, and circular rotating tanks. In-vessel composting systems can be divided into two major categories: plug flow and dynamic (agitated bed). In plug flow systems, the relationship between particles in the composting mass stays the same throughout the process, and the system operates on the basis of a first-in, first-out principle. In a dynamic system, the composting material is mixed mechanically during the processing.

Mechanical systems are designed to minimize odors and process time by controlling environmental conditions such as air flow, temperature, and oxygen concentration. The popularity of in-vessel composting systems has increased in recent years. Reasons cited for this increased use are process and odor control, faster throughput, lower labor costs, and smaller area requirements. The detention

time for in-vessel systems varies from 1 to 2 weeks, but virtually all systems employ a 4- to 12-week curing period after the active composting period.

Other Composting Technologies *Naturizer* composting uses sorting, grinding and mixing, primary and secondary composting including three grinding operations, aeration, and screening. Digested wastewater sludge, raw-wastewater sludge, water, or segregated wet garbage is added at the first grinding for dust and moisture control. The total operation takes place in one building in about six days.

The *Dano* composting (stabilizer) plant consists of sorting, crushing, biostabilization three to five days in a revolving drum to which air and moisture are added, grinding, air separation of nonorganics, and final composting in open windrows. Temperatures of 140°F (60°C) are reached in the drum. Composting can be completed in 14 days by turning the windrows after the fourth, eighth, and twelfth days. Longer periods are required if the windrows are not kept small, turned, and mixed frequently and if grinding is not thorough. In a more recent version, the drum treatment is for 8 hours followed by screening, final composting in covered aerated piles for about three weeks, and then three weeks of aging in static piles.

The *Fairfield-Hardy* process handles garbage and trash and wastewater sludge. The steps in the process are (1) sorting—manual and mechanical to separate salvageable materials; (2) coarse shredding; (3) pulping; (4) wastewater sludge addition, if desired; (5) dewatering to about 50 percent moisture; (6) three-to five-day digestion with mixing and forced air aeration, temperature ranges from 140° to 170°F (60°–76°C); (7) air curing in covered windrows; and (8) pelletizing, drying, and bagging. Compost from the digester is reported to have heat values of 4,000 Btu/lb and, when pelletized and dried, 6,450 Btu/lb.

The *Bangalore* process is used primarily in India. Layers of unshredded solid waste and night soil are placed in a shallow trench; the top is covered with soil. The duration of the treatment is 120 to 150 days.

Compost Process Design and Operational Considerations

The principal design considerations associated with the aerobic biological decomposition of prepared solid wastes are presented in Table 3.18. It can be concluded from this table that the preparation of a composting process is not a simple task, especially if optimum results are to be achieved. For this reason, most of the commercial composting operations that have been developed are highly mechanized and are carried out in specially designed facilities. Because of their importance, pathogen and odor control are considered further below. Additional details on the design and operation of compost processes may be found in Refs. 13 and 16.

Pathogen Control Pathogenic organisms and weed seeds exposed to the higher temperatures for the times indicated in Table 3.19 will be destroyed. However, because of the nature of solid waste, the processes used, and the

TABLE 3.18 Important Design Considerations for Aerobic Composting Process

Item	Comment
Particle size	For optimum results, the size of solid wastes should be between 25 and 75 mm (1 and 3 in).
Carbon to nitrogen (C/N) ratio	Initial C/N ratios (by mass) between 25 and 50 are optimum for aerobic composting. At lower ratios ammonia is given off. Biological activity is also impeded at lower ratios. At higher ratios, nitrogen may be a limiting nutrient.
Blending and seeding	Composting time can be reduced by seeding with partially decomposed solid wastes to the extent of about 1–5% by weight. Wastewater sludge can also be added to prepared solid wastes. Where sludge is added, the final moisture content is the controlling variable.
Moisture content	Moisture content should be in the range between 50 and 60% during the composting process. The optimum value appears to be about 55%.
Mixing/turning	To prevent drying, caking, and air channeling, material in the process of being composted should be mixed or turned on a regular schedule or as required. Frequency of mixing or turning will depend on the type of composting operation.
Temperature	For best results, temperature should be maintained between 122° and 131°F (50° and 55°C) for the first few days and between 131° and 140°F (55° and 60°C) for the remainder of the active composting period. If temperature goes beyond 151°F (66°C), biological activity is reduced significantly.
Control of pathogen	If properly conducted, it is possible to kill all the pathogens, weeds, and seeds during the composting process. To do this, the temperature must be maintained between 140° and 158°F (60° and 70°C) for 24 hours.
Air requirements	The theoretical quantity of oxygen required can be estimated using the stiochiometric equation for the conversion of organic matter. Air with at least 50% of the initial oxygen concentration remaining should reach all parts of the composting material for optimum results, especially in mechanical systems.
pH control	To achieve an optimum aerobic decomposition, pH should remain at 7–7.5 range. To minimize the loss of nitrogen in the form of ammonia gas, pH should not rise above about 8.5.
Degree of decomposition	The degree of decomposition can be estimated by measuring the reduction in the organic matter present using the chemical oxygen demand (COD) test. Another measurement that has been used to determine the degree of decomposition is the use of respiratory quotient (RQ)
Land requirement	The land requirements for a plant with a capacity of 50 tons/day will be 1.5–2.0 acres. The land area required for larger plant will be less.

Note: $1.8 \times ^\circ\text{C} + 32 = ^\circ\text{F}$.

Source: G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002; and U.S. EPA, *Composting of Municipal Solid Wastes in the United States*, EPA, Washington, DC, 1971.

TABLE 3.19 Temperature and Time of Exposure Required for Destruction of Some Common Pathogens and Parasites

Organism	Observations
<i>Salmonella typhosa</i>	No growth beyond 46 °C; death within 30 min. at 55–60 °C and within 20 min. at 60 °C; destroyed in a short time in compost environment.
<i>Salmonella</i> sp.	Death within 1 hr at 55 °C and within 15–20 min. at 60 °C.
<i>Shigella</i> sp.	Death within 1 hr at 55 °C.
<i>Escherichia coli</i>	Most die within 1 hr at 55 °C and within 15–20 min. at 60 °C.
<i>Entamoeba histolytica</i> cysts	Death within a few min. at 45 °C and within a few sec at 55 °C.
<i>Taenia saginata</i>	Death within a few min. at 55 °C.
<i>Trichinella spiralis</i> larvae	Quickly killed at 55 °C; instantly killed at 60 °C.
<i>Brucella abortus</i> or <i>Br. suis</i>	Death within 3 min. at 62–63 °C and within 1 hr at 55 °C.
<i>Micrococcus pyogenes</i> var. <i>aureus</i>	Death within 10 min. at 50 °C.
<i>Streptococcus pyogenes</i>	Death within 10 min. at 54 °C.
<i>Mycobacterium tuberculosis</i> var. <i>hominis</i>	Death within 15–20 minutes at 66 °C or after momentary heating at 67 °C.
<i>Corynebacterium diphtheria</i>	Death within 45 min. at 55 °C.
<i>Necator americanus</i>	Death within 50 min. at 45 °C.
<i>Ascaris lumbricoides</i> eggs	Death in less than 1 hr at temperatures over 50 °C.

Note: $1.8 \times (^\circ\text{C}) + 32 = ^\circ\text{F}$.

Source: G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.

range in temperature within compost clumps or zones and between the outside and inside of a mass of compost, the required lethal temperatures cannot be ensured. The EPA requires 131 °F (55 °C) for three days to obtain pathogen destruction before compost land spreading, but this temperature does not kill all pathogens. The World Health Organization (WHO) recommends that the compost attain a temperature of at least 140 °F (60 °C). It has been found that salmonella repopulation is possible in a soil amendment from composted sludge. Microbial activity is greatest when mean municipal compost temperature is 114° to 140 °F (40°–60 °C), using aeration to control the temperature to achieve the highest composting rates. Temperatures above 140 °F (60 °C) tend to slow down the process as many organisms die off at and above this temperature.

Control of Odor The majority of the odor problems in aerobic composting processes are associated with the development of anaerobic conditions within the compost pile. In many large-scale aerobic composting systems, it is common to find pieces of magazines or books, plastics (especially plastic films), or similar

materials in the organic material being composted. These materials normally cannot be decomposed in a relatively short time in a compost pile. Furthermore, because sufficient oxygen is often not available in the center of such materials, anaerobic conditions can develop. Under anaerobic conditions, organic acids will be produced, many of which are extremely odorous. To minimize the potential odor problems, it is important to reduce the particle size, remove plastics and other nonbiodegradable materials from the organic material to be composted, or use source-separated and uncontaminated feedstocks.

Issues in the Implementation of Composting Facilities

The principal issues associated with the use of the compost process are related to (1) the production of odors, (2) the presence of pathogens, (3) the presence of heavy metals, and (4) definition of what constitutes an acceptable compost. The blowing of papers and plastic materials is also a problem in windrow composting. Unless the questions related to these issues are resolved, composting may not be a viable technology in the future.

Production of Odors Without proper control of the composting process, the production of odors can become a problem, especially in windrow composting. It is fair to say that every existing composting facility has had an odor event and in some cases numerous events. As a consequence, facility siting, process design, and biological odor management are of critical importance.

Facility Siting Important issues in siting as related to the production and movement of odors include proper attention to local microclimates as they affect the dissipation of odors, distance to odor receptors, the use of adequate buffer zones, and the use of split facilities (use of different locations for composting and maturation operations).

Proper Process Design and Operation Proper process design and operation are critical in minimizing the potential for the production of odors. If composting operations are to be successful, special attention must be devoted to the following items: preprocessing, aeration requirements, temperature control, and turning (mixing) requirements. The facilities used to prepare the waste materials for the composting process must be capable of mixing any required additives, such as nutrients, seed (if used), and moisture with the waste material to be composted completely and effectively. The aeration equipment must be sized to meet peak oxygen demand requirements with an adequate margin of safety. In the static pile method of composting, the aeration equipment must also be sized properly to provide the volume of air required for cooling of the composting material. The composting facilities must be instrumented adequately to provide for positive and effective temperature control. The equipment used to turn and mix the compost to provide oxygen and to control the temperature must be effective in mixing all portions of the composting mass. Unmixed compost will undergo anaerobic

decomposition, leading to the production of odors. Because all of these operations are critical to the operation of an odor-free composting facility, standby equipment should be available.

Biological Odor Management Because occasional odor events are impossible to eliminate, special attention must be devoted to the factors that may affect biological production of odors. Causes of odors in composting operations include low carbon-to-nitrogen (C/N) ratios, poor temperature control, excessive moisture, and poor mixing. For example, in composting operations where the compost is not turned and the temperature is not controlled, the compost in the center of the composting pile can become pyrolyzed. When subsequently moved, the odors released from the pyrolyzed compost have been *extremely severe*. In enclosed facilities, odor control facilities such as packed towers, spray towers, activated-carbon contactors, biological filters, and compost filters have been used for odor management. In some cases, odor-masking agents and enzymes have been used for the temporary control of odors.

Public Health Issues If the composting operation is not conducted properly, the potential exists for pathogenic organisms to survive the composting process. The absence of pathogenic organisms is critical if the product is to be marketed for use in applications where the public may be exposed to the compost. Although pathogen control can be achieved easily with proper operation of the composting process, not all composting operations are instrumented sufficiently to produce pathogen-free compost reliably. In general, most pathogenic organisms found in MSW and other organic material to be composted will be destroyed at the temperatures and exposure times used in controlled composting operations (typically 55°C for 15–20 days). Temperatures required for the control of various pathogens were given previously in Table 3.19.

Health Hazards

Exposure of workers to dust at a wastewater sludge and other composting site might cause nasal, ear, and skin infections, burning eyes, skin irritation, and other symptoms, pointing to the need for worker protection safeguards.

Other concerns are possible leachate contamination of groundwater and surface water, toxic chemicals remaining in the finished compost, insect and rodent breeding, noise, and survival of pathogens, including molds and other parasite spores and eggs. Pathogens may be spread by leachate, air, insects, rodents, and poor housekeeping and personal hygiene. Tests for pathogens, and the toxic level of chemicals and metals listed in Table 3.16 should be made periodically. Precautions are indicated in view of the potential hazards. Workers should be advised of the infectious and hazardous materials likely to be present in the solid waste handled and the personal hygiene precautions to be taken and be provided with proper equipment, protective gear, and housing. Their health should be monitored. All solid waste should be inspected before acceptance to ensure that it does not

contain hazardous wastes. A dressing room, including lockers, toilet, lavatory, and shower facilities, is needed. Equipment cabs should have air conditioning, including dust filters.

Heavy-Metal Toxicity A concern that may affect all composting operations, but especially those where mechanical shredders are used, involves the possibility of heavy-metal toxicity.⁵ When metals in solid wastes are shredded, metal dust particles are generated. In turn, these metal particles may become attached to the materials in the light fraction. Ultimately, after composting, these metals would be applied to the soil. While many of them would have no adverse effects, metals such as cadmium (because of its toxicity) are of concern. In general, the heavy-metal content of compost produced from the organic fraction of MSW is significantly lower than the concentrations found in wastewater treatment plant sludges. The metal content of source separated-wastes is especially low. The co-composting of wastewater treatment plant sludges and the organic fraction of MSW is one way to reduce the metal concentrations in the sludge.

Product Quality Product quality for compost material can be defined in terms of the nutrient content, organic content, pH, texture, particle size distribution, moisture content, moisture-holding capacity, presence of foreign matter, concentration of salts, residual odor, degree of stabilization or maturity, presence of pathogenic organisms, and concentration of heavy metals. Unfortunately, at this time, there is no agreement on the appropriate values for these parameters. The lack of agreement on appropriate values for these parameters has been and continues to be a major impediment to the development of a uniform compost product from location to location. For compost materials to have wide acceptance, public health issues must be resolved in a satisfactory manner.

Cost The cost of composting should reflect the total cost of the operation less the savings effected. The cost of the operation would include the cost of the site, site preparation, compost concrete or asphalt platform, worker housing and facilities, utilities, equipment (grinder, bucket loader, and composting drum and aeration facilities if part of the process), power, separation and recycling preparation, and disposal of noncompostable materials as well as leachate collection, treatment and disposal, odor control, final screening, bagging, and maintenance. Savings would include reduced landfill disposal cost, income from sale of salvaged material, and sale of stabilized compost. Under favorable conditions, the total net cost of composting might be less compared to other methods. The size of the operation, labor costs, process used, sustained market for recovered materials, need for an enclosure, and other factors will determine the net cost.

A comprehensive market analysis should be made in the planning stage. The cost of an indoor system is much higher than an outdoor system. The operation of an outdoor system is significantly affected by the ambient temperature and precipitation. The indoor system makes possible better temperature, leachate,

odor, and operation control as well as better public relations. Composting is not a profit-making operation.

SANITARY LANDFILL PLANNING, DESIGN, AND OPERATION

A sanitary landfill is a controlled method of solid waste disposal. The site must be geologically, hydrologically, and environmentally suitable. *It is not an open dump.* The nuisance conditions associated with an open dump, such as smoke, odor, unsightliness, and insect and rodent and seagull and other bird problems, are not present in a properly designed, operated, and maintained sanitary landfill. The principal types of landfills used for the disposal of residual material after materials recovery are identified in Table 3.20. Although several types of landfills are identified in Table 3.20, the primary focus of this section is planning, design and operation, and landfill closure of municipal landfills. Details on the other types of landfills may be found in Refs. 2,15, and 17.

Sanitary Landfill Planning

Key elements in the planning and implementation of a landfill include (1) legal requirements, (2) intermunicipal cooperation, (3) social and political factors, and (4) long-term planning issues. Landfill design considerations are considered in the section following the description of the types of landfills.

Legal Requirements State environmental protection agency regulations and local sanitary codes or laws usually build on federal regulatory requirements. A new solid waste disposal location may not be established until the site, design, and method of proposed operation, including waste reduction, resource recovery, and recycling, have been approved by the agency having jurisdiction. The agency should be authorized to approve a new solid waste disposal area and require such plans, reports, specifications, and other necessary data to determine whether the site is suitable and the proposed method of operation feasible. Intermunicipal planning and operation on a multimunicipal, multicounty, or multiregional basis should be given very serious consideration before a new solid waste disposal site is acquired. Larger landfills usually are more efficient and result in lower unit costs.

The principal federal requirements for municipal solid waste landfills are contained in Subtitle D of the Resource Conservation and Recovery Act (RCRA) and in EPA Regulations on Criteria for Classification of Solid Waste Disposal Facilities and Practices (*Code of Federal Regulations*, Title 40, Parts 257 and 258). The final version of Part 258—Criteria for Municipal Solid Waste Landfills (MSWLFs)—was signed on September 11, 1991. The subparts of Part 258 deal with the following areas:

- Subpart A General
- Subpart B Location restrictions
- Subpart C Operating criteria

TABLE 3.20 Types of Landfills Used in the United States^a

Classification of Landfill	Description
Conventional, municipal	A sanitary landfill is a controlled method of solid waste disposal, following the recovery of materials for recycling, which complies with the legal federal requirements for municipal solid waste landfills contained in Subtitle D of the Resource Conservation and Recovery Act (RCRA) and in EPA Regulations on Criteria for Classification of Solid Waste Disposal Facilities and Practices (<i>Code of Federal Regulations</i> , Title 40, Parts 257 and 258) Conventional municipal landfills are discussed in detail in this section.
Municipal bioreactor	Three types are identified: aerobic, anaerobic, and hybrid. Bioreactor landfills are designed to accelerate the biological stabilization of the organic fraction of municipal solid waste.
Aerobic	Air is injected into the waste mass, using vertical or horizontal wells, to promote aerobic activity and accelerate waste stabilization. Leachate, removed from the bottom layer, is stored, and recirculated into the landfill in a controlled manner to obtain optimal moisture levels and, thus, both stimulate and accelerate the biological activity within the landfill.
Anaerobic	Leachate, removed from the bottom layer, is stored, and recirculated into the landfill in a controlled manner to obtain optimal moisture levels and, thus, both stimulate and accelerate the biological activity within the landfill. Biodegradation occurs anaerobically (in the absence of oxygen) and produces landfill gases (carbon dioxide and methane). Landfill gas, primarily methane, is captured to minimize greenhouse gas emissions and for the production of energy.
Hybrid (Aerobic/anaerobic)	The biodegradation of the waste degradation is accelerated by employing a sequential aerobic-anaerobic strategy to degrade organics in the upper sections of the landfill and to collect gas from lower sections.
Construction and demolition (C & D)	There are special landfills for the disposal of construction and demolition waste that is not recovered.
Ash monofill	There are special landfills for the disposal of ash from the combustion of municipal solid waste.
Industrial commercial	There are special landfills for the disposal of industrial wastes such as coal ash, paper mill sludges and similar materials.

^aAdapted in part from G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002; U.S. EPA, *Process Design Manual, Municipal Sludge Landfills*, EPA-625/1-78-010, EPA, Washington, DC. 1978; and U.S. EPA, *Bioreactors*, Office of Solid Waste, EPA, Washington, DC. 2008, <http://www.epa.gov/garbage/landfill/bioreactors.htm>.

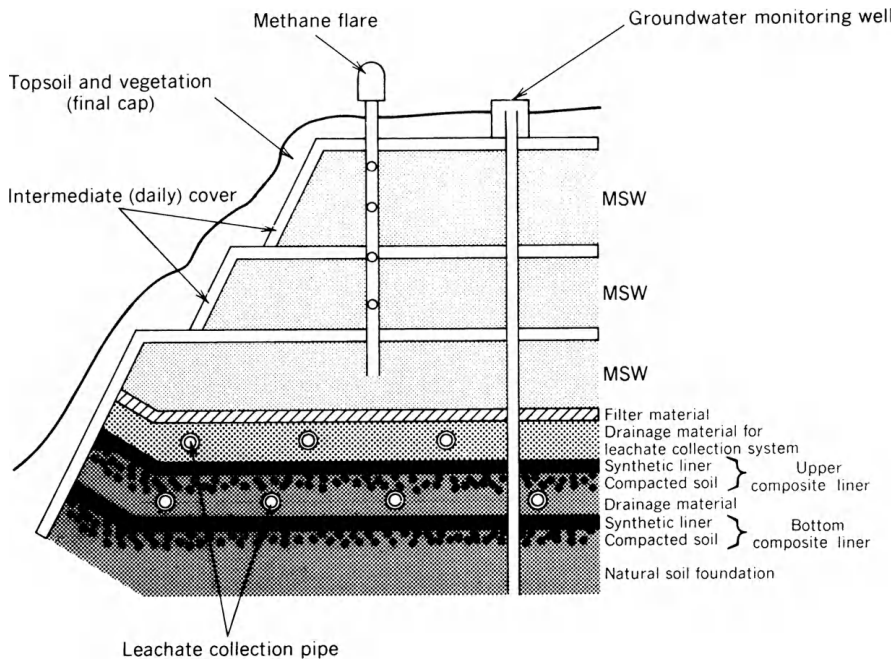


FIGURE 3.23 Schematic diagram of configuration of selected engineering features at MSW landfills.

- Subpart D Design criteria
- Subpart E Groundwater monitoring and corrective action
- Subpart F Closure and postclosure care
- Subpart G Financial assurance

In addition, many state environmental protection agencies have parallel regulatory programs that deal specifically with their unique geologic and soil conditions and environmental and public policy issues.

Intermunicipal Cooperation – Advantages County or regional areawide planning and administration for solid waste collection, treatment, and disposal can help overcome some of the seemingly insurmountable obstacles to satisfactory solution of the problem. Some of the advantages of county or regional areawide solid waste management are the following:

1. It makes possible comprehensive study of the total area generating the solid wastes and consideration of an areawide solution of common problems on short-term and long-term bases. A comprehensive study can also help overcome the mutual distrust that often hampers joint operations among adjoining municipalities.

2. There is usually no more objection to one large site operation than to a single town, village, or city operation. Coordinated effort can therefore be directed at overcoming the objections to one site and operation, rather than to each of several town, village, and city sites.
3. The unit cost for the disposal of a large volume of solid waste is less. Duplication of engineering, overhead, equipment, labor, and supervision is eliminated.
4. Better operation is possible in an areawide service, as adequate funds for proper supervision, equipment, and maintenance can be more easily provided.
5. More sites can be considered. Some municipalities would have to resort to a more costly method because suitable landfill sites may not be available within the municipality.
6. County or regional financing for solid waste disposal often costs less, as a lower interest rate can usually be obtained on bonds because of the broader tax base.
7. A county agency or a joint municipal survey committee, followed by a county or regional planning agency, and then an operating department, district, or private contractor, is a good overall approach because it makes possible careful study of the problem and helps overcome interjurisdictional resistance.

Social and Political Factors An important aspect of solid waste disposal site selection, in addition to the factors mentioned below, is the evaluation of public reaction and education of the public so that understanding and acceptance are developed. A long-term program of public information is needed. Equally important are the climate for political cooperation, cost comparison of alternative solutions, available revenue, aesthetic expectations of the people, organized community support, and similar factors. Films and slides that explain proper sanitary landfill operations are available from state and federal agencies and equipment manufacturers. Sites having good operations can be visited to obtain first-hand information and show the beneficial uses to which a completed site can be put.

Long-Term Planning and Design Issues Local officials can make their task easier by planning ahead together on a county or regional basis for 20 to 40 years in the future and by acquiring adequate sites at least 5 years prior to anticipated needs and use. The availability of federal and state funds for planning, collection, recycling, treatment, and disposal of solid waste on an areawide basis such as a county or region should be explored. The planning will require compliance with public health, environmental, planning, and zoning requirements, both state and local; and an engineering analysis of alternative sites. Also required are population projections, volume and characteristics of all types of solid wastes to be handled, cost of land and site preparation, expected life of the site, haul distances from the sources of solid waste to the site, cost of equipment, cost of

operation, cost of closure and maintenance, and possible use and value of the finished site.

Consideration must also be given to the climate of the region, including precipitation and prevailing winds; geology, soils, hydrology, flood levels, and topography; and the need for liners, leachate collection and treatment [National Pollutant Discharge Elimination System (NPDES) permit], and methane gas control. Location and drainage to prevent surfacewater and groundwater pollution, groundwater monitoring (at least one well up gradient and three wells down gradient), access roads to major highways, location of airports and wetlands, and availability of suitable cover material are other considerations. *Public information and involvement should be an integral and continuing part of the planning process leading to a decision.* The reader is referred to Chapter 6 for a discussion of the broad aspects of community and facility planning and environmental impact analysis.

Once a decision is made, it should be made common knowledge and plans developed to show how it is proposed to reclaim, improve, and reuse the site upon completion. Public education should include a series of talks, slides, news releases, question-and-answer presentations, and inspection of good operations. To aid in the planning process, Table 3.21 presents some general guidelines for landfill design, construction, and operation. Artist's renderings and architectural models are very helpful in explaining construction methods and final land use. Landscape architects can make a contribution in converting the sanitary landfill to a community asset, such as parks, playgrounds with picnic areas, nature trails, bicycle and jogging paths, and hills with scenic observation sites. Unfilled land sites or islands could be set aside for permanent buildings.

Sanitary Landfill Methods

There are many methods of operating a sanitary landfill. The most common are the trench, area, ramp, and valley fill methods, as illustrated in Figure 3.24. These landfill methods are described as follows. With the regulatory requirements for constructed liner and leachate collection and removal systems now imposed by the EPA as set forth in RCRA, a defined operational area and well-designed operational plan are essential and must be closely followed to ensure an efficient and environmentally sound operation.

Trench Method The trench method (see Figure 3.24a) is used primarily on level ground, although it is also suitable for moderately sloping ground. In this method, trenches are constructed by making a shallow excavation and using the excavated material to form a ramp above the original ground. Solid waste is then methodically placed within the excavated area, compacted, and covered at the end of each day with previously excavated material. Because of the need to install landfill control measures (e.g., liners), a number of trenches are typically excavated at one time. Trenches are made 20 to 25 feet wide and at least twice as wide as any compacting equipment used. The depth of fill is determined by the established finished grade and depth to groundwater or rock. If trenches can be made deeper, more efficient use is made of the available land area.

TABLE 3.21 Some General Sanitary Landfill Design, Construction, and Operation Guidelines

Benchmark—Survey benchmark measured from U.S. Geological Survey benchmark established on-site and landfill cells referenced to it; a benchmark for each 25 acres of landfill.

Bottom liners—As specified by the regulatory agency and as indicated by the hydrogeological survey. See Figure 3.27.

Distance from any surface water—Based on soil attenuation, drainage, natural and manmade barriers, but not less than 100 feet, preferably 200 feet or more.

Equipment—Adequate numbers, type, and sizes; properly maintained and available.

Equipment shelter—Available for routine maintenance and repair.

Flood plains—No solid waste management facility permitted unless provisions made to prevent hazard.

Gas control—Prevent hazard to health, safety, and property; provide vents, barriers, collection, monitoring. Gas monitoring is required, also for volatile organic chemical and toxic emissions. See Figures 3.34 to 3.35.

Leachate—Not to drain or discharge into surface waters, except pursuant to State Pollutant Discharge Elimination System, and shall not contravene groundwater quality standards. Leachate collection system maintained.

Limits of fill—No closer than 100 feet from boundary lines of property. Restrictions primarily on proximity to water supply aquifers, wellhead areas, wetlands, floodplains, and surface waters.

Monitoring wells—Four or more at new or modified facility; at least three located down gradient for a small site. Regulatory agency may require wells at existing facility. Off-site wells may be used. Wells must reflect groundwater flow and quality under the landfill site.

- Water monitoring may be required. Safe Drinking Water Act MCLs are used to determine pollution and evaluate pollution travel.
- Baseline water quality and annual seasonal data are required at a new site and some existing sites.

Plans and construction—Engineering plans and specifications as required and approved by regulatory agency. Construction under supervision of project engineer who certifies construction is in accordance with approved plans and specifications.

Site—A hydrogeological survey of the site and surrounding land, soil borings, permeability, and groundwater levels. Check with Federal Aviation Administration.

Termination—Prevent contravention of surface water, groundwater, and air-quality standards and gas migration, odors, vectors, and adverse environmental or health effects. At least 2 feet final cover, including an impervious barrier and gas-venting layer, along with an upper grass cover crop; 4% slope to minimize infiltration, prevent ponding and a surface water drainage system.

Vertical separation—five-foot separation between bottom liner and high groundwater. If natural soil is equivalent to 10 ft of soil with coefficients of permeability less than 5×10^{-6} cm/sec, separation may be reduced if a doubleliner system is provided; 10-ft vertical separation required to bedrock.

Access—Permitted when attendant on duty; controlled by fencing, signs, or other means.

Compaction and cover—Solid waste spread in 2 feet or less layers and promptly compacted. Working face minimal.

- Ten feet of maximum lift height.
- At least 6 in. daily cover at end of each day, or more often.
- At least 12 in. intermediate cover if solid waste not deposited within 30 days.
- Surface water drainage control during operation.
- Final cover when additional lift is not applied within 1 year; when final elevation is reached and within 90 days; when a landfill is terminated. Capped as required by regulatory agency. See Figure 3.37.

(continues)

TABLE 3.21 (continued)

Hazardous wastes—No industrial or commercial solid waste or septage, or other materials producing hazardous waste, without specific permit authorization. No bulk liquids or 55-gal drums filled with liquids.

Litter and papers—Confined by fencing or suitable means. Vehicles confining papers and litter to be admitted.

Maintenance—Cover material and drainage control designed and maintained to prevent ponding and erosion, and to minimize infiltration, based on a 25-year storm and from a 24-hour, 25-year storm. Prepare a landscape plan.

- Grass or ground cover established within 4 months and maintained.
- Soil cover integrity, slopes, cover vegetation, drainage, groundwater and gas monitoring, and structures maintained for a period of 30 years or longer.
- Leachate collection and removal system, inspection manholes, and lift stations maintained operational as long as necessary.
- Liner leakage monitored and reported to regulatory agency.
- Establish a trust fund, surety bond, insurance, etc., to ensure long-term maintenance.

Noise—Shall not cause excessive sound levels beyond property lines in residential areas. Level 7 a.m.–10 p.m.: rural 60 dBA, suburban 65 dBA, urban 70 dBA. Level 10 p.m.–7 a.m., rural 50 dBA, suburban 55 dBA, urban 60 dBA.

On-site roads—Maintained passable and safe.

Open burning—Prohibited except under permit.

Personnel shelter—Adequately heated and lighted; includes safe drinking water, sanitary toilet and shower facilities, telephone or radio communications.

Reports—As required in permit.

Safety—Safety hazards minimized.

Salvaging—Controlled, if permitted.

Small loads—Separate facility (convenience station) at the site for use of local residents and small trucks.

Solid waste disposal—Confined to an area effectively maintained, operated, and controlled. No industrial, commercial solid waste, no sludge or septage unless specifically approved. Inspection for hazardous waste required.

Supervision—Operation supervised by a certified operator, including dumping sequence, compaction, cover, surface drainage.

Vectors, dust, and odors—Controlled to prevent nuisance or hazard to health, safety, or property.

Weigh station—For weight measurement, fees, and waste inspection.

Note: See also applicable federal and state regulations.

Source: J. A. Salvato, *Environmental Engineering and Sanitation*, 4th ed., Wiley, New York, 1992.

Area or Ramp Method On fairly flat and rolling terrain, area method (see Figure 3.24*b*) can be utilized by using the existing natural slope of the land. The width and length of the fill slope are dependent on the nature of the terrain, the volume of solid waste delivered daily to the site, and the approximate number of trucks that will be unloading at the site at one time. Side slopes are 20 to 30 percent; width of fill strips and surface grades are controlled during operation by means of line poles and grade stakes. The working face should be kept as small as practical to take advantage of truck compaction, restrict dumping to a

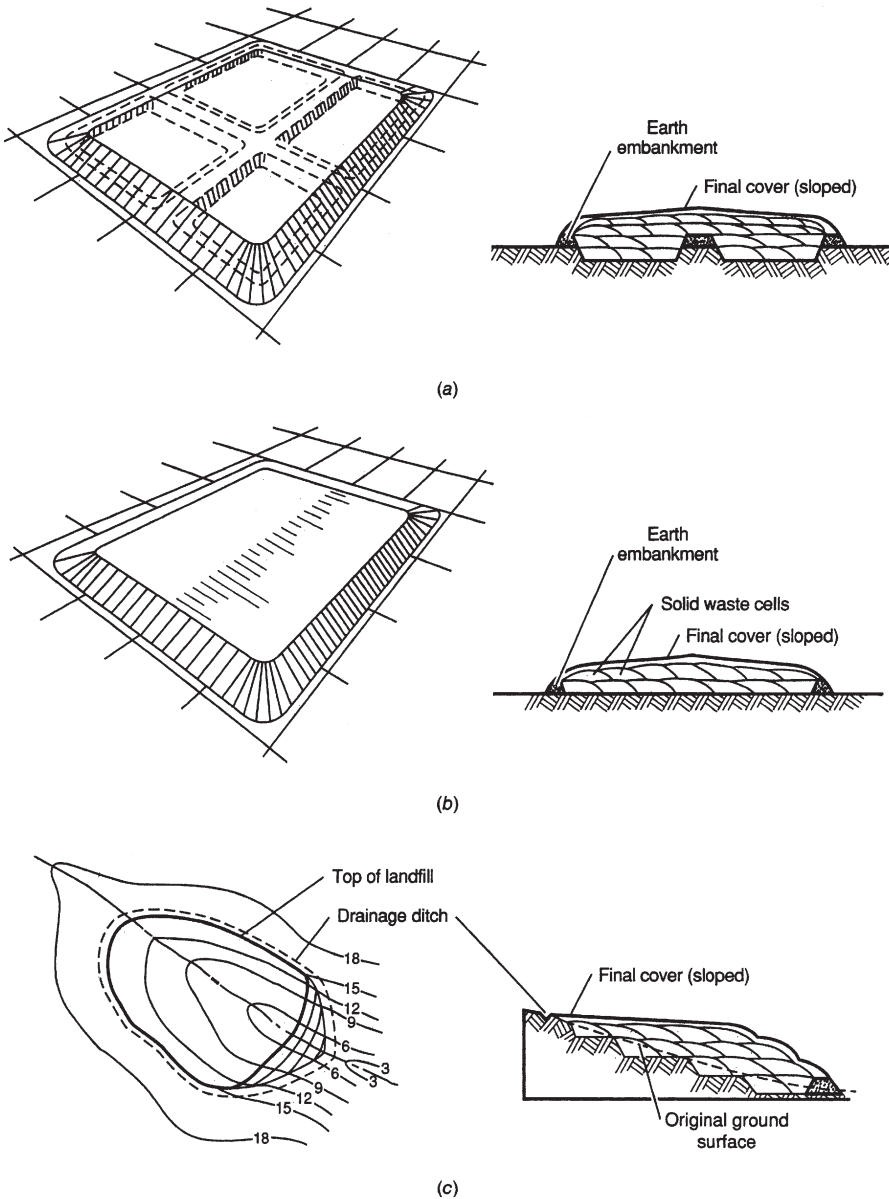


FIGURE 3.24 Schematic view of different types of landfills: (a) trench, (b) area; (c) canyon or ravine. (Source: G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.)

limited area, and avoid scattering of debris. In the area method, cover material is hauled in from a nearby stockpile or other source. The base of the landfill is established by the previously determined elevation of bedrock, groundwater, and bottom liners and leachate collection and removal systems.

Valley or Ravine Area Method In valleys and ravines, the ravine method (see Figure 3.24c) is usually the best method of operation. The development of a large ravine landfill site is illustrated in Figure 3.25. In those areas where the ravine is deep, the solid waste should be placed in “lifts” from the bottom up with a depth of 8 to 10 feet. Cover material is obtained from the sides of the ravine. It is not always desirable to extend the first lift the entire length of the ravine. It may be desirable to construct the first layer for a relatively short distance from the head of the ravine across its width. The length of this initial lift should be determined so that a one-year settlement can take place before the next lift is placed, although this is not essential if operation can be controlled carefully. Succeeding lifts are constructed by trucking solid waste over the first lift to the head of the ravine. When the final grade has been reached (with allowance for settlement), the lower lift can be extended and the process repeated. The bottom landfill liner and leachate collection and removal system must be designed carefully to ensure that slope stability of the liner system and the waste placed is adequately maintained.



FIGURE 3.25 Development of large ravine landfill site. Equipment is compacting sub-base of landfill in preparation for placement of geomembrane liner.

General Landfill Design Issues

The general planning process described above is followed by specific site selection and preparation. Site preparation requires that an engineering survey be made and a map drawn at a scale of not less than 200 feet to the inch with contours at 2-foot intervals, showing the boundaries of the property; location of lakes, streams, springs, marine waters, and structures within 1,000 feet; adjoining ownership; and topography. Also required are soil borings, including *in situ* hydraulic conductivity determinations, designs for liners and leachate collection systems, groundwater levels, up-gradient and down-gradient monitoring wells, water quality samples, prevailing winds, and drainage plans.

Location The site location directly affects the total solid waste collection and disposal cost. If the site is remotely situated, the cost of hauling to the site may become high and the total cost excessive. It has been established that the normal, economical hauling distance to a solid waste disposal site is 10 to 15 miles, although this will vary depending on the volume of solid waste, site availability, and other factors. Actually, a suitable site and the hauling time and route are more important than the hauling distance. The disposal site may be as far as 40 to 80 miles away if a transfer station is used. Rail haul and barging introduce other possibilities. The cost of transferring the solid waste per ton is used to compare solid waste collection and disposal costs and make an economic analysis. Open excavations left by surface mining operations may be considered for solid waste disposal as a means of reclaiming land and restoring it to productive use.

Accessibility Another important consideration in site selection is accessibility. A disposal area should be located near major highways to facilitate use of existing arterial roads and lessen the hauling time to the site. Highway wheel load and bridge capacity and underpass and bridge clearances must also be investigated. It is not good practice to locate a landfill in an area where collection vehicles must constantly travel through residential streets to reach the site. The disposal area itself should normally be located at least 500 feet from habitation, although lesser distances have been successfully used to fill in low areas and improve land adjacent to residential areas for parks, playgrounds, or other desirable uses. Where possible, a temporary attractive screen should be erected to conceal the operation. To allow vehicular traffic to utilize the site throughout the year, it is necessary to provide good access roads to the site so that trucks can move freely in and out of the site during all weather conditions and seasons of the year. Poorly constructed and maintained roads to a site can create conditions that cause traffic tie-ups and time loss for the collection vehicles.

Land Area (Volume) Required The volume needed for solid waste disposal is a function of population served, per-capita solid waste contribution, resource recovery and recycling, density and depth of the solid waste in place, number of lifts, total amount of earth cover used, and time in use, adjusted for nonhazardous commercial and industrial wastes. Because of the high startup costs associated

with a modern landfill, the capacity of a proposed landfill should be sufficient for a 20- to 40-year period (see Figure 3.25). Further, because the population in an area will not usually remain constant, it is essential that population projections and development be taken into account. These factors plus the probable nonhazardous solid waste contributions by commercial establishments, industry, and agriculture must be considered in planning for needed land. A density of compacted fill of 800 to 1,000 lb/yd³ is readily achieved with proper operation; 600 lb/yd³ or less is poor; 1,200 lb/yd³ or more is very good.

Leachate Generation, Control, and Treatment

The best solution to the potential leachate problem is to prevent its development. Landfill leachate generation cannot in practice be entirely avoided, particularly during operation, except possibly in some arid climates. A tight soil cap and/or liner on completion can greatly minimize the possibility; however, a leachate-free landfill may not be *entirely* desirable. Leachate control measures for groundwater and surface-water quality protection must be incorporated in the site design and monitoring started before operation (see Figure 3.26). A water balance for the landfill disposal facility should be established to serve as a basis for the design of leachate control and surface runoff systems, taking into consideration heavy rainfall, landfill, cap construction, in addition to runoff, infiltration, and evapotranspiration.

Leachate from existing community sanitary landfills and from industrial waste storage and disposal sites can be expected to contain organic and inorganic chemicals characteristic of the contributing community and industrial wastes. Household hazardous wastes may include small amounts of cleaning solvents, paints and paint thinners, oils, pesticides, and drugs if not restricted or their sale prohibited. The EPA and others have reported that hazardous wastes probably represent less than 0.5 percent of the total waste generated by households. A knowledge of the industry and its production will provide a starting point in the selection of parameters to be analyzed in characterizing the leachate from an existing site.

Leachate Generation The precipitation less runoff, transpiration, and evaporation will determine the amount of infiltration. Infiltration and percolation will, in the long term, after field capacity has been reached, determine the amount of leachate, if any, produced, assuming groundwater and lateral flow are excluded. A major factor is a cover material that is carefully graded, which ideally permits only limited infiltration and percolation to support vegetative cover and solid waste decomposition, with optimal runoff but without erosion to prevent significant leachate production. The soil cover should have a low permeability with low swell and shrink tendency upon wetting and drying. Runoff depends on rainfall intensity and duration, permeability of the cover soil, surface slope (4 percent, not greater than 30 percent for side slopes), condition of the soil and its moisture content, and the amount and type of vegetative cover. Evapotranspiration during the growing season for grasses and grains may be 20 to 50 inches.

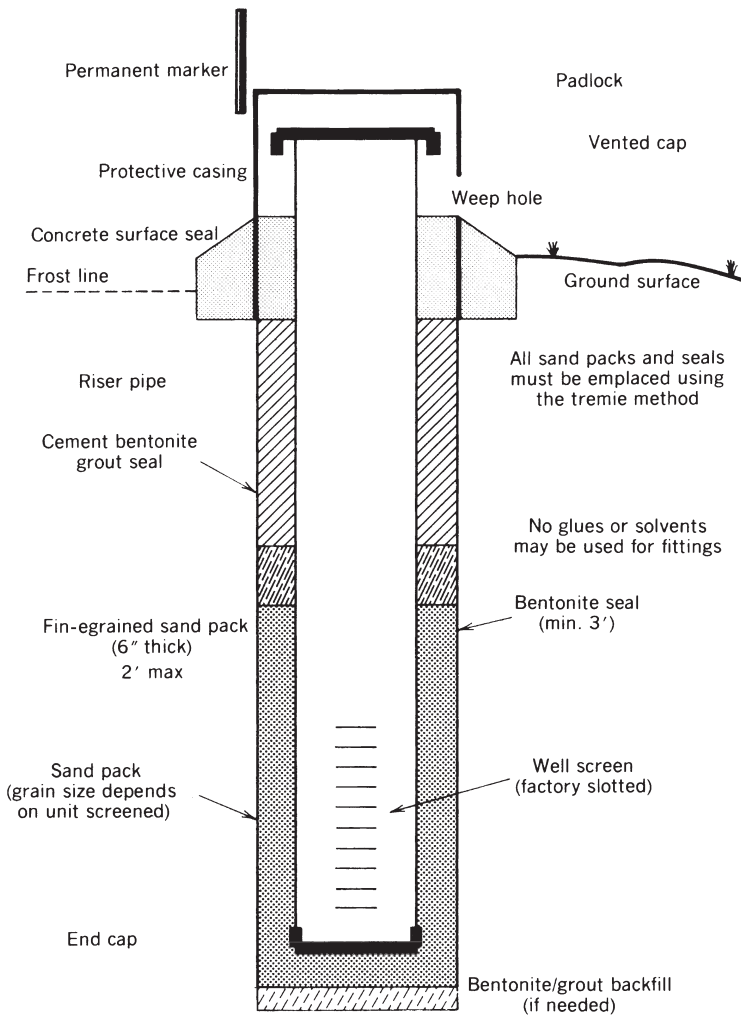


FIGURE 3.26 Typical monitoring well diagram. (Source: New York State, 6 NYCRR Part 360, *Solid Waste Management Facilities*, New York State Department of Environmental Conservation, Division of Solid Waste, Albany, 1990a.)

Leachate Control It should be noted that if all infiltration is excluded and the solid waste kept dry, biodegradation by bacteria, fungi, and other organisms will cease and the solid waste will be preserved in its original state. Bacterial activity will generally cease when the moisture content drops below 14 to 16 percent. The maintenance of an optimal amount of moisture in the fill, as in controlled composting (an aerobic process), is necessary for biodegradation (an anaerobic process in a landfill), methane production, final stabilization, and possible future recycling of the solid waste or reuse of the site.

The objective in the design of landfill liners is to minimize or eliminate the infiltration of leachate into the subsurface soils below the landfill so as to eliminate the potential for the groundwater contamination. A number of liner designs have been developed to minimize the movement of leachate into the subsurface below the landfill. One of the many types of liner designs that have been proposed is illustrated in Figure 3.27. In the multilayer landfill liner design illustrated in Figure 3.27, each of the various layers has a specific function. For example, in Figure 3.27, two composite liners are used as a barrier to the movement of leachate and landfill gas. The drainage layer is to collect any leachate that may be generated within the landfill. The final soil layer is used to protect the drainage and barrier layers. The placement of a geomembrane liner in an area-type landfill is illustrated in Figure 3.28. A modification of the liner design shown in Figure 3.27 is shown in Figure 3.29. The liner system shown in Figure 3.29 is for a monofill (e.g., a landfill for a single waste component such as glass). Composite liner designs employing a geomembrane and clay layer provide more protection and are hydraulically more effective than either type of liner alone.

If leachate migration is or may become a problem at an old or existing landfill, and depending on the local situation and an engineering evaluation, several options may be considered. These include a cap on the surface consisting of clay or a liner regraded with topsoil seeded to grass to effectively shed precipitation;

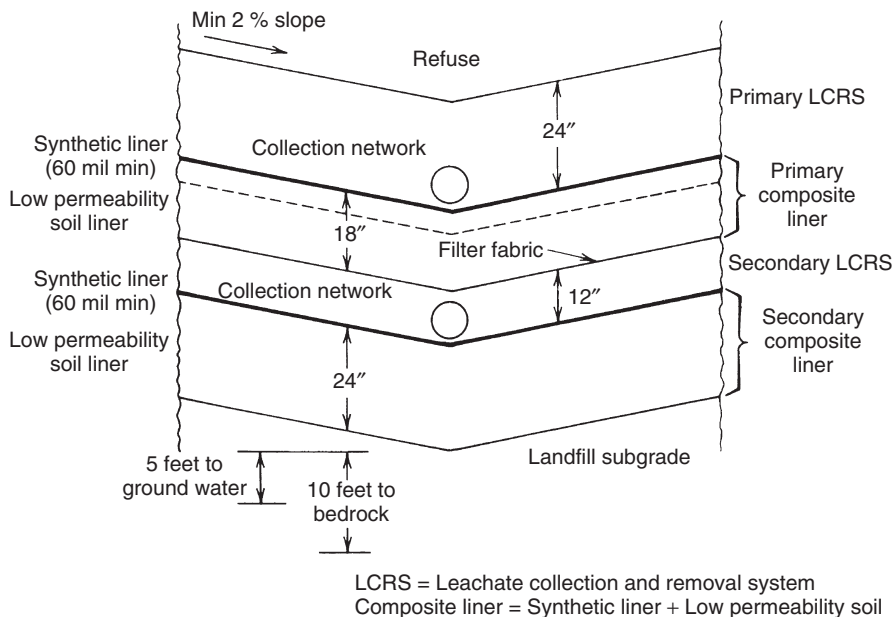


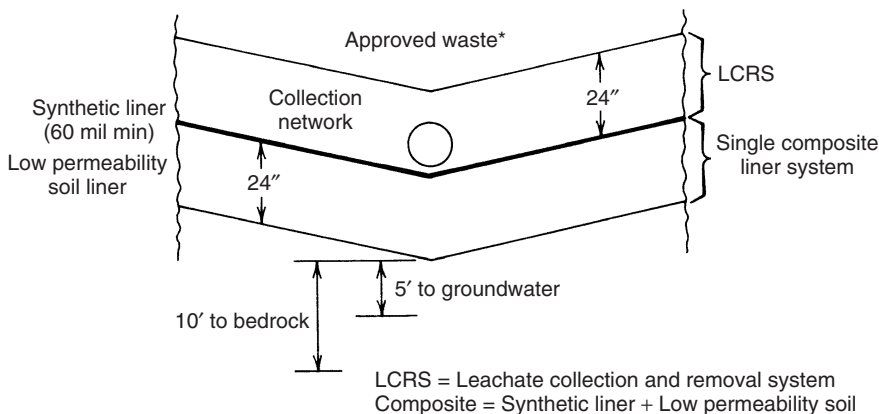
FIGURE 3.27 Double-bottom composite liner system. (New York State, *6 NYCRR Part 360, Solid Waste Management Facilities*, New York State Department of Environmental Conservation, Division of Solid Waste, Albany, 1990a.)



FIGURE 3.28 Placement of geomembrane liner in area-type landfill.

cutoff walls or dams keyed into an impermeable stratum to isolate the fill; pressure treatment and sealing of the bottom and sides of the fill; surface-water drains up-gradient and around the landfill area; curtain drains or wells to intercept and drain away the contributing groundwater flow, collection and recirculation of leachate with treatment of any excess, or, in special cases and if warranted, the material in the landfill can be excavated, treated, recycled, and/or disposed of at a controlled site. The excavation of an existing landfill may, however, introduce other problems if hazardous wastes are involved and hence must be carefully evaluated in advance.

Leachate Recirculation Waste biodegradation and stabilization of the biodegradable organic matter in a landfill can be accelerated by leachate



*Based on volume and the physical, chemical, and biological characteristics of the solid waste.

FIGURE 3.29 Industrial/commercial and ash monofill waste landfill liner configuration. (New York State, *6 NYCRR Part 360, Solid Waste Management Facilities*, New York State Department of Environmental Conservation, Division of Solid Waste, Albany, 1990a.)

recirculation. Controlled leachate recirculation, including nutrient addition to maintain optimum moisture and pH, can enhance anaerobic microbial activity, breakdown organics as shown by reduced total organic carbon (TOC) and chemical oxygen demand (COD), convert solid waste organics to methane and carbon dioxide, and precipitate heavy metals. Complete biological stabilization can be achieved in four to five years. Heating of recirculated leachate to 86 °F (30 °C) has been found to accelerate the stabilization process.

A landfill designed for leachate recirculation should, as a minimum, incorporate a conservatively designed liner system and an effectively maintained leachate collection, removal, and recirculation distribution system, in addition to a gas collection and venting system (see Figure 3.30). A double-liner system with leak detection monitoring wells would enable the landfill owner and regulatory agency to monitor the liner system performance. The leachate collection and removal system should be designed to be accessible for routine maintenance and cleaning in view of the potential for biological film clogging. Recirculation would increase the strength of the recirculated leachate and accelerate fill stabilization. Establishment of early gradual recirculation and an active anaerobic biomass is important as each cell is closed. A final site closure utilizing a relatively impermeable crowned cap and surface-water drainage system should be implemented for final site closure.

Leachate Treatment Leachates containing a significant fraction of biologically refractory high-molecular-weight organic compounds (i.e., those in excess of 50,000) are best treated by physicochemical methods, such as lime addition followed by settling. Leachates containing primarily low-molecular-weight organic compounds are best treated by biological methods, such as activated sludge.

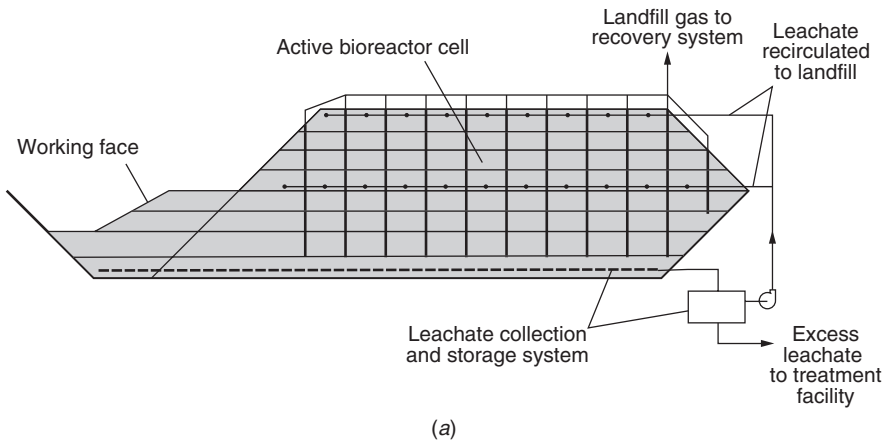


FIGURE 3.30 Bioreactor type landfill with leachate recirculation: (a) schematic diagram and (b) photograph of a highly instrumented anaerobic landfill bioreactor located at Davis, California. Photo of bioreactor was taken shortly after landfill was completed, before significant decomposition had occurred. (Source: O’Leary, P. R., and G. Tchobanoglous, “Landfilling,” in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 14.)

Combinations of these methods may be required to achieve permit requirements and stream discharge standards. In the final analysis, the treatment required will depend on the composition of the fill material, leachate volume and characteristics, and the water pollution control standards to be met.

TABLE 3.22 Typical Constituents in Landfill Gas

Component	Percent (dry volume basis)
Methane	45–60
Carbon dioxide	40–60
Nitrogen	2–5
Oxygen	0.1–1.0
Sulfides, disulfides, mercaptans, etc.	0–1.0
Ammonia	0.1–1.0
Hydrogen	0–0.2
Carbon monoxide	0–0.2
Trace constituents	0.01–0.6
Characteristic	Value
Temperature, °F	100–120
Specific gravity	1.02–1.06
Moisture content	Saturated
High heating value, Btu/sft ^{3a}	475–550

^asft³ = standard cubic foot.
Source: G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.

Landfill Gas Generation, Control, and Recovery and Utilization

Gases found in landfills include ammonia (NH₃), carbon dioxide (CO₂), carbon monoxide (CO), hydrogen (H₂), hydrogen sulfide (H₂S), methane (CH₄), nitrogen (N₂), and oxygen (O₂). The typical percentage distribution of the gases found in the landfill is reported in Table 3.22. As shown in Table 3.22, methane and carbon dioxide are the principal gases produced from the anaerobic decomposition of the biodegradable organic waste components in MSW. In addition, a number of trace gases will also be found in landfill gas. The type and concentration of the trace gases will depend to a large extent on the past history of the landfill. Issues related to the generation, control of migration, and utilization of landfill gas are considered in the following discussion.

Generation of the Principal Landfill Gases The generation of principal landfill gases is thought to occur in five more or less sequential phases, as illustrated in Figure 3.31. Each of these phases is described briefly here. Additional details may be found in Ref. 15.

Phase I: Initial adjustment. Phase I is the *initial adjustment phase*, in which the organic biodegradable components in municipal solid waste begin to undergo bacterial decomposition soon after they are placed in a landfill. In phase I, biological decomposition occurs under aerobic conditions because a certain amount of air is trapped within the landfill.

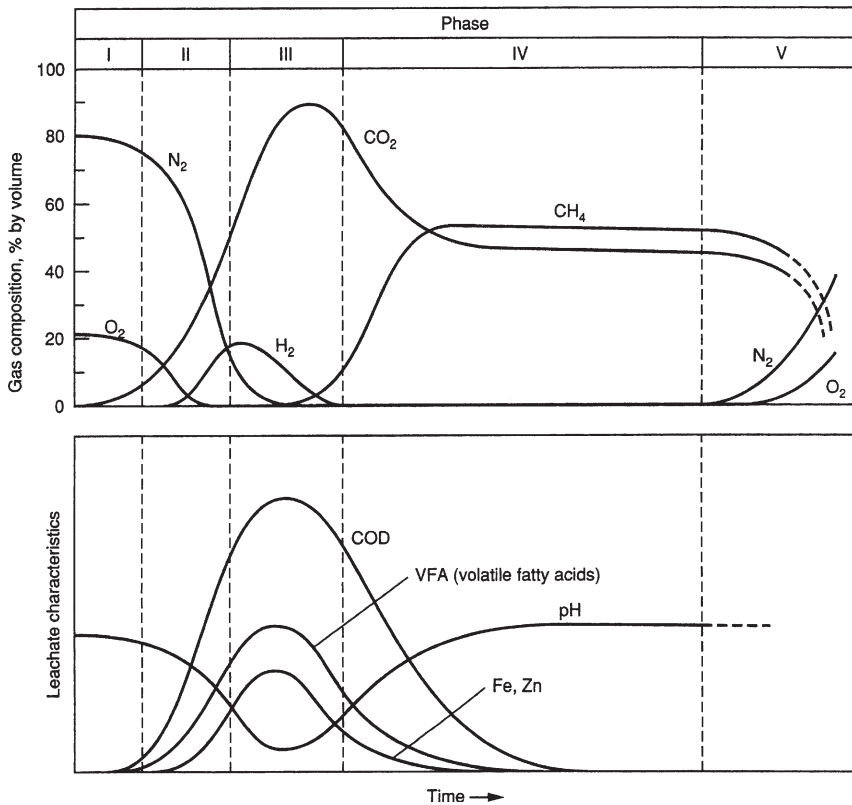


FIGURE 3.31 Generalized phases in generation of landfill gases (I—initial adjustment, II—transition phase; III—acid phase; IV—methane fermentation; V—maturation phase) (Source: G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.)

Phase II: Transition phase. In phase II, identified as the *transition phase*, oxygen is depleted and anaerobic conditions begin to develop.

Phase III: Acid phase. In phase III, the bacterial activity initiated in phase II is accelerated with the production of significant amounts of organic acids and lesser amounts of hydrogen gas. The first step in the three-step process involves the enzyme-mediated transformation (hydrolysis) of higher molecular mass compounds (e.g., lipids, organic polymers, and proteins) into compounds suitable for use by microorganisms as a source of energy and cell carbon. The second step in the process (acidogenesis) involves the bacterial conversion of the compounds resulting from the first step into lower molecular weight intermediate compounds, as typified by acetic acid (CH_3COOH) and small concentrations of fulvic and other more complex organic acids. Carbon dioxide (CO_2) is the principal gas generated during phase III.

Phase IV: Methane fermentation phase. In phase IV, a second group of microorganisms that convert the acetic acid and hydrogen gas formed by the acid formers in the acid phase to methane (CH_4) and CO_2 becomes more predominant. Because the acids and the hydrogen gas produced by the acid formers have been converted to CH_4 and CO_2 in phase IV, the pH within the landfill will rise to more neutral values in the range of 6.8 to 8.

Phase V: Maturation phase. Phase V occurs after the readily available biodegradable organic material has been converted to CH_4 and CO_2 in phase IV. As moisture continues to migrate through the waste, portions of the biodegradable material that were previously unavailable will be converted.

Control of Landfill Gas Migration When methane is present in the air in concentrations between 5 and 15 percent, it is explosive. Because only limited amounts of oxygen are present in a landfill when methane concentrations reach this critical level, there is little danger that the landfill will explode. However, methane mixtures in the explosive range can be formed if landfill gas migrates off site and is mixed with air. The lateral migration of methane and other gases can be controlled by impermeable cutoff walls or barriers (see Figure 3.32) or by the provision of a ventilation system such as gravel-filled trenches around the perimeter of the landfill (see Figure 3.33). Gravel-packed perforated pipe wells or collectors may also be used to collect and diffuse the gas to the atmosphere, if not recovered. To be effective, the system must be carefully designed, constructed, and maintained.

Cutoff walls or barriers should extend from the ground surface down to a gas-impermeable layer such as clay, rock, or groundwater. Clay soils must be water saturated to be effective. Perforated pipes have been shown to be of limited effectiveness and are not recommended for the reduction of gas pressure when used alone. Gravel-filled trenches may permit migration of gases across the trench, especially when covered by snow or ice; vertical perforated pipes reduce somewhat the effect of snow or ice. Gravel-filled trenches require removal of leachate or water from the trench bottom and are susceptible to plugging by biomass buildup. Gravel-filled trenches in combination with an impermeable barrier provide good protection against gas migration when keyed to a gas-impermeable strata below the landfill. Induced exhaust wells or trenches with perforated pipes and pump or blower are reported to be very effective. Where enclosed structures are constructed over or in close proximity to a landfill, it is necessary to have these places continuously monitored. A combustible gas detection system to provide early warning (light and alarm) can alert personnel. The monitors comprising the detection system can also activate ventilation fans at present low methane levels. Soil and cement bentonite trenches or cutoff walls have also been used to prevent lateral gas migration.

Methane Recovery and Utilization Methane is produced in a landfill when anaerobic methane-producing bacteria are active. The condition shown

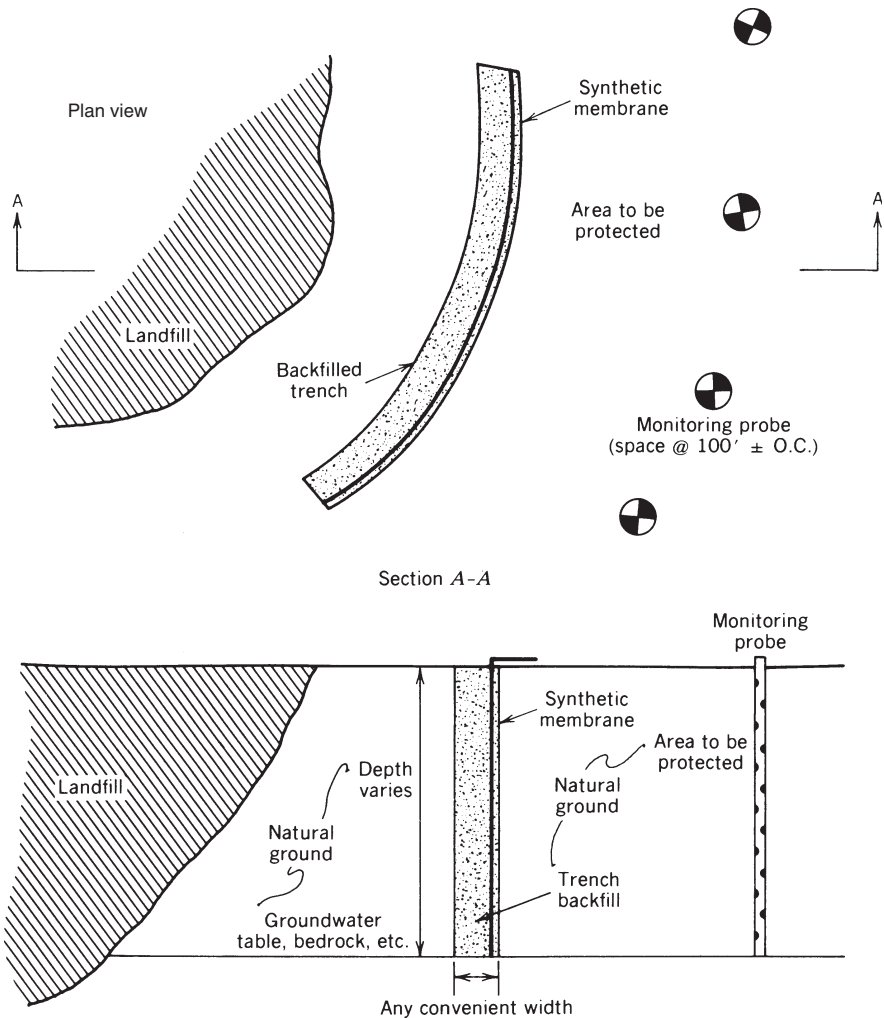


FIGURE 3.32 Typical passive gas control synthetic membrane.

in Figure 3.31 may be reached in six months to five years depending on the landfill. Acidic conditions inhibit growth of methane-producing bacteria; alkaline conditions have the opposite effect. Methane production is quite variable depending on the amount and type of decomposable material in the landfill, moisture content, temperature, and resulting rate of microbial decomposition under anaerobic conditions.

Methane is odorless, has a heat value of about 500 Btu/ft³ compared to 1000 Btu for commercial gas, has a specific gravity less than air, and is nearly insoluble in water. The gases from landfills, after anaerobic conditions have been established, are quite variable, ranging from 50 to 60 percent methane and 40

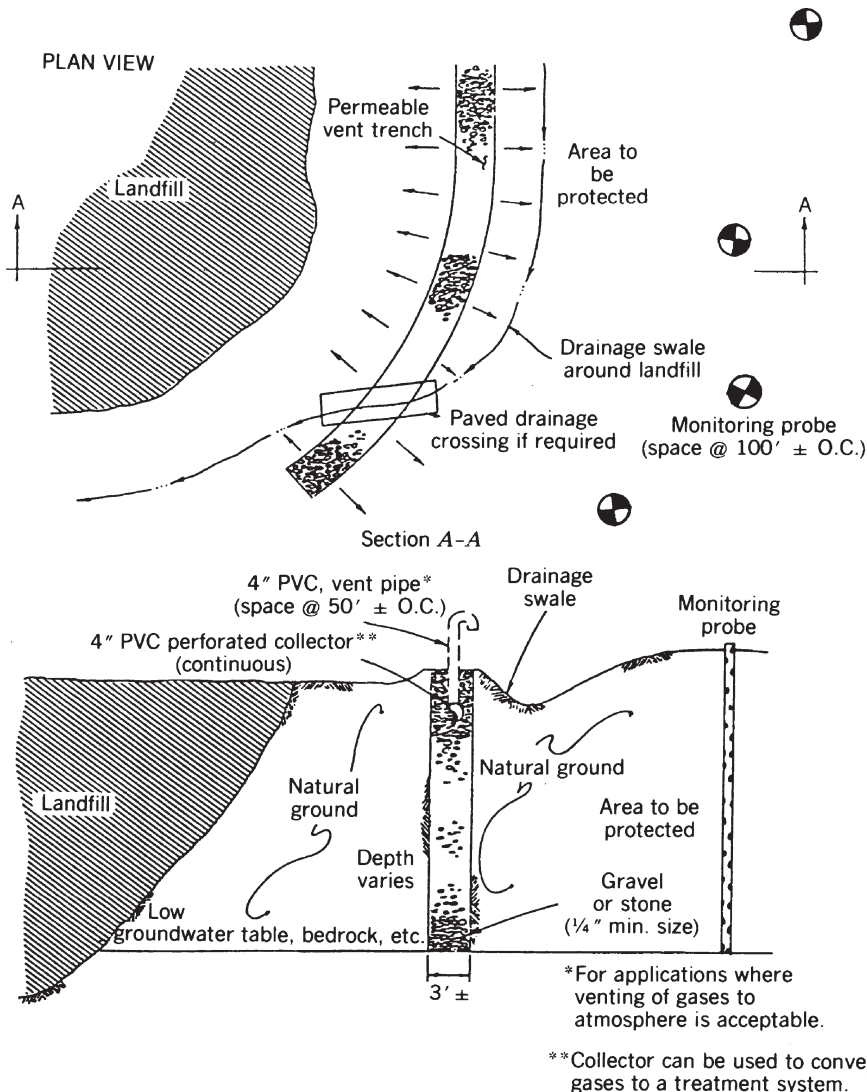


FIGURE 3.33 Passive gas control using permeable trench. (Source: SCS Engineers, Inc., *Procedural Guidance Manual for Sanitary Landfills: Volume I Landfill Leachate Monitoring and Control Systems and Volume II Landfill Gas Monitoring and Control Systems*, California Waste Management Board, Sacramento, CA, April, 1989.)

to 50 percent carbon dioxide. Included are small amounts of nitrogen, oxygen, water, mercaptans (very odorous), and hydrocarbons. Hydrogen sulfide may also be released if large amounts of sulfates are in the landfill. Vinyl chloride, benzene, and other toxics in trace amounts may also be produced by the action of bacteria on chlorinated solvents deposited in the fill. The presence of oxygen and

nitrogen with methane gas would indicate the entrance of air into the landfill due to methane being withdrawn too rapidly. If methane extraction is not controlled to reduce or eliminate the entrance of oxygen and nitrogen, the production of methane will slow down or stop.

In the early stages the landfill gases are primarily carbon dioxide, with some methane. The carbon dioxide is heavier than air and can dissolve in water to form carbonic acid, which is corrosive to minerals with which it comes into contact. Mercaptans, carbon dioxide, and water are usually extracted to upgrade the methane to pipeline quality. Removal of carbon dioxide may improve Btu content to 900 or 1,000 Btu/ft³. Methane as it comes from a landfill is often very corrosive. Deep landfills, 30 feet or deeper, and 30 acres or more in area with a good cover are better methane producers. Actually, gas will be generated as long as biodegradable material remains and is primarily dependent on precipitation, infiltration, and moisture content. Gas can be extracted using plastic tube wells in each cell with perforations or well screens toward the bottom connected to a controlled vacuum pump (see Figure 3.34) or a series of covered horizontal gravel trenches connected to a pipe collection system (see Figure 3.35). The extracted gas may be used for heating and generating electricity.

Management of Surface Waters

The runoff from the drainage area tributary to the solid waste disposal site must be determined by hydraulic analysis to ensure that the surface-water drainage system, such as ditches, dikes, berms, or culverts, is properly designed and that flows are diverted to prevent flooding, erosion, infiltration, and surface-water and groundwater pollution, both during operation and on completion. The design basis should be the maximum 25-year, 24-hour precipitation. The topography and soil cover should be examined carefully to ensure that there will be no obstruction of natural drainage channels. Obstructions could create flooding conditions and excessive infiltration during heavy rains and snow melt. Uncontrolled flooding conditions can also erode the cover material.

A *completed* landfill for residential solid waste that is properly capped should, ideally, not present any serious hazard of groundwater pollution, *provided surface water (and groundwater) and most of the precipitation are drained, transpired, and evaporated off the landfill and the landfill site*. Two different types of landfill covers are presented in Figures 5.36 and 5.37. The major source of water for leachate production would then be precipitation–infiltration during operation, before the final cap is put in place. Precipitation–infiltration can be minimized by the temporary use of impervious geo-membrane sheets over the completed landfill. A small amount of infiltration is desirable to support biological decomposition of the solid waste, as already noted. It becomes essential, therefore, that the solid waste working face be kept at a minimum, that the final cover be placed and graded promptly, and that a surface-water drainage system be installed as soon as possible.

Cover Material The site should preferably provide adequate and suitable cover material. The most suitable soil for cover material is one that is easily worked and

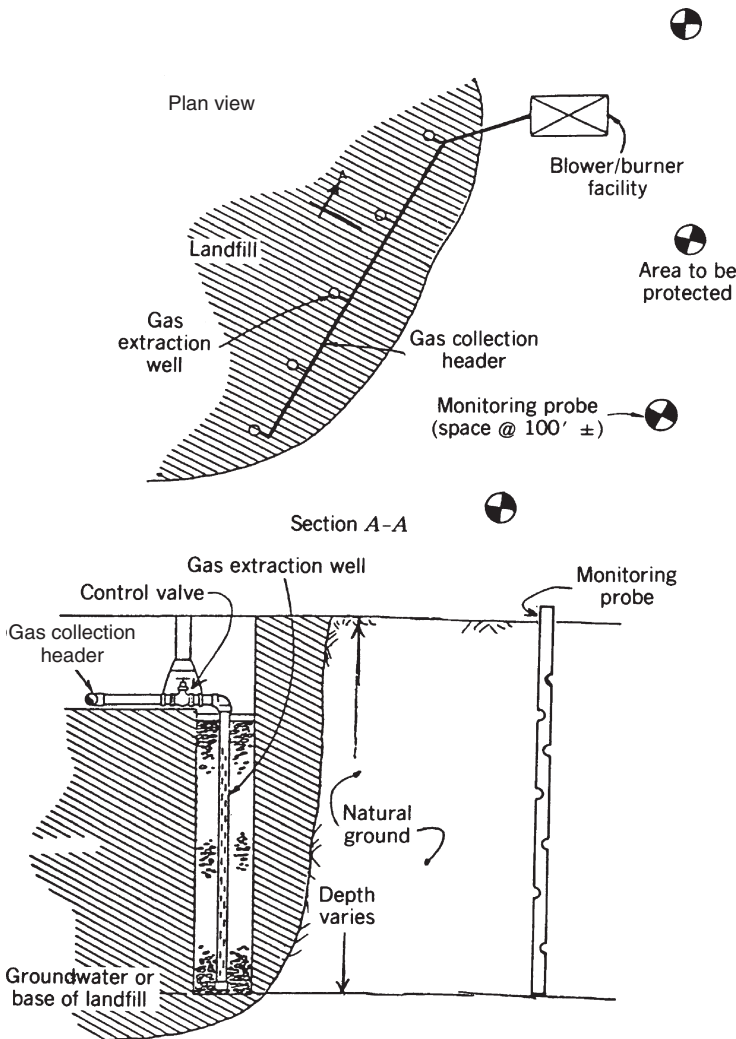


FIGURE 3.34 Typical gas extraction system. (Source: U.S. EPA, *Handbook Remedial Action at Waste Disposal Sites*, EPA/625/6-85/006, Hazardous Waste Engineering Research Laboratory, Office of Research and Development, EPA, Cincinnati, OH, 1985.)

yet minimizes infiltration; however, this is not always available. It is good practice to stockpile topsoil for final cover and other soil for cold-weather operation and access road maintenance. Shredded (milled) solid waste in a landfill does not cause odors, rodent or insect breeding, or unsightliness, and it may not require daily earth cover. However, precipitation will be readily absorbed and leachate produced unless the waste is covered with a low-permeability soil that is well graded to shed water.

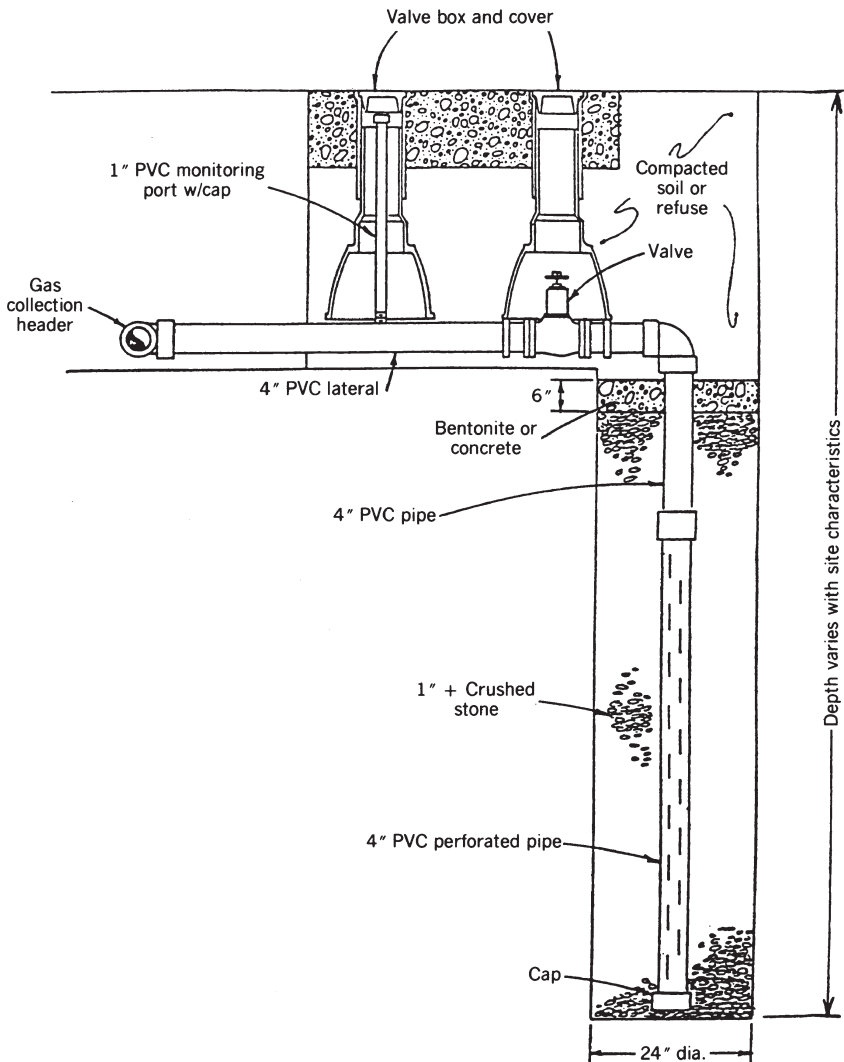


FIGURE 3.35 Typical gas extraction well. (Source: U.S. EPA, *Handbook Remedial Action at Waste Disposal Sites*, EPA/625/6-85/006, Hazardous Waste Engineering Research Laboratory, Office of Research and Development, EPA, Cincinnati, OH, 1985.)

The control of leachate and methane and the role played by the final earth cover, including the importance of proper grading of the landfill final cover (4 percent slope) to minimize infiltration, promote runoff, and prevent erosion, have been previously discussed. A final cover to minimize infiltration of precipitation, support vegetation, and encourage evapotranspiration is recommended. The vegetation, such as seeded grass (hydroseeded for rapid cover), will prevent

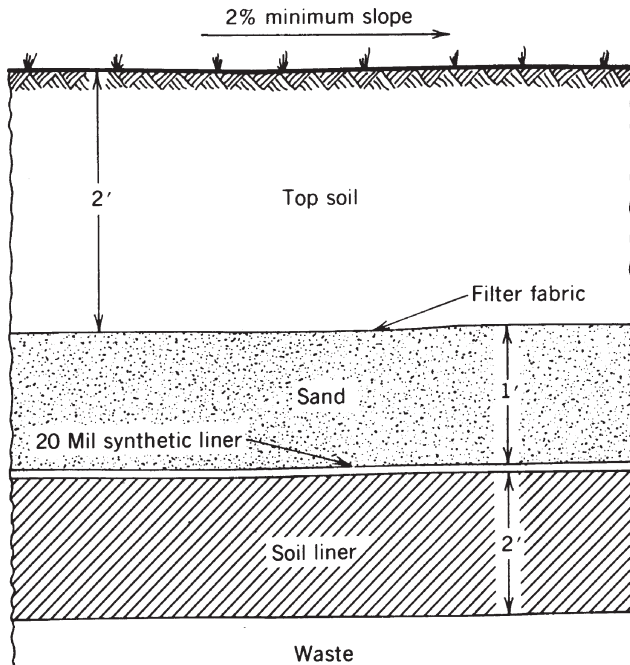


FIGURE 3.36 Typical multiplayer landfill cap. Minimum of 4 percent surface slope is usually preferred (Source: U.S. EPA, *Handbook Remedial Action at Waste Disposal Sites*, EPA/625/6-85/006, Hazardous Waste Engineering Research Laboratory, Office of Research and Development, EPA, Cincinnati, OH, 1985.)

wind and water erosion and contribute to transpiration and evaporation. The final slope should be maintained at 1:30. A tight cover or membrane cap requires provision for effective gas collection and release.

Landfill Vegetation Four feet or more earth cover is recommended if the area is to be landscaped, but the amount of cover depends on the plants to be grown. Native grasses may require 2 feet of topsoil, and large trees with deep tap roots may require 8 to 12 feet. The carbon dioxide and methane gases generated in a landfill may interfere with vegetation root growth, if not prevented or adequately diffused. The gases can be collected and disposed of through specially designed sand or gravel trenches or a porous pipe gas-venting system. Oxygen penetration to the roots is necessary. Carbon dioxide as low or lower than 10 percent in the root zone can be toxic to roots; methane-utilizing bacteria deplete the oxygen. Precautions to help maintain a healthy vegetation cover include selecting a tolerant species and seeking professional advice, avoiding areas of high gas concentrations, excluding gas from root zone (use built-up mounds for planting or line with membrane or clay soil barrier and vent trench and plant in suitable backfill soil), avoiding heavily compacted soil (loosen first if necessary and

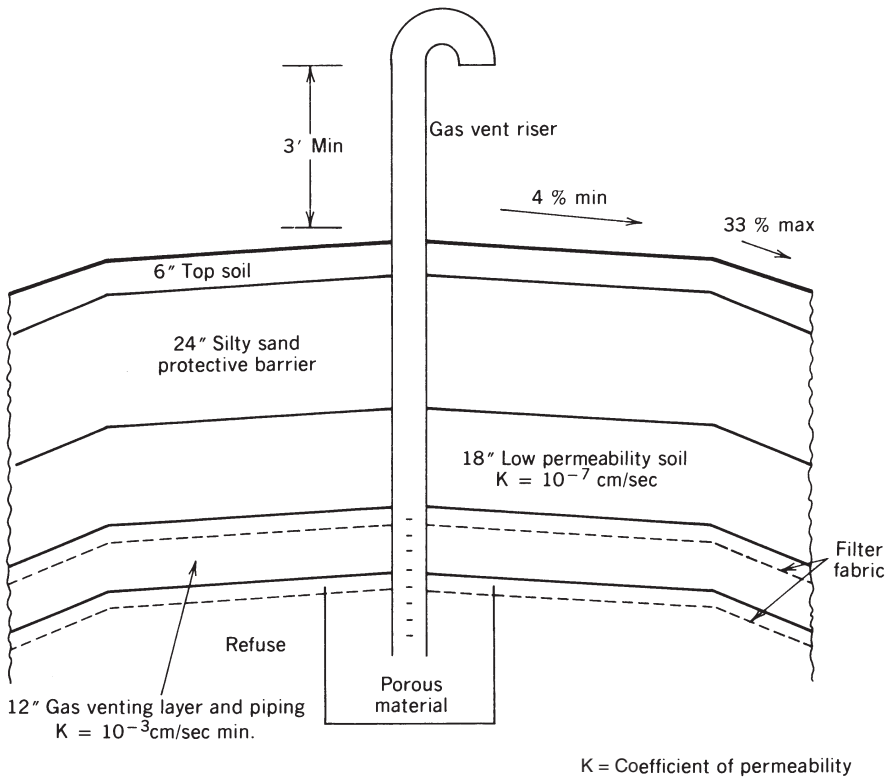


FIGURE 3.37 Final cover with passive gas vent. (Source: New York State, *Municipal Energy Recovery Facilities Handbook*, New York State Environmental Facilities Corporation, Albany, 1988.)

supplement soil fertility and improve its physical condition following good nursery practice), using smaller plant stock, and providing adequate irrigation (see Figure 3.38).

Landfill Mining

The excavation and recycling of a landfill waste appears to be feasible where there has been adequate moisture to permit decomposition and stabilization of the waste. On the one hand, in locations where rainfall averages 60 inches/year or more, a portion of the decomposed waste is generally suitable for recycling or for use as cover material for a new landfill at the same location excavated. On the other hand, in arid regions where the rainfall averages 10 to 20 inches/year or less, the waste placed in landfills is often well preserved after more than 20 years. Other factors such as landfill design, type of cover material, waste composition, and age of the landfill must be evaluated and regulatory approval obtained.



FIGURE 3.38 Completed landfill with irrigation system.

A thorough hydrogeological investigation of an old landfill site is necessary before considering its excavation (mining), recycling, and possible reuse. The up-gradient and down-gradient groundwater levels and quality, the depth and type of soil beneath the fill, the thickness of the fill and its composition, including the possible presence of hazardous wastes, are among the conditions to be investigated. Numerous tests are necessary as landfill waste is not homogeneous. If reuse of the excavated site as a municipal landfill site is proposed, preliminary discussions with the regulatory agency are essential.

Landfill Facilities and Equipment for Disposal by Sanitary Landfill

In addition to the control of leachate and landfill gases, a number of other facilities and operating equipment are required for the effective implementation of a sanitary landfill. Personnel requirements are discussed in the following section.

Fire Protection The availability of fire protection facilities at a site should also be considered as fire may break out at the site without warning. Protective measures may be a fire hydrant near the site with portable pipe or fire hose, a watercourse from which water can be readily pumped, a tank truck, or an earth stockpile. The best way to control deep fires is to separate the burning solid waste and dig a firebreak around the burning solid waste using a bulldozer. The solid waste is then spread out so it can be thoroughly wetted down or smothered with earth. Limiting the solid waste cells to about 200 tons, with a depth of 8 feet and 2 feet of compacted earth between cells (cells 20×85 feet assuming 1 yd^3 of compacted solid waste weighs 800 lb), will minimize the spread of underground fires. The daily 6-inch cover will also minimize the start and spread

of underground fires. Fires are a rare occurrence at a properly compacted and operated sanitary landfill.

Weigh Station It is desirable to construct a weigh station at the entrance to the site. Vehicles can be weighed upon entering and, if necessary, billed for use of the site. Scales are required to determine tonnage received, unit operation costs, relation of weight of solid waste to volume of in-place solid waste, area work loads, personnel, collection rates, organization of collection crews, and need for redirection of collection practices. However, the cost involved in construction of a weigh station cannot be always justified for a small sanitary landfill handling less than 20 to 50 tons/day. Nevertheless, estimates of volume and/or weights received should be made and records kept on a daily or weekly basis to help evaluate collection schedules, site capacity, usage, and so on. At the very least, an annual evaluation is essential.

Equipment Requirements To attain proper site development and ensure proper utilization of the land area, it is necessary to have sufficient proper equipment available at all times at the site (see Figure 3.39). One piece of solid waste compaction and earth-moving equipment is needed for approximately each 80 loads per day received at the solid waste site. The type of equipment should be suitable for the method of operation and the prevailing soil conditions. Additional standby equipment should be available for emergencies, breakdowns, and equipment maintenance. Typical equipment requirements are summarized in Table 3.23.

Excavating, Spreading, and Compaction Equipment The type of equipment used at landfills for the spreading and compaction of the material to be landfilled include the crawler, rubber-tired, and steel-wheeled types equipped with bulldozer blade, bullclam, or front-end loader. The crawler tractor with a front-end bucket attachment is an all-purpose piece of equipment (see Figure 3.40). It may be used to excavate trenches, place and compact solid waste, transport cover material, and level and compact the completed portion of the landfill. Some types can also be used to load cover material into trucks for transportation and deposition near the open face. The steel-wheeled compactor is a common piece of equipment at landfills.

A bulldozer blade on a crawler tractor is good for landfills where hauling of cover material is not necessary. It is well suited for the area method landfill in which cover material is taken from nearby hillsides. It can also be used for trench method operation where the trench has been dug with some other type of equipment. A bulldozer is normally used in conjunction with some other type of earth-moving equipment, such as a scraper, where earth is hauled in from a nearby source.

The life of a tractor is figured at about 10,000 hours. Contractors usually depreciate their equipment over a five-year period. On a landfill, if it is assumed that the equipment would be used 1,000 hours a year, the life of the

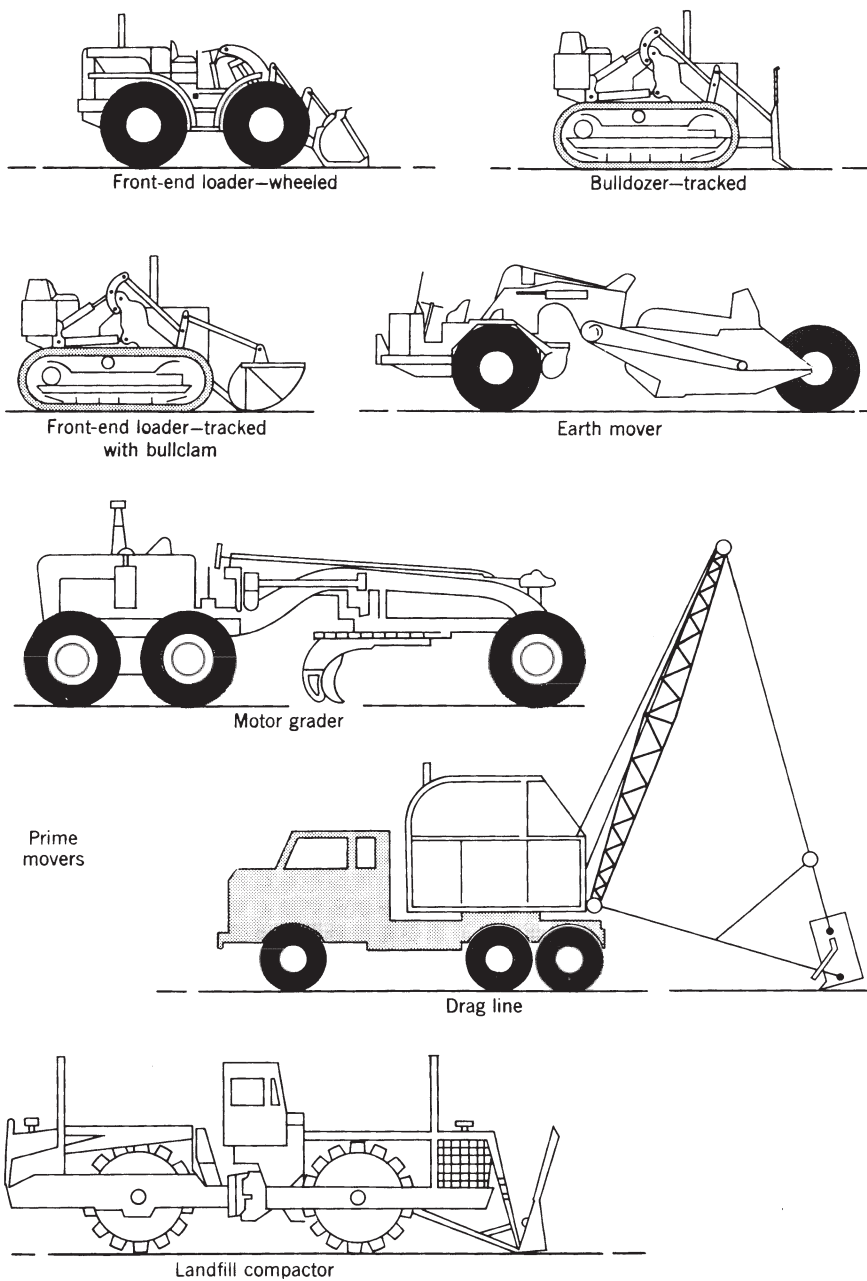


FIGURE 3.39 Typical equipment used for operation of sanitary landfill.

TABLE 3.23 Typical Minimum Landfill Equipment Requirements

Service Population	Daily Tonnage	Equipment		Accessory
		Number	Type	
0–15,000	0–50	1	Tractor, crawler, or rubber-tired	Dozer blade, landfill blade, front-end loader (1–2 yd ³)
15,000–50,000	50–150	1	Tractor, crawler, or rubber-tired	Dozer blade, landfill blade, front-end loader (2–4 yd) multipurpose bucket
50,000–100,000	150–300	1–2	Tractor, crawler, or rubber-tired	Dozer blade, landfill blade, front-end loader (2–5 yd), multipurpose bucket
100,000 or more	300 or more	2 or more	Tractor, crawler, or rubber-tired	Dozer blade, landfill blade, front-end loader, multipurpose bucket

Source: Adapted from D. R. Brunner, and D. J. Keller, *Sanitary Landfill Design and Operation*, EPA (SW-65ts), Washington, DC, 1972.



(a)



(b)

FIGURE 3.40 Common types of compaction equipment used at sanitary landfills: (a) track compactor with trash blade and (b) wheeled compactor with trash blade.

equipment could be 10 years. After 10 years, operation and maintenance costs can be expected to approach or exceed the annual cost of new equipment. Lesser life is also reported. Equipment maintenance and operator competence will largely determine equipment life.

The size and type of machine needed at the sanitary landfill are dependent on the amount of solid waste to be handled, availability of cover material, compaction to be achieved, and other factors.¹⁸ A rule that has been used is that a community with a population of less than 10,000 requires a 1 1/8-yd³ bucket on a suitable tractor. Communities with a population between 10,000 and 30,000 should have a 2 1/4-yd³ bucket, and populations of 30,000 to 50,000 should have at least a 3-yd³ bucket. Larger populations will require a combination of earth-moving and compaction equipment depending on the site and method of operation. A heavy tractor (D-8) can handle up to 200 tons of solid waste per day, although 100 to 200 tons per day per piece of equipment is a better average operating capacity. Tire fill foam and special tire chains minimize tire puncture and other damage on rubber-tired equipment.

Many small rural towns have earth-moving equipment that they use for highway maintenance and construction. For example, a rubber-tired loader with special tires can be used on a landfill that is open two days a week. On the other three days the landfill can be closed (with fencing and locked gate), and the earth-moving equipment can be used on regular road construction work and maintenance. The people and contract users of the site should be informed of the part-time nature of the operation to receive their full cooperation. The public officials responsible for the operation should establish a definite schedule for the assignment of the equipment to the landfill site to ensure the operation is always under control and maintained as a sanitary landfill.

Other Equipment The dragline is suitable for digging trenches, stockpiling cover material, and placing cover material over compacted solid waste. An additional piece of equipment is necessary to spread and compact the solid waste and cover material. Although not commonly used, the backhoe is suitable for digging trenches on fairly level ground, and the power shovel is suitable for loading trucks with cover material.

In large operations, earth movers can be used for the short haul of cover material to the site when adequate cover is not readily available nearby. Dump trucks may also be needed where cover material must be hauled in from some distance. Other useful equipment is a grader, a sheepsfoot roller, and a water tank truck equipped with a sprinkler to keep down dust or a power sprayer to wet down the solid waste to obtain better compaction.

Equipment Shelter An equipment shelter at the site will protect equipment from the weather and possible vandalism. The shelter can also be used to store fire protection equipment and other needed materials and for routine equipment maintenance and repair. Operators of sanitary landfills have found a shelter to be of great value during the winter months since there is much less difficulty

in starting motorized equipment. However, the shelter location must be on solid ground, not subject to gas migration from the landfill.

Landfill Operation and Supervision

Operational issues for modern landfills include operational control, personnel and operation, salvaging policy, area policing, insect and rodent control, maintenance, and operational policies (see also Table 3.21).

Operation Control The direction of operation of a sanitary landfill should be with the prevailing wind to prevent the wind from blowing solid waste back toward the collection vehicle and over the completed portion of the landfill. To prevent excessive wind scattering of solid waste throughout the area, snow fencing or some other means of containing papers should be provided. The fencing can be utilized in the active area and then moved as the operation progresses. In some instances, the entire area is fenced. Other sites have natural barriers around the landfill, such as is the case in heavily wooded areas. It is desirable to design the operation so that the work area is screened from the public line of sight. Noise levels between 7 a.m. and 10 p.m. are generally required to be kept below 60 dBA in rural areas, 65 in suburban areas, and 70 in urban areas beyond property lines.

Large items such as refrigerators, ranges, and other “white goods” and tires should be recycled. Brush and yard wastes are preferably composted. Other bulky items not recyclable should be placed in a separate area of the landfill for periodic burial. Prior compression or shredding of bulky objects will improve compaction of the fill, reduce land volume requirements, and allow more uniform settlement. Consideration should always be given to resource recovery and recycling where possible. Tires are usually not acceptable in landfills but may be if chipped or properly cut.

Drivers of small trucks and private vehicles carrying rubbish and other solid wastes interfere with the operation of a landfill. To accommodate these individuals on weekends and avoid traffic and unloading problems during the week, it is good practice to provide a special unloading area (convenience station) adjacent to the landfill entrance. A satellite transfer station is also an alternative, in conjunction with a regional landfill.

Personnel and Operation Proper full-time supervision is necessary to control dumping, compaction, and covering. Adequate personnel are needed for proper operation. Depending on the size of the community, there should be a minimum of one man at a site and six men per 1,000 yd³ dumped per day that the site is open. The supervisor should erect signs for direction of traffic to the proper area for disposal. It is essential that the supervisor be present at all hours of operation to ensure that the landfill is progressing according to plan. Days and hours of operation should be posted at the entrance to the landfill. A locked gate should be provided at the entrance to keep people out when closed. It is also advisable to inform the public of the days and hours of operation.

Solid waste treatment and disposal facilities represent very large investments. They have the potential for grave air, water, and land pollution and contain complex equipment and controls. Proper operation meets regulatory agency permit conditions and requires continuous, competent operational control. The training and certification of operators of resource recovery facilities, landfills, incinerators, and hazardous waste sites are provided by various state and private organizations.

In supervising an operation, the length of the open face should be controlled, since too large an open face will require considerably more cover material at the end of a day's operation. Too small an open face will not permit sufficient area for the unloading of the expected number of collection vehicles that will be present at one time. After vehicles have deposited the solid waste at the top or, preferably, at the base of the ramp as directed, the solid waste should be spread and compacted from the bottom up into a 12- to 18-inch layer (24 in. maximum) with a tractor. Three to five passes should give a compaction of 1,000 to 1,250 lb/yd³. *Passing over the waste should be done continually throughout the day* to ensure good compaction and vermin and fire control. If solid waste is allowed to pile up without spreading and compaction for most of the day, proper compaction will not be achieved, resulting in uneven settlement and extra maintenance of the site after the fill is completed. At the end of each day, the solid waste should be covered with at least 6 inches of earth or a suitable foam. For final cover of solid waste, at least 2 feet of earth is required.

No Burning or Salvaging Air pollution standards and sanitary codes generally prohibit any open burning. Limited controlled burning might be permitted in some emergency cases (for uncontaminated wood and stumps), but special permission would be required from the air pollution control agency, health department, and local fire chief. Arrangements for fire control, complete burning in one day, control over material to be burned (no rubber tires or the like), and restrictions for air pollution control would also be required. Salvaging at sanitary landfills is not recommended since, as usually practiced, it interferes with the operation. It will slow down the entire operation and thus result in time loss. Salvaging can also result in fires and unsightly stockpiles of the salvage material in the area.

Area Policing Since wind will blow papers and other solid waste around the area as the trucks are unloading, it will be necessary to clean up the area and access road at the end of each day. One of the advantages of portable snow fencing is that it will usually confine the papers near the open face, thereby make the policing job easier and less time consuming. At many sanitary landfills, dust will be a problem during dry periods of the year. A truck-mounted water sprinkler can keep down the dust and can also be used to wet down dry solid waste to improve compaction. The bulldozer operator should be protected by a dust mask, special cab, or similar device.

Insect and Rodent Control An insect and rodent control program is not usually required at a properly designed and operated landfill. However, from

time to time, certain unforeseen conditions may develop that will make control necessary. For this reason, prior arrangement should be made to take care of such emergencies until the proper operating corrections can be made. Prompt covering of solid waste is necessary.

Maintenance Once a sanitary landfill, or a lift of a landfill, is completed or partially completed, it will be necessary to maintain the surface to take care of differential settlement. Settlement will vary, ranging up to approximately 20 to 30 percent, depending on the compaction, depth, and character of solid waste. Ninety percent of the settlement can be expected in the first five years. Settlement maintenance is required for perhaps 20 or 30 years. Maintenance of the cover is necessary to prevent excessive precipitation and surface-water infiltration, erosion, ponding, and excessive cracking, allowing insects and rodents to enter the fill and multiply.

It is necessary to maintain proper surface-water drainage to reduce precipitation–infiltration and minimize percolation of contaminated leachate through the fill to the groundwater table or the surface. A final 4 percent grade, with culverts and lined ditches as needed, is essential. The formation of water pockets is objectionable since this will promote surface-water infiltration. Vehicular traffic over these puddles will wash away the final earth cover over the solid waste and cause trucks to bog down. The maintenance of access roads to the site is also necessary to prevent dust and the formation of potholes, which will slow down vehicles using the site. Finally, provision must be made for groundwater, surface-water and gas monitoring, and control. The landfill surface should be properly capped, graded, and planted with suitable tolerant vegetation as previously noted.

Summary of Recommended Operating Practices

1. The sanitary landfill should be planned as an engineering project, to be constructed, operated, and maintained by qualified personnel under technical direction, without causing air, land, or water pollution, safety or health hazards, or nuisance conditions. Surveying benchmarks should be established and maintained to guide fill progression and site closure. Careful supervision must be given to landfill bottom separation and soil compaction, construction of primary and secondary composite liners, synthetic liner placement and seals, and leachate drainage and collection system. Construction of the landfill cap requires similar supervision.
2. The face of the working fill should be kept as narrow as is consistent with the proper operation of trucks and equipment in order to keep the area of exposed waste material to a minimum.
3. All solid waste should be spread as dumped and compacted into 12- to 18-inch-thick layers as it is hauled in. Operate tractor up- and downslope (3:1) of fill to get good compaction—three to five passes.

4. All exposed solid waste should be covered with 6 inches of earth at the end of each day's operation.
5. The final earth covering for the surface and side slopes should minimize infiltration, be compacted, and be maintained at a depth of at least 24 inches. See state regulations.
6. The final level of the fill should provide a 4 percent slope to allow for adequate drainage. Side slopes should be as gentle as possible to prevent erosion. The top of the fill and slopes should be promptly seeded. Drainage ditches and culverts are usually necessary to carry away surface water without causing erosion.
7. The depth of solid waste should usually not exceed an average depth of 8 to 10 feet after compaction. In a landfill where successive lifts are placed on top of the preceding one, special attention should be given to obtain good compaction and proper surface water drainage. A settlement period of preferably one year should be allowed before the next lift is placed.
8. Control of dust, wind-blown paper, and access roads should be maintained. Portable fencing and prompt policing of the area each day after solid waste is dumped are necessary. If possible, design the operation so that it is not visible from nearby highways or residential areas.
9. Salvaging, if permitted by the operator of the solid waste disposal area, should be conducted in such a manner as not to create a nuisance or interfere with operation. Salvaging is not recommended at the site.
10. A separate area or trench may be desirable for the disposal of such objects as tree stumps, large limbs, if not shredded and recycled, and nonrecyclable miscellaneous materials.
11. Where necessary, provision should be made for the disposal, under controlled conditions, of small dead animals and septic tank wastes. These should be covered immediately. The disposal of wastewater sludge, industrial or agricultural wastes, and toxic, explosive, or flammable materials should not be permitted unless study and investigation show that the inclusion of these wastes will not cause a hazard, nuisance, or groundwater or air pollution. See appropriate regulatory agency for details.
12. An annual or more frequent inspection maintenance program should be established for completed portions of the landfill to ensure prompt repair of cracks, erosion, and depressions.
13. Sufficient equipment and personnel should be provided for the spreading, compacting, and covering of solid waste. Daily records should be kept, including type and amount of solid wastes received. *At least annually*, an evaluation should be made of the weight of solid waste received and volume of solid waste in place as a check on compaction and rate at which the site is being used.
14. Sufficient standby equipment should be readily available in case there is a breakdown of the equipment in use.

15. The breeding of rats, flies, and other vermin; release of smoke and odors; pollution of surface waters and groundwaters; and causes of fire hazards are prevented by proper operation, thorough compaction of solid waste in 12- to 18-inch layers, daily covering with earth, proper surface-water and groundwater drainage, and good supervision.
16. Leachate and gas-monitoring wells should be sampled periodically to detect significant changes. This should include methane concentrations in on-site or other nearby buildings.

Site Closure or Conversion

If a disposal site is to be closed, the users, including contractors, should be notified and an alternate site designated. A rat-poisoning (baiting) program should be started at least two weeks before the proposed closing of a site that has not been operated as a sanitary landfill and continued until the site has been completely closed. The site should be closed off and made inaccessible; it should be covered with at least 2 feet of compacted earth on the top and all exposed sides or as required by the regulatory agency, graded to shed water, seeded to grass, and then posted to prohibit further dumping. Side slopes should be no greater than 3:1 to reduce erosion and maintenance. Steps must be taken to prevent contravention of surface-water and groundwater standards, gas migration, or adverse health or environmental hazards. If the site is adjacent to a stream, the solid waste must be moved an appropriate distance back from the high-water level to allow for the construction of an adequate and substantially protected earth dike. Legal closure requirements may be quite onerous if groundwater pollution is suspected or if enclosed structures are in a vicinity that might be affected by methane migration.

Where adequate land is available and the site is suitable as determined by an engineering and hydrogeological analysis, it may be possible to convert the landfill into a properly designed, constructed, operated, and maintained sanitary landfill. Conversion of a *suitable* existing site can overcome the problems associated with the selection of a new site.

Landfill Closure Requirements The state regulatory agency closure requirements must be followed.

Use of Completed Landfill A sanitary landfill plan should provide for landscaping and a specific use for the area after completion. Final grades for a sanitary landfill should be established in advance to meet the needs of the proposed future use. For example, the use of the site as a golf course can tolerate rolling terrain while a park, playground, or storage lot would be best with a flat graded surface. Other uses of completed landfills include toboggan and ski runs for children, nature areas, bicycle and hiking paths, open areas, and airport runway extensions. In planning for the use of such an area, permanent buildings or habitable dwellings should not be constructed close to or over the fill since gas production beneath the ground may migrate into sewers, utility conduits, and basements or

through floor slabs and sump drains of such dwellings or buildings, reaching explosive levels. Some open structures that would not require excavation, such as grandstands and open equipment shelters, can be built on a sanitary landfill with little resulting hazard. Buildings constructed on sanitary landfills can be expected to settle unevenly unless special foundation structures such as pilings are provided; however, special provisions must be made to monitor and dissipate gas production. When the final land use is known beforehand, selected undisturbed ground islands or earth-fill building sites are usually provided to avoid these problems, but gas monitoring is still necessary.

INCINERATION

The incineration (also referred to as combustion) of solid waste involves the conversion of solid wastes into gaseous, liquid, and solid conversion products with the concurrent or subsequent release of heat energy. Incineration is typically implemented to reduce the volume of solid waste and, to the extent possible, recover energy. A properly designed and controlled incinerator is satisfactory for burning combustible municipal solid waste and chemical, infectious, and pathological wastes. In general, incineration is not generally recommended for small towns, villages, apartment buildings, schools, institutions, camps, and hotels unless good design and supervision can be ensured and cost is not a factor. Further, a landfill is a necessary adjunct for the disposal of incinerator residue and unrecycled solid waste. The purpose of this section is to review (1) the basic operations involved in the incineration of solid waste, (2) briefly the principal combustion products and residues formed during combustion, (3) the types of incinerators that are used for solid waste, (4) factors that must be controlled in the incineration process, (5) residuals management, (6) site selection, plant layout, and building design, and (7) issues in the implementation of incineration facilities.

Description of Operation of MSW Incinerator

The basic operations involved in the combustion of commingled MSW are identified in Figure 3.41. The operation begins with the unloading of solid wastes from collection trucks (1) into a storage pit (2). The length of the unloading platform and storage bin is a function of the size of the facility and the number of trucks that must unload simultaneously. The depth and width of the storage bin are determined by both the rate at which waste loads are received and the rate of burning. The capacity of the storage pit is usually equal to the volume of waste for two to four days. The overhead crane (3) is used to batch load wastes into the feed (charging) chute (4), which directs the wastes to the furnace (5). The crane operator can select the mix of wastes to achieve a fairly even moisture content in the charge. Large or noncombustible items are also removed from the wastes. Solid wastes from the feed (charging) chute fall onto the grates (6), where

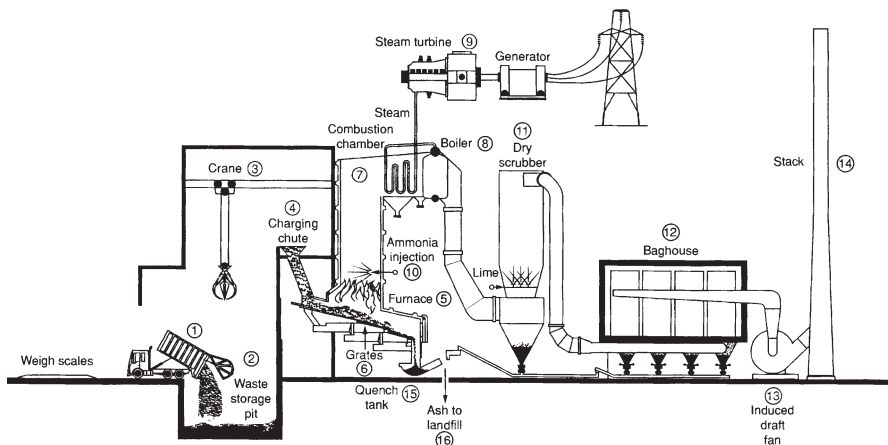


FIGURE 3.41 Definition sketch for operation of modern mass-burn incinerator.

they are mass fired. Several different types of mechanical grates are commonly used. Typical physical and chemical characteristics of incinerator solid waste are reported in Table 3.24.

Air may be introduced from the bottom of the grates (under-fire air) by means of a forced-draft fan or above the grates (over-fire air) to control burning rates and furnace temperature. Because most organic wastes are thermally unstable, various gases are driven off in the combustion process taking place in the furnace. These gases and small organic particles rise into the combustion chamber (7) and burn at temperatures in excess of 1600 °F. Heat is recovered from the hot gases using water-filled tubes in the walls of the combustion chamber and with a boiler (8) that produces steam that is converted to electricity by a turbine generator (9). When 30 percent or less of the solid waste is rubbish or when the solid waste contains more than 50 percent moisture, additional supplemental fuel will be needed.

Air pollution control equipment is required on all new incinerators. Air pollution control equipment may include ammonia injection for NO_x (nitrogen oxides) control (10), a dry scrubber for SO and acid gas control (11), and a bag house (fabric filter) for particulate removal (12). To secure adequate air flows to provide for head losses through air pollution control equipment, as well as to supply air to the combustor itself, an induced-draft fan (13) may be needed. The end products of combustion are hot combustion gases and ash. The cleaned gases are discharged to the stack (14) for atmospheric dispersion. Ashes and unburned materials from the grates fall into a residue hopper (15) located below the grates where they are quenched with water. Fly ash from the dry scrubber and the bag house is mixed with the furnace ash and conveyed to ash-treatment facilities (16). Details on incinerator design, air pollution control equipment, and ash treatment and disposal may be found in Refs. 2 and 15.

TABLE 3.24 Physical and Chemical Characteristics of Incinerator Solid Waste^a

Constituents	Percent by Weight (as received)
Proximate analysis	
Moisture	15–35
Volatile matter	50–65
Fixed carbon	3–9
Noncombustibles	15–25
Ultimate analysis	
Moisture	15–35
Carbon	15–30
Oxygen	12–24
Hydrogen	2–5
Nitrogen	0.2–1.0
Sulfur	0.02–0.1
Noncombustibles	15–25
Higher heating value (Btu/lb as received)	
Without recycling	3000–6000
With recycling	3000–5000

^aPrincipally residential–commercial waste.

Source: J. DeMarco, D. J. Keller, J. Leckman, and J. L. Newton, *Incinerator Guidelines—1969*, PHS Pub. 2012, Department of Health and Education, Washington, DC, 1969; and G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.

In addition to these operational aspects, complex instrumentation, including transmission to a central control panel, is necessary to properly operate a modern incinerator. Included are temperature indicators, air and water flows, pressure indicators, alarms, waste feed cutoffs when combustion and emission regulations are violated, and other indicators and controls that may be required by the regulatory authority.

Combustion Products and Residues

Municipal solid waste burned in incinerators will result in the production of combustion gases, particulates, and bottom and fly ash. The characteristics of these products will depend on the types of wastes burned and the incinerator design, operating temperature, residence time, and controls.

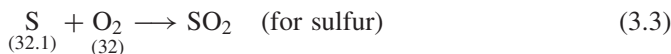
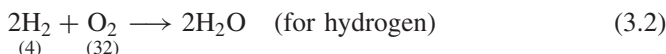
Combustion Essentials The three essentials for combustion, as outlined previously, are (1) time, (2) temperature, and (3) turbulence, including sufficient oxygen. There must be sufficient time to drive out the moisture, the temperature must be raised to the ignition point, and there must be sufficient turbulence to ensure mixing of the gases formed with enough air to burn completely the volatile combustible matter and suspended particulates. The combustion process

involves first, drying, volatilization, and ignition of the solid waste and, second, combustion of unburned furnace gases, elimination of odors, and combustion of carbon suspended in the gases. The second step requires a high temperature, at least 1500 to 1800 °F (816–982 °C) sufficient air, and mixing of the gas stream to maintain turbulence until burning is completed. The temperature in the furnace may range from 2100 to 2500 °F (1149–1371 °C) if not controlled. A combustion temperature of 2500 °F (1371 °C) is normal for steam generation and energy recovery.

When the gases leave the combustion chamber, the temperature should be between 1500 and 1800 °F (816 and 982 °C), and the gas entering the stack should be 1000 °F (538 °C) or less. The minimum temperature for burning carbonaceous wastes to avoid release of smoke is 1500 °F (816 °C). A temperature of less than 1500 °F will also permit the release of dioxins and furans. The exit temperature will have to be lowered to 200 °F (93 °C) for wool or cotton filters, 450 ° to 500 °F (232 °–260 °C) for glass fiber filters before the gas is filtered, or 600 °F (316 °C) or less if electrical precipitators are used. At a temperature of 1200 to 2000 °F (649–1093 °C) or higher, depending on temperature and residence time, oxides of nitrogen are formed that contribute to air pollution. Hospital wastes require incineration at a temperature of 1800 to 2000 °F (982–1093 °C) to ensure degradation of organic compounds. Inorganic agents are not destroyed.

Gaseous Combustion Products The principal elements of solid wastes are carbon, hydrogen, oxygen, nitrogen, and sulfur. Under ideal conditions, the gaseous products derived from the combustion of municipal solid wastes would include carbon dioxide (CO₂), water (H₂O, flue gas), oxygen (O₂), nitrogen (N₂), and small amounts of sulfur dioxide (SO₂). Because many different reaction sequences are possible, depending on the exact nature of the wastes and the operating characteristics of the combustion reactor, the gaseous emissions from combustion may include sulfur and nitrogen oxides and smaller amounts of hydrogen chloride, mercury, lead, arsenic, cadmium, dioxins and furans, and organic compounds. The amounts and concentrations going up the stack are determined also by the combustion effectiveness and the efficiency of air pollution control equipment.

The basic reactions for the oxidation (combustion) of the carbon, hydrogen, and sulfur contained in the organic fraction of MSW are as follows:



If it is assumed that dry air contains 23.15 percent oxygen by weight, then the amount of air required for the oxidation of 1 lb of carbon would be equal

to 11.52 lb $[(32/12)(1/0.2315)]$. The corresponding amounts for hydrogen and sulfur are 34.56 and 4.31 lb, respectively. Thermal processing systems are often categorized on the basis of their air requirements. Combustion with exactly the amount of oxygen (or air) needed for complete combustion is known as *stoichiometric combustion*. Combustion with oxygen in excess of the stoichiometric requirements is termed *excess air combustion*.

Combustion Residues The principal solid residues are (1) bottom ash, (2) fly ash, and (3) noncombusted organic and inorganic materials. The residue after burning (bottom and fly ash) is about 25 percent of the original weight (10 to 15 percent by volume), 5 percent where intensive recycling is practiced. Other residuals associated with the incineration of solid waste may include scrubber sludge and wastewater treatment plant sludge, both of which will tend to concentrate contaminants. It is essential, therefore, that the fly ash, bottom ash, and scrubber and wastewater sludge be analyzed for contaminants likely to be present and evaluated for their significance. The disposal method and facility should be tailored to ensure protection of the public health and the environment.

Types of Incinerators (Combustors)

A variety of incinerator types have been used for the combustion of solid waste, including (1) mass-fired combustors, (2) refuse-derived fuel- (RDF) fired combustors, (3) modular combustion units, and (4) on-site commercial and industrial incinerators.

Mass-Fired Combustors In a mass-fired combustor, minimal processing is given to solid waste before it is placed in the hopper used to feed the combustor. The crane operator in charge of loading the charging hopper can manually reject obviously unsuitable items. However, it must be assumed that anything in the MSW stream may ultimately enter the combustor, including bulky oversize noncombustible objects (e.g., broken tricycles) and even potentially hazardous wastes deliberately or inadvertently delivered to the system. For these reasons, the combustor must be designed to handle these objectionable wastes without damage to equipment or injury to operational personnel. The energy content of mass-fired waste can be extremely variable, dependent on the climate, season, and source of waste. In spite of these potential disadvantages, mass-fired combustors have become the technology of choice for most existing and planned incineration facilities.²⁵

A typical mass-burn incinerator schematic showing steam and electricity production is illustrated in Figure 3.42. Types of furnaces used are the rectangular refractory lined, the rotary kiln, and the rectangular furnace with waterwalls. In the rectangular furnace, two or more grates are arranged in tiers. The rotary kiln furnace incorporates a drying grate ahead of a rotary drum or kiln where burning is completed. Waterwall furnaces substitute water-cooled tubes for the exposed furnace walls and arches. Other types of furnaces are also available.

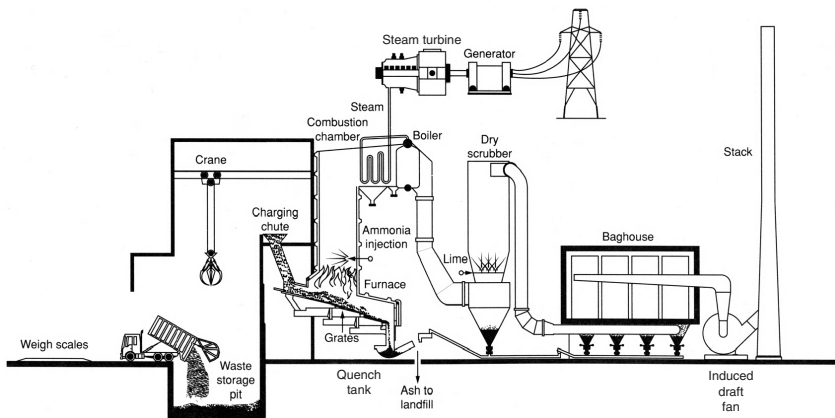


FIGURE 3.42 Schematic of typical mass-burn municipal waste combustion facility with energy production facilities. (Source: County Sanitation Districts of Los Angeles County.)

All furnaces should be designed for continuous feed. Reciprocating or moving and traveling grates are the most common. Mass-burn incinerators usually burn raw solid wastes in a refractory-lined rotary kiln after drying and combustion, with underfire and overfire air and a tube boiler to generate steam, hot water, or electricity. In a cogeneration incinerator, steam and electricity are produced.

Modern furnace walls are usually lined with tile or have waterwalls. With tile refractories, repairs can be readily made without the need for expensive and time-consuming rebuilding of entire solid brick walls found in old plants. Special plastic or precast refractories can be used for major or minor repairs. Waterwalls in a furnace actually consist of water-cooled tubes that also serve as heat exchangers, thereby reducing the outlet gas temperature and simplifying dust collection. The tubes also cover and protect exposed furnace walls and arches. Less air is required: 100 to 200 percent excess air for refractory walls compared to less than 80 percent for waterwalls. External pitting of the water-cooled tubes may occur if the water temperature drops below 300 °F (149 °C) due to condensation of the corrosive gases. Internal tube corrosion must also be prevented by recirculation of conditioned water.

RDF-Fired Combustors Compared to the uncontrolled nature of unprocessed commingled MSW, RDF can be produced from the organic fraction of MSW with fair consistency to meet specifications for energy content, moisture, and ash content. The RDF can be produced in shredded or fluff form or as densified pellets or cubes. Densified RDF (d-RDF) is more costly to produce but easier to transport and store. Either form can be burned by itself or mixed with coal and combusted in a waterwall furnace (see Figure 3.13) equipped with a traveling gate for ash management.

Because of the higher energy content of RDF compared to unprocessed MSW, RDF combustion systems can be physically smaller than comparatively rated

mass-fired systems. However, more space will be required if the front-end processing system needed to prepare the RDF is to be located adjacent to the combustor. A RDF-fired system can also be controlled more effectively than a mass-fired system because of the more homogeneous nature of RDF, allowing for better combustion control and better performance of air pollution control devices. Additionally, a properly designed system for the preprocessing of MSW can effect the removal of significant portions of metals, plastics, and other materials that may contribute to harmful air emissions.¹⁵

Modular Combustion Units Modular combustion units are available for capacities of less than 700 lb/hr to 250 tons/day and include a secondary combustion chamber. These units may be used for the batch incineration of municipal, hospital, commercial, and industrial wastes. Volume reduction of 80 to 90 percent and energy recovery of about 55 percent are claimed. Emission control (scrubber and/or baghouse) is needed and skilled operation is required.

On-site Commercial and Industrial Incinerators When possible, a large municipal incinerator should be used in preference to a small on-site incinerator. Better operation at lower cost with less air pollution can usually be expected. Based on past experience, conventional mass-fired incinerators generally are not economically feasible for communities with a population of less than 50,000 to 100,000, but modular controlled air units incorporating heat recovery are suitable for smaller volumes of waste. However, on-site incinerators are used in hospitals, schools, and commercial and industrial establishments. Their continued use is being severely limited by air pollution control requirements. Many of the units now in use need to be replaced or redesigned to meet modern air-pollution control standards. The controlled-air incinerator with a waste-heat boiler for energy recovery can overcome many, if not all, of the deficiencies.

Incinerator Capacity and Stack Heights Incinerators are rated in terms of tons of burnable or incinerable waste per day. For example, an incinerator having a furnace capacity of 600 tons/day can theoretically handle 600 tons in 24 hours with three-shift operation, 400 tons in 16 hours with two-shift operation, and 200 tons in 8 hours with one-shift operation. Hence, if 400 tons of incinerable wastes collected per day are to be incinerated in 8 hours, an incinerator with a rated capacity of 1,200 tons per day will be required plus a 15 percent downtime allowance for repairs. In determining design capacity, consideration must also be given to daily and seasonal variations, which will range from 85 to 115 percent of the median.

High stacks (chimneys) 150 to 200 feet above ground level are usually constructed to provide natural draft and air supply for combustion. Stack heights of 300 to 600 feet are not uncommon. Discharge of gases at these heights also facilitates dilution and dispersal of the gases. In some designs, short stacks are used for aesthetic reasons, and the equivalent effective stack height is obtained by induced draft. Meteorological conditions, topography, adjacent land use, air pollution standards, and effective stack height should govern.

Control of the Incineration Process

The poor image that incineration has in the eyes of many people is due largely to the failure to control the operation, with resultant destruction of the equipment and air pollution. A properly designed and operated incinerator requires control instrumentation for (1) temperature, (2) draft pressures, (3) smoke emission, (4) weights of solid wastes coming in and leaving the plant, and (5) air pollution control equipment. Competent well-trained operators are also essential.

Temperature Temperature monitoring is necessary for control purposes to monitor the incoming air and gases leaving the combustion chamber at the settling chamber outlet, the cooling chamber outlet, the dust collector inlet and outlet, and the stack temperature. Furnace temperature can be controlled by adjusting the amount of overfire or underfire air. The temperature of the gases leaving the furnace is reduced by spraying with water (causes a white stack plume unless the flue gas is reheated before discharge), dilution with cool air (high equipment cost to handle large volumes of diluted gases), or passing through heat exchangers (ready market for heat, steam, electricity, or high-temperature water needed). Gas scrubbers using water sprays can be used to cool effluent gas so that an induced-draft fan can be used to reduce the chimney height; large particulates can also be removed.

Draft Pressure Draft pressure measurements are needed to control the induced-draft fan and the stack draft. Measurements should be made at the underfire air duct, overfire air duct, stoker compartment, sidewall air duct, sidewall low-furnace outlet, dust collector inlet and outlet, and induced fan inlet. Control of underfire air can provide more complete combustion with less fly-ash carryover up the stack.

Smoke Density The smoke emission can be controlled by continuous measurement of the particulate density in the exhaust gas. A photoelectric pickup of light across the gas duct is used, preferably located between the particulate collector and the induced fan duct.

Weigh Station Platform scales to weigh and record the incoming solid waste and outgoing incinerator residue, fly ash, siftings, and other materials are generally required.

Instrumentation Devices should include those to keep record of overfire and underfire air flow rates; temperature and pressure in the furnace, along gas passages, in the particulate collectors, and in the stack; electrical power and water use; and grate speed.

Odor Odor control requires complete combustion of hydrocarbons—that is, excess air and a retention time of 1 sec at 1500°F (816°C) [above 1400°F (760°C) at the exit of the furnace]. Adequate dilution of gases leaving the stack

by an effective stack height (actual stack height plus plume rise) is another possible method for odor control, but its effectiveness is related to meteorological conditions and persistence of the odors. Wet scrubbers can also be used to absorb odors while removing particulates.

Gaseous Emissions The principal gaseous emissions from the combustion of mixed wastes are: carbon dioxide, water vapor, sulfur oxides, nitrogen oxides, carbon monoxide, and hydrogen chloride. Hydrogen chloride and other acids can cause corrosion of air pollution control equipment. A lime spray dry scrubber followed by a baghouse (fabric) filter is effective in greatly reducing sulfur dioxide and hydrogen chloride gases, metals, dioxins, furans, and organic emissions, as well as fly ash. There is some evidence that the lower the temperature of flue gases [below about 300 °F (149 °C)] entering the pollution control devices, the greater the amount of phenols, benzenes, dioxins, and other organics condensed and collected on the particulates. Typical gaseous emission guidelines are presented in Table 3.25.

Particulate Emissions These can be controlled by settling chambers, wetted baffle spray system, cyclones, wet scrubbers, electrostatic precipitators, and fabric filters. Apparently, only wet scrubbers, electrostatic precipitators, and bag filters can meet air pollution code requirements. Cyclones in combination with other devices might approach the standard. Typical particulate emission design and operating guidelines are presented in Table 3.25.

Residue Management

Incinerator ash and fly ash leaving the furnace (collected by scrubber, baghouse, electrostatic precipitator) may contain various concentrations of hazardous pollutants. These may require treatment and disposal so as not to endanger the public health or the environment. Concentrations of pollutants in incinerator bottom ash and fly ash will be determined by the characteristics of the waste burned, plant design, operation, efficiency of air cleaning devices, and other factors. It should also be noted that the EPA does not consider ash from an incinerator burning residential solid waste a hazardous waste, even though it may contain some metals.

To minimize the potential for the release of leachate from incinerator ash, there is a trend toward stabilization of the ash by cementing, vitrification, or asphaltting. Recycling of ash into a useful material is the preferred solution. Prevention of hazardous leachate is the goal. Up to 30 percent ash, by weight, can be used as an additive to cement for building materials and solidification in ceramics or glass. Incinerator bottom ash can be mixed with fly ash and lime from a dry scrubber. When properly moistened, the resultant ash–lime mixture will form a pozzolan-like cement in which the metals are immobilized and cannot leach out under normal conditions. It can be used as a road base or for similar purposes.

It is recommended that bottom and fly ash, if not reused, be disposed of in a properly designed and constructed sanitary landfill with a double liner or a

TABLE 3.25 Some Municipal Solid Waste Incineration Emission Design and Operation Guidelines

Control	Guidelines
Particulate emissions	Not greater than 0.010 grains ^a per dry standard cubic foot of exhaust (stack) gas, corrected to 7% oxygen; not greater than 0.015 grains at startup; existing, small to midsize units, up to 0.030 grains.
Carbon monoxide	Outlet concentration not greater than 50 ppm on an 8-hr average; 4-hr average and 100 ppm maximum proposed.
Hydrogen chloride emissions	A running 8-hr average emission of not greater than 10% by weight of uncontrolled emissions reduced by not less than 90%, or less than 50 ppm stack concentration (25 ppm proposed); flue gas at control device outlet not greater than 300 °F (149 °C); RCRA requires, for hazardous waste, 99% HCl removal, unless less than 4 lb/hr.
Sulfur dioxide	Not greater than 30 ppm or not less than 70% reduction, 24-hr daily average.
Nitrogen oxides	Best available technology to limit emissions, additional requirements in nonattainment areas.
Furnace design—operating temperature and residence time	Residence time for flue gas of at least 1 sec at no less than 1800 °F (982 °C) in combustion zone or a furnace design to provide a residence time for flue gas and a temperature which, in combination, are shown to be equivalent; auxiliary burner required; combustion index ^b of 99.9% for 8-hr average or 99.5% based on 7-day average; minimum furnace temperature of 1500 °F (816 °C) after last overfire air injection and 10% plume opacity, 15 min average; auxiliary burners to maintain furnace temperature.
Stack testing (at startup and at 18-month interval)	Within specified periods for carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen dioxide, oxygen, hydrogen chloride, and trace contaminants including arsenic, beryllium, cadmium, chromium, copper, zinc, lead, mercury ^c , nickel; polychlorinated dibenzo- <i>p</i> -dioxins, polychlorinated dibenzofurans, benzo- <i>a</i> -pyrene, total aromatic hydrocarbons, formaldehyde, and polychlorinated biphenyls; also particulates.
Continuous emission monitoring	Instrumentation for continuously monitoring emissions and operation parameters, including oxygen, plume opacity, sulfur dioxide, hydrogen chloride, nitrogen oxides, carbon monoxide, carbon dioxide, temperatures, and combustion index ^b ; file is kept of measurements and operation parameters, including steam pressure and flow, auxiliary fuel used, operation controls of electrostatic precipitators, fabric filters, gaseous contaminant emission control devices.

(continues)

TABLE 3.25 (continued)

Control	Guidelines
Dioxin or furan emissions ^d	Minimize to approach 0.2 ng/dry m ³ corrected to 7% oxygen, but not in excess of 2.0 ng/dry m ³ ^e .
Startup shutdown	Plan of practices and procedures to avoid unacceptable or excess emissions.
Operator certification	Operator training program; operation is directed at all times by certified operator.
Noise	Not greater than 60 dBA between 7 a.m. and 10 p.m. in rural area, 65 dBA suburban, and 70 dBA urban; between 10 p.m. and 7 a.m., 50 dBA rural, 55 dBA suburban, and 70 dBA urban.
Opacity	No emissions having average opacity of 10% or greater for any consecutive 6-min period, but may exceed 20% in 60-min period.
Operating records	As specified, retained at least 3 years; plan prepared for proper operation and maintenance prior to operation.

^a 1 grain = 0.064 g $\leq$ 180 mg/dry m³ (RCRA).

^b CI = CO₂ $\times$ 100/CO₂ + CO; CO₂ and CO in the exhaust gas, ppm by volume (dry) = combustion Index at 7% oxygen ($\leq$ 99.80% 8-hr average). Continuous monitoring is required.

^cMercury and mercury compounds in flue gas exist as a gas. They are not captured by fabric filters or electrostatic precipitators and hence may escape out of the stack. Mercury release should not exceed 0.002 lb Hg/ton of solid waste. Wet scrubbers remove mercury by condensing, but sludge requires treatment.

^dRCRA requires 99.9999% destruction and removal efficiency.

^eApproximately equivalent to 70 nanograms per normal cubic meter (ng/Nm³) (EPA). One nanogram = one billionth of a gram. A limit of 30 ng/m³ has been proposed.

Note: Plants and animals around incinerators can cumulate pollutants (contaminants) and serve as biological monitors for airborne metal and organic pollutants. Additional guidelines (and regulations) are being developed. See the Clean Air Act of 1990 and state regulations.

Source: J. A. Salvato, *Environmental Engineering and Sanitation*, 4th ed., Wiley, New York, 1992.

dedicated monofill. Bottom ash alone or bottom ash combined with fly ash may be disposed of in a sanitary landfill with a single liner. Control of dioxin, cadmium, and lead in ash is the major concern. The preferred landfill design would have two liners with groundwater monitoring and leachate collection above and between the liners, or the equivalent, to prevent the migration of hazardous leachate into groundwater.

Site Selection, Plant Layout, and Building Design

It is extremely important that a careful investigation be made of the social, physical, and economic factors involved when incineration is proposed. Some of the major factors are the following:

1. Public acceptance in relation to the surrounding land use and precautions to be taken in location and design to offset public objections should be

considerations. A location near the wastewater treatment plant, for example, may meet with less objection. Heat utilization for sludge drying or burning and use of treated wastewater for cooling are possibilities.

2. Site suitability in reference to foundation requirements, prevailing winds, topography, surface water and groundwater, floods, adjacent land uses, and availability of utilities should be considered. A location central to the source of wastes for minimum haul distance and smooth movement of traffic in and out of the site and readily accessible to major highways without interrupting traffic are important considerations.
3. Plant layout should be arranged to facilitate tasks to be performed and provide for adequate space, one-way traffic, parking, paving, drainage, and equipment maintenance and storage.
4. Building design should be attractive and provide adequate toilets, showers, locker room, and lunchroom. A control room, administrative offices, weighmaster office, maintenance and repair shops, and laboratory should be included. Adequate lighting contributes to attractiveness, cleanliness, and operating efficiency. Good landscaping will promote public acceptance.
5. Also to be evaluated are the availability and cost of providing electric power, water supply, sanitary sewers, and pretreatment required before plant wastewater can be discharged to the sewer and availability of storm sewers, telephone, and fuels.
6. The proposed method and cost of handling bulky and nonincinerable wastes should be taken into consideration when incineration is proposed. Also to be determined are the location and size of the sanitary landfill and its ability to receive incinerator residue as well as the bulky and nonincinerable solid wastes that are not recycled.
7. The incinerator design should provide for resource and energy recovery to the extent feasible.

The reader is referred to Chapter 2 for the broad aspects of community and facility planning and environmental impact analysis.

Issues in the Implementation of Incineration Facilities

The principal issues associated with the use of the incineration facilities for the transformation of MSW are related to (1) siting, (2) management of emissions, (3) public health, and (4) economics. Unless the questions related to these issues are resolved, implementation of solid waste incineration facilities will continue to be an uphill battle. These subjects are introduced briefly as follows.

Siting As with the siting of MRFs, discussed previously, it has been possible to build and operate combustion facilities in close proximity to both residential and industrial developments; however, extreme care must be taken in their operation if they are to be environmentally and aesthetically acceptable. Ideally, to minimize

the impact of the operation of combustion facilities, they should be sited in more remote locations where adequate buffer zones surrounding the facility can be maintained. In many communities, combustion facilities are in remote locations or at the landfill site.

Management of Emissions The operation of incineration facilities, as noted previously, results in the production of a variety of emissions, including (1) gaseous and particulate emissions, many of which are thought to have serious health impacts; (2) solid residuals, including bottom ash, fly ash, and scrubber product; and (3) liquid emissions, which can result from one or more of the following sources: wastewater from the ash removal facilities; effluent from wet scrubbers; wastewater from pump seals, cleaning, flushing, and general housekeeping activities; wastewater from treatment systems used to produce high-quality boiler water; and cooling tower blowdown. The demonstrated ability to control these emissions from an incineration facility effectively is of fundamental importance in the siting of incineration facilities. The proper design of control systems for these emissions is a critical part of the design of incineration facilities. In some cases, the cost and complexity of the environmental control system(s) are equivalent to or even greater than those of the combustion facilities.

Public Health Issues Emissions from a modern, properly designed and operated incineration facility are considered to be of little, if any, health significance but are perceived by some to be a serious hazard. The evidence is not conclusive as emissions are widely dispersed and their effects are difficult to evaluate. Nevertheless, pollution controls to prevent accidental emissions must be ensured. Sensitive individuals who have been exposed to high concentrations of dioxin have developed chloracne, a persistent skin dermatitis, and suffered liver and other disorders. Birth defects and cancer have not been demonstrated. Additional studies are needed to better identify and measure the effects of air pollutants inhaled and the effects of fallout. The significance of the types and amounts of pollutants and their persistence in the environment remain to be clarified.

Economics The economics of incineration must be evaluated carefully to choose between competing systems. The least expensive operation for a particular community would be determined by comparing the total annual cost, including operating costs and fixed charges on the capital outlay, for each method. It will generally be found that, for large cities, three-shift operation will be the least expensive. The two- or one-shift operation will be somewhat cheaper for the smaller community. The relative cost of maintenance, however, will be higher and the efficiency poor because of startup and shutdown of the furnace, with accompanying refractory brick spalling due to differential expansion and air pollution from fly ash. The best way to compare alternatives is by the use of life-cycle costing, which accounts for operating and maintenance costs over the lifetime of the system. The solid waste industry has developed a standardized approach to life-cycle costing through the use of the pro forma income statement.

HAZARDOUS WASTES

The identification and management of hazardous waste have become a major environmental undertaking and are the subject of a number of textbooks and numerous reference books. The purpose here is to introduce the subject of hazardous waste management. Topics to be considered include (1) definition of hazardous waste, (2) a review of pertinent legislation, (3) the generation of hazardous wastes, and (4) an introduction to hazardous waste management. Additional details may be found in Ref. 19.

Definition of Hazardous Waste

Under the RCRA of 1976, the term *hazardous waste* means a solid waste, or combination of solid wastes, that, because of its quantity, concentration, or physical, chemical, or infectious characteristics, may do one of two things:

1. Cause or significantly contribute to an increase in mortality or an increase in serious irreversible or incapacitating reversible illness.
2. Pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of or otherwise managed.

Hazardous wastes include chemical, biological, flammable, explosive, and radioactive substances. They may be in a solid, liquid, sludge, or gaseous (contained) state and are further defined in various federal acts designed to protect the public health and welfare, including land, air, and water resources.

A waste is regarded as hazardous if it is lethal, nondegradable, and persistent in the environment, can be magnified biologically (as in food chains), or otherwise causes or tends to cause detrimental cumulative effects. The EPA lists four characteristics of hazardous wastes:

1. *Ignitability*—wastes that pose a fire hazard during routine management. Fires not only present immediate dangers of heat and smoke but also can spread harmful particles (and gases) over wide areas.
2. *Corrosivity*—wastes requiring special containers because of their ability to corrode standard materials or requiring segregation from other wastes because of their ability to dissolve toxic contaminants.
3. *Reactivity* (or explosiveness)—wastes that, during routine management, tend to react spontaneously, react vigorously with air or water, are unstable to shock or heat, generate toxic gases, or explode.
4. *Toxicity*—wastes that, when improperly managed, may release toxicants in sufficient quantities to pose a substantial hazard to human health or the environment. Toxic wastes are harmful or fatal when ingested or absorbed. When toxic wastes are disposed of on land, contaminated liquid may

drain (leach) from the waste and pollute groundwater. Toxicity is identified through a laboratory procedure called the toxicity characteristics leaching procedure, which replaces the extraction procedure leach test. Organic chemicals, metals, and pesticides regulated under the toxicity rule are reported in Table 3.26.

Not included in RCRA hazardous waste regulations are domestic wastewater, irrigation waters or industrial discharges permitted under the federal Water Pollution Control Act, certain nuclear materials as defined by the Atomic Energy Act, household wastes (including toxic and hazardous waste), certain mining wastes, agricultural wastes (excluding some pesticides), and small-quantity wastes from businesses generating fewer than 220 lb of hazardous waste per month.

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended in 1986, defines hazardous substances as used in the Clean Air Act and the Clean Water Act (federal Water Pollution Control Act). The Department of Transportation, the Food and Drug Administration, the Occupational Safety and Health Administration, and the Consumer Product Safety Commission also define toxic or hazardous substance exposure.

Legislation

The RCRA of 1976, as amended, expands the purposes of the Solid Waste Disposal Act of 1965. It promotes resource recovery and conservation and mandates government (federal and state) control of hazardous waste from its point of generation to its point of ultimate disposal, including a manifest identification and permitting system. Legislation was prompted by the serious dangers associated with the improper handling and disposal of hazardous waste. The most common problems associated with the disposal of hazardous waste, in addition to public opposition, are groundwater pollution from lagoons, landfills, dumps, sludge disposal, other land disposal systems, spills, and unauthorized dumping.

RCRA Amendments In 1984, the RCRA was amended to require double liners or the equivalent and leachate collection systems at hazardous waste surface impoundments and landfills. Variances from groundwater monitoring to characterize the water quality before, during, and after operation are not allowed. The act as amended in 1984 applies to generators producing as little as 220 lb (100 kg) of hazardous waste in a calendar month, which must be sent to a state or federal approved facility.

The RCRA as amended also prohibits land disposal of certain classes of untreated hazardous wastes beyond specified dates unless it can be demonstrated to the EPA that there will be no migration of hazardous constituents from the land disposal unit for as long as the wastes remain hazardous. Land disposal includes landfill, surface impoundment (treatment and surface storage), waste pile, injection well, land treatment facility, salt dome or salt bed formation, and underground mine or cave.

TABLE 3.26 Organic Chemicals, Metals, and Pesticides Regulated under RCRA Toxicity Characteristic Rule^a

New Constituents	Regulatory Levels ^b (mg/l)	Old EP Constituents	Regulatory Levels ^c (mg/l)
Benzene	0.50	Arsenic	5.0
Carbon tetrachloride	0.50	Barium	100.0
Chlordane	0.03	Cadmium	1.0
Chlorobenzene	100.0	Chromium	5.0
Chloroform	6.0	Lead	5.0
<i>m</i> -Cresol	200.0 ^d	Mercury	0.2
<i>o</i> -Cresol	200.0	Selenium	1.0
<i>p</i> -Cresol	200.0	Silver	5.0
1,4-Dichlorobenzene	7.5	Endrin	0.02
1,2-Dichloroethane	0.50	Lindane	0.4
1,1-Dichloroethylene	0.70	Methoxychlor	10.0
2,4-Dinitrotoluene	0.13 ^e	Toxaphene	0.5
Heptachlor (and its hydroxide)	0.008	2,4-Dichlorophenoxyacetic acid	10.0
Hexachloro-1,3-butadiene	0.5	2,4,5-Trichlorophenoxy propionic acid	1.0
Hexachlorobenzene	0.13 ^e		
Hexachloroethane	3.0		
Methyl ethyl ketone	200.0		
Nitrobenzene	2.0		
Pentachlorophenol	100.0 ^f		
Pyridine	5.0 ^e		
Tetrachloroethylene	0.7		
Trichloroethylene	0.5		
2,4,5-Trichlorophenol	400.0		
2,4,6-Trichlorophenol	2.0		
Vinyl chloride	0.20		

^aBased on the Toxicity Characteristics Leaching Procedure (TCLP)

^bAdded in 1990.

^cBased on old Extraction Procedure (EP) leach test

^dIf *o*-, *m*-, and *p*-Cresol concentrations cannot be differentiated, the total cresol concentration is used. The regulatory level for total cresol is 200.0 mg/L.

^eQuantification limit is greater than the calculated regulatory level. The quantification limit, therefore, becomes the regulatory level.

^fThe agency will propose a new regulatory level for this constituent, based on the latest toxicity information.

Source: U.S. EPA (1990).

It should be noted that domestic wastewater, any mixture of domestic wastewater and any other waste that passes through a sewer system to a publicly operated treatment works (POTW) for treatment, and industrial wastewater discharges that are point-source discharges subject to NPDES permits are not considered to be solid or hazardous wastes. The POTW is then responsible to ensure that discharges to its sewers or plant do not contravene its NPDES permit or interfere with plant operation or sludge management.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980 CERCLA (Superfund) regulates leachate and other releases of hazardous substances from inactive and abandoned hazardous waste sites or from sites operating prior to November 1980. Businesses that produce between 220 and 2,000 lb of hazardous wastes in a calendar month are also regulated.

Most of the existing hazardous waste sites were created by the petroleum and chemical industries. Some municipal landfills received mixed solid waste, including toxic and hazardous commercial and industrial waste, in addition to small quantities of household cleaners, solvents, and pesticides. The result was pollution of the soil, groundwater, and surface water due to the infiltration and percolation of rain and snow melt, dissolution, and migration in the waste. In addition, toxic gases could be released from evaporating liquids, sublimating solids, and chemical reactions. CERCLA comes into play when hazardous waste sites are identified and classified.

The federal government can require the “person” who generated or transported the waste or owned or operated the disposal site to clean up the site. If a responsible person cannot be found, the federal government can perform the cleanup using a special fund (Superfund) established mainly by a tax on chemical production. Under such circumstances, states are required to contribute 10 percent of the cost of the cleanup. The federal and state governments may recover the cost, if the responsible person can be found.

Toxic Substances Control Act of 1976 The Toxic Substances Control Act (TSCA) of 1976 regulates the production, use, and disposal of chemical substances that may present an unreasonable risk of injury to health or environment. Manufacturers must give notice of plans to produce a new chemical or market a significant new use for an old chemical; they may be required to provide and keep records and reports.

Other Laws Other laws controlling hazardous substances include the following:

Clean Air Act (EPA)—regulates the emission of hazardous air pollutants.

Clean Water Act (EPA)—regulates the discharge of hazardous pollutants into the nation’s waters.

Marine Protection, Research, and Sanctuaries Act (EPA)—regulates waste disposal at sea.

Occupational Safety and Health Act (OSHA)—regulates hazards in the workplace, including worker exposure to hazardous substances.

Hazardous Materials Transportation Act (Department of Transportation)—regulates the transportation of hazardous materials.

Atomic Energy Act (Nuclear Regulatory Commission)—regulates nuclear energy production and nuclear waste disposal.

Surface Mining Control and Reclamation Act (Department of the Interior)—regulates the environmental aspects of mining (particularly coal) and reclamation.

Priority Toxic Pollutants and Hazardous Wastes Twenty-four toxic substances have been identified by the EPA, the Consumer Products Safety Commission (CPSC), the Food and Drug Administration (FDA), and the Occupational Safety and Health Administration (OSHA) for *joint* attack. The National Institute for Occupational Safety and Health (NIOSH) is also concerned with the control of toxic substances. The substances include acrylonitrile, arsenic, asbestos, benzene, beryllium, cadmium, chlorinated solvents (trichloroethylene, perchloroethylene, methylchloroform, and chloroform), chlorofluorocarbons, chromates, coke oven emissions, diethylstilbestrol (DES), dibromochloropropane (DBCP), ethylene dibromide, ethylene oxide, lead, mercury and mercury compounds, nitrosamines, ozone, polybrominated biphenyls (PBBs), polychlorinated biphenyls (PCBs), radiation, sulfur dioxide, vinyl chloride and polyvinyl chloride, and toxic waste disposals that may enter the food chain. Initially, the EPA listed 129 specific toxic pollutants, as reported in Table 3.27, for priority action.

Although legislation is very important, control also requires consideration of the social, political, and economic impacts of hazardous materials, in addition to health and environmental factors. Continual surveillance of spills and existing and abandoned waste sites for the present and for as long as the waste remains hazardous will be necessary.

Generation of Hazardous Waste

The major generators of hazardous waste among 15 industries studied by the EPA are as follows, more or less in order of the quantities produced:

- Primary metals
- Organic chemicals
- Electroplating
- Inorganic chemicals
- Textiles
- Petroleum refining
- Rubber and plastics

Examples of hazardous waste types generated by businesses and industries are given in Table 3.28. Hazardous wastes that are characterized as ignitable,

TABLE 3.27 Original 129 Priority Toxic Pollutants Identified by Council on Environmental Quality

Pollutant	Characteristics	Sources	Remarks
Pesticides: Generally chlorinated hydrocarbons	Readily assimilated by aquatic animals, fat soluble, concentrated through food chain (biomagnified), persistent in soil and sediments	Direct application to farmland and forestland, runoff from lawns and gardens, urban runoff, discharge in industrial wastewater	Several chlorinated hydrocarbon pesticides already restricted by EPA; aldrin, dieldrin, DDT, DDD, endrin, heptachlor, lindane, chlordane
Polychlorinated biphenyls (PCBs): used in electrical capacitors and transformers, paints, plastics, insecticides, other industrial products	Readily assimilated by aquatic animals, fat soluble, subject to biomagnification, persistent, chemically similar to chlorinated hydrocarbons	Municipal and industrial waste discharges disposed of in dumps and landfills	TSCA ban on production after June 1, 1979, but will persist in sediments; restrictions on many freshwater fisheries as result of PCB pollution (e.g., lower Hudson, upper Housatonic, parts of Lake Michigan)
Metals: antimony, arsenic, beryllium, cadmium, copper, lead, mercury, nickel, selenium, silver, thallium, zinc	Nonbiodegradable, persistent in sediments, toxic in solution, subject to biomagnification	Industrial discharges, mining activity, urban runoff, erosion of metal-rich soil, certain agricultural uses (e.g., mercury as fungicide)	
Asbestos	May cause cancer when inhaled, aquatic toxicity not well understood	Manufacture and use as retardant, roofing material, brake lining, etc.; runoff from mining	
Cyanide	Variably persistent, inhibits oxygen metabolism	Wide variety of industrial uses	

(continues)

TABLE 3.27 (continued)

Pollutant	Characteristics	Sources	Remarks
Halogenated aliphatics: used in fire extinguishers, refrigerants, propellants, pesticides, solvents for oils and greases and dry cleaning Ethers: Used mainly as solvents for polymer plastics	Largest single class of “priority toxics,” can cause damage to central nervous system and liver, not very persistent Potent carcinogen, aquatic toxicity and fate not well understood	Produced by chlorination of water, vaporization during use	Large-volume industrial chemicals, widely dispersed, but less threat to environment than persistent chemicals
Phthalate esters: Used chiefly in production of polyvinyl chloride and thermoplastics as plasticizers	Common aquatic pollutant, moderately toxic but teratogenic and mutagenic properties in low concentrations; aquatic invertebrates are particularly sensitive to toxic effects; persistent and can be biomagnified	Escape during production and use Waste disposal vaporization during use (in nonplastics)	Though some are volatile, ethers have been identified in some natural waters
Monocyclic aromatics (excluding phenols, cresols, and phthalates): used in manufacture of other chemicals, explosives, dyes, and pigments and in solvents, fungicides, and herbicides	Central nervous system depressant; can damage liver and kidneys	Enters environment during production and byproduct production states by direct volatilization; wastewater	

Phenols: large-volume industrial compounds used chiefly as chemical intermediates in production of synthetic polymers, dyestuffs, pigments, pesticides, and herbicides	Toxicity increases with degree of chlorination of phenolic molecule; very low concentrations can taint fish flesh and impart objectionable odor and taste to drinking water; difficult to remove from water by conventional treatment; carcinogenic in mice	Occur naturally in fossil fuels, wastewater from coking ovens, oil refineries, tar distillation plants, herbicide manufacturing, and plastic manufacturing; can all contain phenolic compounds
Polycyclic aromatic hydrocarbons: used as dyestuffs, chemical intermediates, pesticides, herbicides, motor fuels, and oils	Carcinogenic in animals and indirectly linked to cancer in humans; most work done on air pollution; more is needed on aquatic toxicity of these compounds; not persistent and are biodegradable though bioaccumulation can occur	Fossil fuels (use, spills, and production), incomplete combustion of hydrocarbons
Nitrosamines: used in production of organic chemicals and rubber; patents exist on processes using these compounds	Tests on laboratory animals have shown nitrosamines to be some of most potent carcinogens	Production and use can occur spontaneously in food cooking operations

Source: Council on Environmental Quality, *Environmental Quality*, the Ninth Annual Report of the Council on Environmental Quality, U.S. Government Printing Office, Washington, DC, 1978.

TABLE 3.28 Examples of Hazardous Waste Generated by Business and Industries

Waste Generators	Waste Type
Chemical manufacturers	Strong acids and bases, spent solvents, reactive wastes
Vehicle maintenance shops	Heavy-metal paint wastes, ignitable wastes, used lead acid batteries, spent solvents
Printing industry	Heavy-metal solutions, waste inks, spent solvents, spent electroplating wastes, ink sludges containing heavy metals
Leather products manufacturing	Waste toluene and benzene
Paper industry	Paint wastes containing heavy metals, ignitable solvents, strong acids and bases
Construction industry	Ignitable paint wastes, spent solvents, strong acids and bases
Cleaning agents and cosmetics manufacturing	Heavy-metal dusts, ignitable wastes, flammable solvents, strong acids and bases
Furniture and wood manufacturing and refinishing	Ignitable wastes, spent solvents
Metal manufacturing	Paint wastes containing heavy metals, strong acids and bases, cyanide wastes, sludges containing heavy metals

Source: U.S. EPA *Solving the Hazardous Waste Problem*, EPA/530-SW-86-037, EPA, Office of Solid Waste, Washington, DC, 1986.

corrosive, explosive, or toxic should be removed from industrial wastes prior to discharge to a municipal sewer. Many toxic wastes upset biological wastewater treatment processes and are transferred to the effluent and sludge, adding to the disposal problem.

Hazardous Waste Management

Hazardous waste management is a major health and environmental challenge. The ultimate *goal* should be *zero discharge*. However, until that goal is approached, the elements of hazardous waste management that must be dealt with include (1) source reduction at the point of generation; (2) recycling both on- and off-site; (3) transportation to processing and/or disposal facilities; (4) treatment and processing to reduce or eliminate toxicity, to reduce the volume, and to immobilize contaminants; and (5) secure long-term storage and disposal. Each of these subjects is considered briefly in the following discussion. Details on hazardous waste management may be found on the EPA web site and in Ref. 19.

Hazardous Waste Reduction In plant waste, reduction measures can be most effective in reducing the air, liquid, and solid waste contaminants generated, and hence the treatment needed to meet disposal standards, with resultant cost savings. In addition, treatment can result in the recovery of valuable materials that can

offset, in whole or in part, the cost of treatment. However, treatment to recover valuable materials may result in the production of other hazardous wastes, which, in turn, would require treatment and disposal.

Hazardous Waste Recycling Often, it may not be possible to reduce the volume or toxicity of some hazardous wastes. However, it may be possible to reuse the waste material in other processes within the same facility or other related facilities. Hazardous wastes that may be recycled either directly or after processing include water, solvents, spent oils, and selected solids. To enhance the recycling of waste materials at other facilities, waste exchange clearinghouses have been developed to facilitate such exchanges. Information that is required for waste exchange programs includes company ID code, category (acid, solvent, cutting fluid, etc.), primary usable constituents, contaminants, physical state, quantity, packaging, and geographic location.¹⁹

Hazardous Waste Transportation The transportation of hazardous wastes always introduces the possibility of accidental spills. Should this happen, the transporter is required to immediately notify the appropriate authorities (state police, environmental protection agency) and take whatever action is necessary to protect the public health and the environment. Information and advice on what to do and on the characteristics of the chemicals involved (see manifest) in an emergency is available 24 hours a day, 365 days a year, from the Chemical Emergency Center (CHEMTREC) operated by the Chemical Manufacturers Association. CHEMTREC's telephone number is 800-424-9300.

In case of fire or other emergency at a facility having hazardous materials, information concerning the site, materials, and precautions to be taken can be immediately obtained by response personnel from the National Oceanic and Atmospheric Administration (NOAA). A Computer-Aided Management Emergency Operations (CAMEO) system has been developed to facilitate immediate communication. More information is available from NOAA at 206-526-6317. Information availability is required by the Superfund Amendments and Reauthorization Act (SARA).

Hazardous Waste Processing Technologies The principal objectives of hazardous waste treatment are (1) toxicity reduction, (2) conversion to forms that can subsequently be processed by other technologies, (3) total elimination (e.g., complete destruction), (4) volume reduction, and (5) immobilization. Treatment technologies used to process hazardous wastes may be classified as (1) biological methods, (2) physicochemical processes, (3) stabilization and solidification, and (4) thermal destruction. The principal processes comprised by these technologies are reported in Table 3.29.¹⁹⁻²³

Long-Term Storage of Hazardous Wastes So-called secure land burial and deep-well disposal under carefully controlled conditions, *where permitted*,

TABLE 3.29 Typical Treatment Methods for Hazardous Wastes

Method	Typical Processes	Description
Biological methods	(1) Suspended growth processes (aerobic, anoxic, and anaerobic); (2) attached growth processes (aerobic, anoxic, and anaerobic); (3) combined suspended and attached growth processes (aerobic, anoxic, and anaerobic)	Biological processes are used to treat (1) liquids (contaminated groundwater, industrial process wastewaters, and landfill leachate); (2) slurries (sludges and contaminated soils with clean or contaminated water); (3) solids (contaminated soils); and (4) vapors (from other treatment processes).
	(1) Carbon adsorption; (2) chemical oxidation; (3) gas stripping; (4) steam stripping; (5) membrane separation; (6) supercritical fluids extraction and supercritical water oxidation	Granular activated carbon adsorption is used for the sorption of organic compounds from liquids. Powdered activated carbon is typically used in conjunction with the activated sludge treatment process. Chemical oxidation is used to detoxify a wide array of organic compounds. Stripping processes are used to remove volatile and semivolatile organics from industrial process waters. Membrane separation is used to remove contaminants from a variety of process waters and liquids. Supercritical fluids extraction and supercritical water oxidation are used to remove organics from water, sediments, and soil.
Physicochemical processes		

Stabilization and solidification	(1) Cement-based solidification; (2) pozzolan-based aggregate; (3) thermoplastic; (4) organic polymers	Stabilization and solidification processes are used for the (1) treatment of industrial wastes; (2) treatment of a variety of wastes, including incinerator bottom and fly ash, before placement in a secure landfill; and (3) treatment of large quantities of contaminated soil. These processes are all used to immobilize hazardous waste contaminants.
Thermal methods	(1) Vapor, liquid, and solid combustion; (2) catalytic volatile organic chemical (VOC) combustion; (3) fluidized-bed incinerators; (4) pyrolysis reactors	Thermal processes are used to destroy organic fraction of hazardous waste contaminants found in all types of waste streams, including gases and vapors, liquids, slurries, and solids.
Land disposal	(1) Municipal landfills; (2) monofill landfills; (3) land farming; (4) impoundment and storage facilities; (5) deep-well injection	The objective of land disposal is to ensure that wastes placed in such facilities do not migrate off-site. In land farming the objective is to bring about natural and biological decay of hazardous waste materials. The problem with deep-well injection is that the final location of the injected wastes is unknown.

Source: Adapted in part from LaGrega, M. D., P. L. Buckingham, and J. C. Evans, *Hazardous Waste Management*, 2nd ed., McGraw-Hill, New York, 2001.

are a last resort. In general, these types of disposal are strongly discouraged as they simply transfer the problem to another environmental media and must be monitored for the life of the hazardous waste. Some hazardous wastes, both solid and liquid, may be temporarily stored in clay, asphalt, concrete, soil cement, or (sodium) bentonite–soil lined basins, or in polymeric membrane lined basins, pending a decision on the best methods for treatment and disposal. Membrane linings are made of special rubber, polyethylene, polyolefin, polychloroprene, and polyvinyl chloride. All are usually suitable for wastewater and biodegradable industrial wastes. However, solvents, strong acids and caustics, and brines could damage clay or soil-based linings. Benzene and toluene, for example, are not contained by a clay liner, but when mixed with a small proportion of water and placed in a landfill, clay remains a good barrier. These chemicals, including pesticides, are best destroyed by controlled incineration. Petroleum-based organic wastes could damage some polymeric membranes and asphaltic materials. Carbon tetrachloride and xylene cause soil dehydration and possible cracking of clay soil. Clay liners must be carefully constructed with concern for lift thickness, soil moisture, type and weight of roller and number of passes, soil texture, and dry density to achieve the required permeability.

In view of the many limitations, *wastes and lining materials should be tested for effectiveness and compatibility before use*. In any case, all liners should be carefully placed on well-compacted subbases and, in addition, all basins storing hazardous wastes should incorporate a groundwater monitoring and surveillance system, including a leachate collection system and peripheral well monitoring. Two layers of linings with intermediate collection systems to collect possible leachate percolation and a groundwater monitoring system are required by the EPA. It can be assumed that all liners, cutoff walls, or other containments will eventually leak to some degree. Storage should be considered a temporary expedient. In all cases, strict compliance with approved design and construction specifications, and continuous professional inspection during construction must be ensured.

Monitoring of the air, surface water, and groundwater for as long as the waste remains a threat to the public health and the environment is an essential component of any site. Surface-water runoff and groundwater would be monitored for organic and inorganic chemicals. The air would be monitored for odors, volatile organics, and indicated toxic chemicals.

Basic Control Principles for Hazardous Waste Management As with most air, water, solid waste, and other pollution control activities, certain general and basic control principles can also be applied, as appropriate, to hazardous wastes. These include the following nine:

1. Elimination and reduction of waste at the source—This is done by prevention of leakage, segregation of hazardous waste, product reformulation, process or materials change, good housekeeping practices, and inventory control.

2. Recovery, reuse, and recycling of wastes—This includes return to the manufacturer, energy recovery, and waste exchange among compatible industries.
3. Concentration of waste by treatment—centrifugation, coagulation, sedimentation, filtration, flotation, surface impoundment, distillation, reverse osmosis, precipitation, solidification, encapsulation, evaporation, electro-dialysis, absorption, or blending.
4. Thermal decomposition—controlled high-temperature incineration and proper disposal of residue, also ocean incineration. Incinerators used include refractory lined, fixed hearth (controlled air), rotary kiln, cement kiln furnace, and fluidized bed.
5. Chemical treatment—chemical oxidation, precipitation, reduction, neutralization, chlorination, pyrolysis, detoxification, ion exchange, absorption, or chemical dechlorination processes.
6. Burial in a secure landfill—storage or containment with proper monitoring and surveillance (may be banned by the EPA or state).
7. Biological degradation accomplished through activated sludge, lagoon, or other biological treatment.
8. Stabilization, solidification, or encapsulation, including in-place vitrification.
9. Deep-well, mine, and ocean disposal under controlled conditions and if permitted; possibly composting and microwave decomposition. Ocean disposal of sludge has been banned effective December 31, 1991, but this prohibition is being reevaluated.

The methods available are not always completely effective and must be tailored to specific contaminants.

REFERENCES

1. U.S. EPA, *Decision-Makers Guide to Solid Waste Management*, EPA/530-SW89-072, EPA, Washington, DC, 1989; U.S. EPA, *Analysis of the Potential Effects of Toxics on Municipal Solid Waste Management Options*, EPA/600/R-95/047, EPA Office of Research and Development, Risk Reduction Engineering Laboratory, EPA, Cincinnati, OH, 1995, pp. xiv, xv.; G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993; H. L. Hickman, *Principles of Integrated Solid Waste Management*, American Academy of Environmental Engineers Publication, Annapolis, MD, 1999; New York State, *A Planning Guide For Communities Recycling*, New York State Department of Environmental Conservation, Division of Solid Waste, Albany, 1990; G. Tchobanoglous, and F. Kreith, *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002; U.S. EPA, *Decision Makers Guide to Solid Waste Management*, Vol. II, EPA 530-R-95-023, EPA, Washington, DC, 1995; U.S. EPA, *Full Cost Accounting for Municipal Solid Waste Management: A Handbook*, EPA 530-K-95-041, EPA,

- Washington, DC, 1997; and U.S. EPA, *Greenhouse Gas Emissions from Management of Selected Materials in Municipal Solid Waste*, EPA 530-R-92-013, EPA, Washington, DC, 1998.
2. G. Tchobanoglous, F. Kreith, and M. Williams, "Introduction," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 1.
 3. U.S. EPA, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006*, Executive Summary, Office of Solid Waste, EPA, Washington, DC, 2006. <http://www.epa.gov/garbage/pubs/msw06.pdf>; U.S. EPA, *Solid Waste Management And Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*, 3rd ed., Office of Solid Waste, EPA, Washington, DC, 2006.
 4. U.S. EPA, *Characterization of Municipal Solid Waste in the United States: 1998 Update*, EPA 530-R-99-021, EPA, Office of Solid Waste and Emergency Response, Washington, DC, 1999, and yearly updates; U.S. EPA, *Municipal Solid Waste in the United States: 1999 Facts and Figures*, Executive Summary, EPA530/S-01/014, Office of Solid Waste, EPA, Washington, DC, 2001; U.S. EPA, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2005, Executive Summary*, EPA530/S-01/014, Office of Solid Waste, EPA, Washington, DC, 2005, <http://www.epa.gov/garbage/pubs/mswchar05.pdf>; U.S. EPA, *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2006, Executive Summary*, Office of Solid Waste, EPA, Washington, DC, 2006, <http://www.epa.gov/garbage/pubs/msw06.pdf>.
 5. U.S. EPA, *Analysis of the Potential Effects of Toxics on Municipal Solid Waste Management Options*, EPA/600/R-95/047, EPA Office of Research and Development, Risk Reduction Engineering Laboratory, EPA, Cincinnati, OH, 1995, pp. xiv, xv.
 6. U.S. EPA, *Characterization of Construction and Demolition Debris in the United States*, EPA/530-R-96-010, EPA, Washington, DC, 1998.
 7. CFR, Title 40, Code of Federal Regulations, U.S. Government, Washington, DC.
 8. H. Theisen, "Solid Waste Collection," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 7.
 9. U.S. EPA, *Spotlight on Waste Prevention: EPA's Program to Reduce Solid Waste at the Source*, EPA 530-K-95-002, EPA, Washington, DC, 1995; U.S. EPA, *The Consumer's Handbook for Reducing Solid Waste*, EPA 530-K-96-003, EPA, Washington, DC, 1996; U.S. EPA, *Municipal Solid Waste Source Reduction: A Snapshot of State Initiatives*, EPA 530-R-98-017, EPA, Washington, DC, 1998.
 10. U.S. EPA, *Material Recovery Facilities for Municipal Solid Waste Handbook*, EPA625/6-91/031, Office of Research and Development, EPA, Washington DC, 1991.
 11. H. Leverenz, G. Tchobanoglous, and D. B. Spencer, "Recycling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.
 12. A. H. Benedict, E. Epstein, and J. Alpert, *Composting Municipal Sludge: A Technology Assessment*, Noyes Data Corporation, Park Ridge, NJ, 1988.
 13. L. F. Diaz, G. M. Savage, and C. G. Golueke, "Composting of Municipal Waste," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 10.

14. R. T. Haug, *The Practical Handbook of Compost Engineering*, Lewis Publishers, Boca Raton, FL, 1993.
15. G. Tchobanoglous, H. Theisen, and S. Vigil, *Integrated Solid Waste Management: Engineering Principles and Management Issues*, McGraw-Hill, New York, 1993.
16. R. T. Haug, *Compost Engineering*. Ann Arbor: Ann Arbor Science Publishers, Inc., 1980.
17. A. Bagchi, *Design of Landfills and Integrated Solid Waste Management*, 3rd ed., John Wiley and Sons, Hoboken, NJ, 2004.
18. D. R. Brunner, and D. J. Keller, *Sanitary Landfill Design and Operation*, EPA (SW-65ts), Washington, DC, 1972.
19. M. D. LaGrega, P. L. Buckingham, and J. C. Evans, *Hazardous Waste Management*, 2nd ed., McGraw-Hill, New York, 2001.
20. G. W. Dawson and B. W. Mercer, *Hazardous Waste Management*, Wiley, New York, 1986.
21. U.S. EPA, *Handbook Remedial Action at Waste Disposal Sites*, EPA/625/6-85/006, *Hazardous Waste Engineering Research Laboratory, Office of Research and Development*, EPA, Cincinnati, OH, 1985.
22. U.S. EPA *Solving the Hazardous Waste Problem*, EPA/530-SW-86-037, EPA, *Office of Solid Waste*, Washington, DC, 1986.
23. U.S. EPA, *A Compendium of Technologies Used in the Treatment of Hazardous Wastes*, U.S. EPA/625/8-87/014, Center for Environmental Research Information, EPA, Cincinnati, OH, 1987.

BIBLIOGRAPHY

- Benedict, A. H., E. Epstein, and J. Alpert, *Composting Municipal Sludge: A Technology Assessment*, Noyes Data Corporation, Park Ridge, NJ, 1988.
- Corey, R. C., *Principles and Practices of Incineration*, Wiley-Interscience, New York, 1969.
- Council on Environmental Quality, *Environmental Quality*, the Ninth Annual Report of the Council on Environmental Quality, U.S. Government Printing Office, Washington, DC, 1978.
- Dawson, G. W., and B. W. Mercer, *Hazardous Waste Management*, Wiley, New York, 1986.
- DeMarco, J., D. J. Keller, J. Leckman, and J. L. Newton, *Incinerator Guidelines—1969*, PHS Pub. 2012, Department of Health and Education, Washington, DC, 1969.
- Franklin Associates, *Characterization of Municipal Solid Waste in the United States: 1998 Update*, EPA/530-R-99-021, EPA, Washington, DC, 1999.
- Haug, R. T. *The Practical Handbook of Compost Engineering*, Lewis Publishers, Boca Raton, FL, 1993.
- Hickman, H. L., *Principles of Integrated Solid Waste Management*, American Academy of Environmental Engineers Publication, Annapolis, MD, 1999.
- Leverenz, H., G. Tchobanoglous, and D. B. Spencer, "Recycling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 8.
- Malcolm Pirnie Engineers, *Comprehensive Solid Waste Planning Study—1969*, Herkimer-Oneida Counties, State of New York Department of Health, Albany, 1969.

- New York State, *Municipal Energy Recovery Facilities Handbook*, New York State Environmental Facilities Corporation, Albany, 1988.
- New York State, *6 NYCRR Part 360, Solid Waste Management Facilities*, New York State Department of Environmental Conservation, Division of Solid Waste, Albany, 1990a.
- New York State *A Planning Guide For Communities Recycling*, New York State Department of Environmental Conservation, Division of Solid Waste, Albany, 1990b.
- O'Leary, P. R., and G. Tchobanoglous, "Landfilling," in G. Tchobanoglous and F. Kreith (Eds.), *Solid Waste Handbook*, 2nd ed., McGraw-Hill, New York, 2002, Chapter 14.
- Salvato, J. A., *Environmental Engineering and Sanitation*, 4th ed., Wiley, New York, 1992.
- SCS Engineers, Inc., *Procedural Guidance Manual for Sanitary Landfills: Volume I Landfill Leachate Monitoring and Control Systems and Volume II Landfill Gas Monitoring and Control Systems*, California Waste Management Board, Sacramento, CA, April, 1989.
- U.S. EPA, *Composting of Municipal Solid Wastes in the United States*, EPA, Washington, DC, 1971.
- U.S. EPA, *Process Design Manual, Municipal Sludge Landfills*, EPA-625/1-78-010, EPA, Washington, DC, 1978.
- U.S. EPA, *Municipal Waste Combustion Study, Report to Congress*, EPA/530-SW-87-021a, EPA, Washington, DC, 1987.
- U.S. EPA, *Organic Chemicals, Metals, and Pesticides Regulated Under the RCRA Toxicity Characteristic Rule*, U.S. EPA Environmental Fact Sheet, U.S. EPA/530-SW-89-045, Office of Solid Waste and Emergency Response, EPA, Washington, DC, 1990.
- U.S. EPA, *Material Recovery Facilities for Municipal Solid Waste Handbook*, EPA/625/6-91/031, Office of Research and Development, EPA, Washington DC, 1991.
- U.S. EPA, *Analysis of the Potential Effects of Toxics on Municipal Solid Waste Management Options*, EPA/600/R-95/047, EPA Office of Research and Development, Risk Reduction Engineering Laboratory, EPA, Cincinnati, OH, 1995, pp. xiv, xv.
- U.S. EPA, *Spotlight on Waste Prevention: EPA's Program to Reduce Solid Waste at the Source*, EPA 530-K-95-002, EPA, Washington, DC, 1995.
- U.S. EPA, *The Consumer's Handbook for Reducing Solid Waste*, EPA 530-K-96-003, EPA, Washington, DC, 1996.
- U.S. EPA, *Greenhouse Gas Emissions from Management of Selected Materials in Municipal Solid Waste*, EPA 530-R-92-013, EPA, Washington, DC, 1998.
- U.S. EPA, *Characterization of Construction and Demolition Debris in the United States*, EPA/530-R-96-010, EPA, Washington, DC, 1998.
- U.S. EPA, *Solid Waste Management And Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*, 3rd ed., Office of Solid Waste, EPA, Washington, DC, 2006.
- U.S. EPA, *Bioreactors*, Office of Solid Waste, EPA, Washington, DC, 2008, <http://www.epa.gov/garbage/landfill/bioreactors.htm>.
- Weston, R. F., *A Statewide Comprehensive Solid Waste Management Study*, New York State Department of Health, Albany, 1970.

CHAPTER 4

AIR POLLUTION AND NOISE CONTROL

ROBERT JACKO AND TIMOTHY LA BRECHE

Department of Civil Engineering, Purdue University, West Lafayette, Indiana

AIR POLLUTION

Air pollution is the presence of solids, liquids, or gases in the outdoor air in amounts that are injurious or detrimental to humans, animal, plants, or property or that unreasonably interfere with the comfortable enjoyment of life and property. Air pollution inside dwellings or places of assembly is discussed under Indoor Air Quality in Chapter 5, “Environmental Emergencies and Emergency Preparedness” by Pedro M. Armenante, James P. Mack in *Environmental Engineering, Sixth Edition: Prevention and Response To Water-, Food-, Soil-, and Air-Borne Disease And Illness*. The composition of clean air is shown in Table 4.1. The effects of air pollution are influenced by the type and quantity of pollutants and their possible interactions* as well as wind speed and direction, typography, sunlight, precipitation, vertical change in air temperature, photochemical reactions, height at which pollutant is released, and susceptibility of the individual and materials to specific contaminants—singularly and in combination. Air pollution is not a new or recent phenomenon. It has been recognized as a source of discomfort for centuries as smoke, dust, and obnoxious odors. The solution of any air pollution problem must avoid transferring the pollutant removed to another medium, without adequate treatment.

*Synergism, antagonism, additive.

TABLE 4.1 Composition of Clean, Dry Air near Sea Level

Component	Percent by Volume	Content (ppm)
Nitrogen	78.09	780,900
Oxygen	20.94	209,400
Argon	0.93	9,300
Carbon dioxide	0.0318	318 ^a
Neon	0.0018	18
Helium	0.00052	5.2
Krypton	0.0001	1
Xenon	0.000008	0.08
Nitrous oxide	0.000025	0.25 ^b
Hydrogen	0.00005	0.5
Methane	0.00015	1.5 ^c
Nitrogen dioxide	0.0000001	0.001
Ozone	0.000002	0.02
Sulfur dioxide	0.00000002	0.0002
Carbon monoxide	0.00001	0.1
Ammonia	0.000001	0.01

^a352 ppm in 1989; 369 ppm in 2000, Mauna Loa, Hawaii.
^b0.304 ppm in 1985; 0.314 ppm in 1999 based on Advanced Global Atmospheric Gases Experiment (AGAGE), Cape Grim, Tasmania, Australia monitoring sites.
^c1.7 ppm in 1990; 1.73–1.84 ppm in 1999 based on AGAGE values from Cape Grim, Tasmania, Australia and Mace Head, Ireland monitoring sites.
Note: The concentrations of some of these gases may differ with time and place, and the data for some are open to question. Single values for concentrations, instead of ranges of concentrations, are given to indicate order of magnitude, not specific and universally accepted concentrations.
Sources: *Cleaning Our Environment—The Chemical Basis for Action*, American Chemical Society, 1969, p. 4 (copyright 1969 by the American Chemical Society; reprinted with permission); with C. E. Junge, *Air Chemistry and Radioactivity*, Academic, New York, 1963, p. 3; A. C. Stern (ed.), *Air Pollution*, Vol. 1, 2nd ed., Academic, New York, 1968, p. 27; E. Robinson and R. C. Robbins, *Sources, Abundance, and Fate of Gaseous Atmospheric Pollutants*, prepared for American Petroleum Institute by Stanford Research Institute, Menlo Park, CA, 1968.

Health Effects

Humans are dependent on air. We breathe about 35 lb of air per day as compared with the consumption of 3 to 5 lb of water and 1~HF lb (dry) of food. Pollution in the air may place an undue burden on the respiratory system and contribute to increased morbidity and mortality, especially among susceptible individuals in the general population. Particulates greater than 3 μm in diameter are likely to collect in the lung lobar bronchi; smaller particulates (less than 3 μm) end up in the alveoli, the thoracic or lower regions of the respiratory tract, where more harm can be done. Health effects are discussed under under illnesses associated with air pollution—lung disease in Chapter 3 “Control of Diseases of The Air and Land” by Nabarun Dasgupta in *Environmental Engineering, Sixth Edition: Prevention and Response To Water-, Food-, Soil-, and Air-Borne Disease And Illness*.

Some well-known air pollution episodes are given in Table 4.2. The illnesses were characterized by cough and sore throat; irritation of the eyes, nose, throat, and respiratory tract; and stress on the heart. The weather conditions were typically fog, temperature inversion, and nondispersing wind. The precise levels at which specific pollutants become a health hazard are difficult to establish by existing surveillance systems, but they probably are well in excess of levels currently found in the ambient air. Meteorological factors, sample site, frequency and measurement methods, including their accuracy and precision, all enter into data interpretation. Nevertheless, standards to protect the public health are necessary and have been established. (See Tables 4.5 through 4.7 later in the chapter.)

It should be noted that whereas smoking is a major contributor to respiratory disease in the smoker, air pollution, climate, age, sex, and socioeconomic conditions affect the incidence of respiratory disease in the general population. Occupational exposure may also be a significant contributor in some instances. However, the effects may be minimized by engineering and individual controls. Where engineering controls are not adequate, respirators can provide good protection if adapted to the type and concentration of airborne contaminants, provided they are properly fitted, maintained, and actually used. However, respirators should never be considered an equivalent alternate to engineering controls. They should only be used after a thorough review of engineering controls has determined that process modifications and engineering controls are absolutely infeasible or where the risk to human health associated with the failure of an engineering control is excessive.

Economic Effects

Pollutants in the air cause damage to property, equipment, and facilities, in addition to increased medical costs, lost wages, and crop damage. Sulfur and formaldehyde pollution attack copper roofs and zinc coatings. Steel corrodes two to four times faster in urban and industrial areas due to moisture, chloride, sulfate, and ammonium pollution. The usual electrical equipment contacts become unreliable unless serviced frequently; clothing fabric, rubber, plastics, and leather are weakened; lead-based paints, banned in home construction but still in use in certain industrial applications, are degraded by hydrogen sulfide and oil-based paints by sulfur dioxide; and building surfaces and materials (especially carbonate rock by sulfur dioxide) and works of art are corroded and deteriorate. In addition, particulates (including smoke) in polluted air cause erosion, accelerate corrosion, and soil clothes, buildings, cars, and other property, making more frequent cleaning and use of indoor air-filtering equipment necessary. Ozone reduces the useful life of rubber and other elastomers, attacks some paints, discolours dyes, and damages textiles. See also "Measurement of Materials' Degradation," later in this chapter.

The U.S. Environmental Protection Agency (EPA) is required to periodically assess the cost and benefit of the Clean Air Act (CAA). These reviews have

TABLE 4.2 Some Major Air Pollution Episodes

Location	Excess Deaths	Illnesses	Causative Agents
Meuse Valley, Belgium December 1930	63	6000	Probably SO ₂ and oxidation products with particulates from industry—steel and zinc.
Donorra, Pennsylvania October 1948	20	7000	Not proven; particulates and oxides of sulfur high; probably from industry—steel and zinc; temperature inversion
Poza Rica, Mexico 1950 London, England December 1952	22 4,000	320 Increased	H ₂ S escape from a pipeline Not proven; particulates and oxides of sulfur high; probably from household coal-burning; fog
January 1956	1,000	—	—
December 1957	750	—	—
January 1959	200–250	—	—
December 1962	700	—	—
December 1967	800–1,000	—	—
New York, New York November 1953	165	—	Increased pollution
October 1957	130	—	Increased pollution
January–February 1963	200–400	—	SO ₂ unusually high (1.5 ppm maximum)
November 1966	152,168	—	Increased pollution and inversion
New Orleans, Louisiana October 1955	2	350	Unknown
1958	—	150	Believed related to smoldering city dump

Location	Excess Deaths	Illnesses	Causative Agents
Seveso and Meda, Italy ^a July 1976	Unknown, long-term	200+	Dioxin, an accidental contaminant formed in the manufacture of 2,4,5-T and hexachlorophene—a bactericide
Bhopal, India December 1985	2,000–5,000	8,000 disabled, 200,000 injured	Leak of methyl isocyanate from pesticide factory
Chernobyl, Soviet Union ^b April 1986	31 on site, more than 300 total	130,000 evacuated; 6,000 workers	Nuclear power plant accidental release, explosion and fire

^aA reactor overheated, the safety valve opened, and 4~HF lb of dioxin discharged for 30 min to the atmosphere. About 50 persons were hospitalized, 450 children had a skin disease, 200 families (735 persons) were evacuated, and 40,000 contaminated animals were killed. (*Conserv. News*, December 1, 1976, pp. 8–9; Associated Press, Seveso, Italy, July 10, 1977.) Contaminated soil and vegetation over 272 acres was stripped and incinerated. By July 1977, many homes were cleaned and 500 persons were ready to be admitted. No major illnesses or effects reported other than chloracne (dermatitis) and increased stress-related cardiovascular mortality [P. Bertazzi et al., *Am. J. Epidemiol.*, **129**, 1187 (1989).]

^bExcess fallout-related cancer cases over the lifetime of the populations of Europe and the Soviet Union are estimated at 800,000–950,000. (R. H. Nussbaum, Comments on “Health Effects from Radiation,” *Environ. Sci. Technol.*, (July 1988).) The actual risk is not likely to be known. Excess lifetime cancer deaths are estimated at 17,000. (T. G. Davis, “Chernobyl: The Aftermath,” *J. Environ. Health*, (March/April 1989); 185–186.) Perhaps 150,000 people suffered some sort of thyroid illness, of which 60,000 were children, 13,000 very seriously. An estimated 6000 workers became ill. (F. X. Clines, “A New Arena for Soviet Nationalism: Chernobyl,” *New York Times*, December 30, 1990, p. 1.) The United Nations International Atomic Energy Agency concluded in May 1991 that the major harm was that due to anxiety and stress rather than physical illness. (“Ten Years after Chernobyl,” *Ann. Med.*, (April 1996).) Thyroid cancers increased dramatically in Belarus, Ukraine, and Bryansk regions of Russia. [Radioactive Contamination of Wood and Its Products,” *J. Environ. Radioactivity*, **55** (2), (2001): 179–86.] Contamination of timber and subsequent distribution of irradiated products such as furniture and lumber will likely lead to increase in radiation exposure.

been both retrospective and prospective. In a retrospective review of the cost and benefit of the CAA between 1970 and 1990, a mean monetized benefit of \$22.2 trillion (in 1990 dollars) was estimated. The cost of compliance in the same period was estimated at \$0.5 trillion. Specific benefits included in these estimates were as follows:

- Agriculture; net surplus due to ozone reduction, \$23 billion
- IQ (intelligence quotient, lost IQ points + children with IQ < 70 points), \$399 billions
- Chronic bronchitis, \$3.3 trillion
- Reduced mortality due to particulate matter reduction, \$16.6 billion

All of these values are mean values and have varying ranges based on the uncertainty associated with estimating each parameter. For example, the 5th percentile “low” benefit associated with the period of 1970 to 1990 was \$5.6 trillion, while the 95th percentile “high” benefit was \$49.4 trillion. The costs associated with complying with the CAA are more easily monetized and have much less variability because they are primarily associated with pollution control equipment design, purchase, and maintenance. Other control costs include policy development, regulatory enforcement, and regulatory pollution monitoring, all of which are eventually borne by shareholders, customers, and taxpayers.¹ The daily personal cost of air pollution can be tallied by over-the-counter medicines to treat the medical symptoms of air pollution as well as lost work days and decreased productivity and quality of life.²

Effects on Plants

It has been suggested that plants be used as indicators of harmful contaminants because of their greater sensitivity to certain specific contaminants. Hydrogen fluoride, sulfur dioxide, smog, ozone, and ethylene are among the compounds that can harm plants. Urban smog is likely to contain carbon monoxide, soot, dust, and ozone from the reaction of sunlight on nitrogen oxides, hydrocarbons, and other volatile organic compounds. Assessment of damage shows that the loss can be significant, although other factors such as soil fertility, temperature, light, and humidity also affect production. Ozone has been indicated in forest decline and in damage to a variety of other agriculture products.³ Among the plants that have been affected are truck garden crops (New Jersey), orange trees (Florida), orchids (California), and various ornamental flowers, shade trees, evergreen forests, alfalfa, grains, tobacco, citrus, lettuce (Los Angeles), and many others. In Czechoslovakia more than 300 mi² of evergreen forests was reported severely damaged by sulfur dioxide fumes.⁴ Smog such as the type found in Los Angeles is the product of a photochemical reaction involving nitrogen oxides, hydrocarbons and oxygen. Where local topography and meteorology inhibit dispersion, smog can accumulate to unhealthy concentrations. Photochemical smog has also been reported in New York, Japan, Mexico City, Madrid, the United

Kingdom, and other congested areas with high motor vehicle traffic. The brown clouds associated with smog are due to excess NO_x , which preferentially absorbs light from the blue-green spectrum. The remaining colors result in the brownish color associated with smog that can reduce visibility and is aesthetically displeasing.⁵

Injury to plants due to ozone shows up as flecks, stipple and bleaching, tip burns on conifers, and growth suppression. Peroxyacyl nitrate* (PAN) injury is apparent by glazing, silvering, or bronzing on the underside of the leaf. Sulfur dioxide injury shows up as bleached and necrotic areas between the veins, growth suppression, and reduction in yield. Hydrogen fluoride injury is evidenced by plant leaf tip and margin burn, chlorosis, dwarfing, abrupt growth cessation, and lowered yield.⁶ See also "Acid Rain (Acidic Precipitation)," later in this chapter.

Effects on Animals

Fluorides have caused crippling skeletal damage to cattle in areas where fluorides absorbed by the vegetation are ingested. Animal laboratory studies show deleterious effects from exposure to low levels of ozone, photochemical oxidants, and PAN. Lead and arsenic have also been implicated in the poisoning of sheep, horses, and cattle. All of the canaries and about 50 percent of the animals exposed to hydrogen sulfide in the Poza Rica, Mexico, incident (see Table 4.2) were reported to have died. Morbidity and mortality studies are ongoing to determine actual impacts of air pollutants on animals.

Aesthetic, Climatic, and Related Effects

Insofar as the general public is concerned, smoke, dust, and haze, which are easily seen, cause the greatest concern. Reduced visibility not only obscures the view but is also an accident hazard to air, land, and water transportation. Soiling of statuary, clothing, buildings, and other property increases municipal and individual costs and aggravates the public to the point of demanding action on the part of public officials and industry. Correction of the air pollution usually results in increased product cost to the consumer, but failure to correct pollution is usually more costly.

Air pollution, both natural and manmade, affects the climate. Dust and other particulate matter in the air provide nuclei around which condensation takes place, forming droplets and thereby playing a role in snowfall and rainfall patterns. Haze, dust, smoke, and soot reduce the amount of solar radiation reaching the surface of the earth. Aerosol emissions from jet planes also intercept some of the sun's rays.

Certain malodorous gases interfere with the enjoyment of life and property. In some instances, individuals are seriously affected. The gases involved include hydrogen sulfide, sulfur dioxide, aldehydes, phenols, polysulfides, and some

*Also cause of eye irritation.

olefins. Air pollution control equipment such as thermal oxidizers and carbon absorbers are available to eliminate or control these objectionable compounds.

Effect of Carbon Dioxide and Other Gases on Global Warming Solar energy, as light in the form of short-wavelength radiation, that reaches the earth is absorbed and reradiated back to the atmosphere as long-wavelength infrared radiation or heat energy. (Ultraviolet radiation has little effect on earth warming.) However, carbon dioxide, methane, chlorofluorocarbons (CFCs), clouds and atmospheric water vapor, and nitrous oxides tend to trap the reradiated heat, causing a reflection of that heat back to the earth and a warming of the lower atmosphere, oceans, and the earth's surface—known as the greenhouse effect. According to the EPA, carbon dioxide constitutes 49 percent of the greenhouse effect, as compared to methane 18 percent, CFCs 14 percent, nitrous oxides 6 percent, and other gases 13 percent.⁷ Still other estimates place the relative contributions as carbon dioxide 57 percent, CFCs 25 percent, methane 12 percent, and nitrous oxide 6 percent.⁸ The relative contributions will always be flux depending on the concentration in the atmosphere and because all greenhouse gases are not equal in their warming potential. Certain manmade compounds are far more effective greenhouse gases than other naturally occurring compounds. Nitrous oxide, both man made and naturally occurring, is 310 times more effective than carbon dioxide. Hydrofluorocarbon (HFC) 23, a manmade refrigerant, is 11,700 times more effective than carbon dioxide.⁹

Industrial, power plant, and automobile emissions and the burning of fossil fuels and forests contribute carbon dioxide and other gases to the atmosphere. This is in addition to the carbon dioxide naturally released during respiration and decomposition. Methane is produced by the decay of organic matter in wetlands, rice paddies, ruminant animals and termites, forest fires and wood burning, landfills, and gas drilling and releases. Chlorofluorocarbon sources include refrigerants, solvents, and plastic foam manufacture. Sources of nitrogen oxides include burning coal and other fossil fuel, fertilizer breakdown, and soil bacteria reactions. Other gases involved to a lesser extent are carbon monoxide and sulfur dioxide.

The warming effect of the gases in the lower atmosphere is offset to some extent by the cooling effect of the haze, dust, smoke, soot, and dust from volcanic eruptions that intercept and reduce the solar radiation reaching the earth. However, evaporation from the warmed oceans and other bodies of water and land surfaces due to greenhouse warming would be increased, as would vegetation transpiration, causing further cooling. The increased evaporation would also cause an increase in precipitation in some areas. In addition, the oceans, rain, and growing forests and other vegetation during photosynthesis altogether remove or absorb significant quantities of carbon dioxide. These processes that remove carbon dioxide from the environment are often referred to as carbon dioxide "sinks." Tropical rain forests are a major carbon dioxide sink, and their destruction both adds carbon dioxide to the atmosphere and removes a carbon repository.

There seems to be agreement that the destruction of tropical rain forests should be brought under control and that a massive global reforestation program is

desirable. However, the planting of even a billion trees a year for 10 years is estimated to absorb only about 1 to 3 percent of the carbon dioxide produced by human activity in the United States. Federal analysts have reached similar conclusions. They estimated that planting 20 billion trees per year could capture up to 67 percent of the nation's annual emissions of carbon dioxide under the best of conditions. Although trees take in carbon dioxide and return oxygen to the air, storing the carbon in the wood, fully mature trees neither store nor emit carbon. Eventually, annual tree growth roughly equals the loss and decay of branches and leaves.¹⁰ But there are many other ecological and aesthetic reasons to save the tropical forests.

Ultimately, large reductions in oil and coal burning are needed to substantially reduce carbon dioxide emissions. Energy conservation and greater use of renewable resources such as hydroelectric power, solar energy, wind power, geothermal energy, wave energy, and biomass energy, where possible, can all reduce the net increase of global warming gases. However, they are not without their own technical and feasibility issues. Nuclear power generation is essentially carbon dioxide emission free, but political as well as safety concerns have prevented wider adoption of the technology in the United States. The result has been the expansion of fossil-fueled power plants. The release of carbon dioxide will expand for many years to come if alternate sources of energy are not developed.

New-generation nuclear reactors such as pebble bed systems offer the possibility of intrinsic safety and even decentralized power systems. Recent research has shown that if the full production process is considered when comparing nuclear to coal-fueled power systems, the actual damage to human health has been far greater historically with coal power production than with nuclear production. These analyses consider the total product cycle from raw-material extraction to power delivery. When the dangers of fuel extraction and processing are factored into the risk associated with coal power production, the nuclear options appear safer.¹¹

In addition to temperature rise, the probable net projected effects of increased greenhouse gases include changes in rain, snow, and wind patterns that affect agriculture, overall precipitation, humidity, soil moisture, and storm frequency. The growing season would be lengthened. Melting polar ice would raise ocean levels.

In spite of many uncertainties, according to *Climate Change 2001: The Science Basis*, and *Climate Change 2007: The Physical Science Basis*,¹² it appears that the carbon dioxide level and global warming are increasing. However, many scientists believe that the facts (and assumptions) do not adequately support the predictions.¹³ A recently published journal article points out that the earth has been in a warming cycle since the year 1800 and the increased use of fossil fuels beginning in about 1950 has had no effect on glacier shortening. Moreover, Arctic air temperature appears to correlate well with solar activity, while hydrocarbon use does not correlate.¹⁴ An astrophysicist with the Harvard Smithsonian Centre for Astrophysics commented that the "best current science offers little justification for rapid cuts in carbon dioxide" and believes "human-made global warming is relatively minor and will be slow to develop."¹⁵ In any case, there is agreement

on the need to maintain and improve environmental quality and conserve natural resources.

Effect of Ozone and Chlorofluorocarbons Another global factor is the ozone layer in the upper atmosphere (stratosphere), about 8 to 30 miles above the earth's surface. It helps shield the earth by filtering out or absorbing harmful UV solar radiation. Ozone is formed naturally by the action of sunlight on the oxygen molecule. When released in the lower atmosphere (troposphere), CFCs and halons (a compound consisting of bromine, chlorine, and carbon) migrate upward to the stratosphere through the mixing force of wind, where they remain chemically stable as long as 400 years. When exposed to UV solar radiation, CFCs release chlorine atoms and certain other gases that react with ozone in the stratosphere, reducing the total amount of ozone available to intercept destructive UV radiation. The chlorine in one CFC molecule is believed to destroy tens of thousands of ozone molecules. Bromine is more than 40 times as destructive as chlorine. Nitrous oxide also contributes to ozone depletion.¹⁶ Chemical fertilizers, soil bacteria, burning forests, and fossil fuels are sources of nitrous oxide.

The destruction of ozone by CFCs, halons, and other compounds permits more of the solar radiation to reach the earth, which could cause an increase in skin cancer, eye cataracts, and changes in climate and animal and plant life. This additional solar radiation could also overexpose and kill phytoplankton, a major source of food for fish, seals, penguins, and whales. Subsequent phytoplankton reduction, including algae, would result in less uptake of carbon dioxide. This would cause an increase in the atmospheric carbon dioxide level and contribute to the earth's warming and a reduction in aquatic life and our food supply, as previously noted.

Chlorofluorocarbons remain in the stratosphere for 75 to 110 years.¹⁷ Because of the potential health and environmental effects, steps have been taken to phase out products containing CFCs and halons throughout the world. The product sources include refrigerants (dichlorodifluoromethane, or freon), industrial solvents, volatile paints, plants manufacturing plastic foams, and aerosol spray cans containing CFC propellant. The CFCs are no longer used as blowing agents in the manufacture of food service disposables.¹⁸ Bromine from halons used primarily in fire extinguishers and from chemicals used to make fire retardants, soil fumigants, and agricultural products also destroy ozone by reacting with chlorine synergistically in the absence of oxygen and sunlight.¹⁹ Methyl chloroform and carbon tetrachloride contribute to the problem. Existing refrigerating systems using CFCs that are scrapped remain future sources of CFC release if not contained, recycled, or otherwise controlled. Suggested alternatives to CFCs include hydrochlorofluorocarbons (HCFCs),²⁰ which, although not as harmful as CFCs, should nevertheless be recycled. A global attack was started in 1987—the Montreal Protocol on Substances that Deplete the Ozone Layer—was signed by 32 countries, with a goal to reduce the 1986 level of use of CFCs and halons by 50 percent.²¹ In May 1989, representatives of the European Economic Community (EEC) and 81 other countries, including the United States and Canada, agreed to phase out all CFC use by the year 2000, if possible, as well as the use of halons,

carbon tetrachloride, and methyl chloroform.²² In June 1990, environment ministers from 93 nations met in London and agreed to phase out the production and use of CFCs and related chemicals, including halons and carbon tetrachloride, by the end of the century and methyl chloroform by 2005. The HCFCs are to be phased out between 2000 and 2040.

Ozone is also formed in the lower atmosphere (troposphere), which extends upward for about 8 miles. There, nitrogen oxides, gasoline vapors, and other hydrocarbon emissions from refineries, motor vehicles, solvents, and the like react with sunlight and heat. However, the EPA believes that ozone in the lower atmosphere near the ground level does not replace ozone lost from the upper levels.²³ Ozone at ground level causes lung dysfunction and irritation of the mucous membranes of the eyes, nose, and throat as well as tree and crop damage. Under stable conditions, ozone interactions cause smog and deterioration of exterior paints, rubber, synthetic fibers, and plastics.

Acid Rain (Acidic Precipitation) Releases of nitrogen and sulfur oxides and carbon dioxide, as well as other pollutants, are carried into the atmosphere, where they interact with sunlight and vapor and may be deposited as *acid rain* many miles from the source. The term includes rain, snow, sleet, fog, mist, and clouds containing sulfuric acid, nitric acid, and carbonic acid, as well as direct dry deposition. Large regional emissions and then deposition over a limited area exacerbate the acid rain problem, such as in the northeast United States and eastern Canada. The Southeast, Midwest, West, Rocky Mountain states, western Europe, Scandinavia, and eastern Europe are also affected. In New York and the Northeast, 60 to 70 percent of the reported acidity is due to sulfuric acid, 30 to 40 percent to nitric acid. The relative proportion of each is indicative of the probable preponderant pollutant sources.²⁴ Major sources of sulfur dioxide, nitrogen oxides, and carbon dioxide are coal- and oil-burning power plants, refineries, and copper and other metal smelters. Principal sources of nitrogen oxide emissions²⁵ are electric utility and industrial boilers and motor vehicles. Nitrogen oxides from motor vehicle and high-temperature combustion not only contribute to photochemical smog but to changes in the atmosphere, and they return to earth in acid form mixed with precipitation.

High stacks permit the discharge of pollutants into the upper air stream that are then carried great distances by prevailing winds, usually from west to east in the United States. Natural sources of sulfur dioxide, such as active volcanoes, the oceans, and anaerobic emissions from decaying plants, fertilizers, and domestic animals, contribute to the problem. However, the risk to the public health and welfare is complex and very difficult to quantify.²⁶ There does not appear to be any significant threat to the public health,²⁷ although this is debatable. About half of all atmospheric sulfur worldwide is reported to come from natural sources.²⁸ The main contributor to *natural* acidity is carbon dioxide. The natural acidity of precipitation may vary from pH 5.4 to 5.7* (with the lower pH in the northeast

*Lemon juice has a pH of 2, vinegar 3, pure rain 5.6, distilled water 7, and baking soda 8.2.

United States according to the National Acid Deposition Program of 1978 to 1984) and may be as low as 4.0 to 4.6 or lower. While a forest canopy may reduce acidity and ammonia, particulates in the air may, in part, neutralize the acid.

As previously noted, acidic precipitation contributes to deterioration of buildings, monuments and statues, roofing materials, and automobiles. It is also believed to adversely affect trees (mainly conifers at high altitudes), possibly crops and other vegetation. Ozone at ground level is also reported to be a major cause of forest decline.²⁹ Acidic precipitation may be temporarily beneficial to some vegetation.³⁰ However, a second stage of acid rain can kill nitrogen-fixing microorganisms and cause decreased production, and then death, as acidity penetrates the soil profile and root system. Calcium and magnesium, necessary for tree growth, are leached from the soil. Aluminum in the soil also becomes available for vegetative uptake. The calcium and magnesium/aluminum ratio is decreased, impairing tree and root growth as the toxic aluminum accumulates in the roots. Susceptibility to insects and stresses due to cold, drought, and heat increase.³¹ Forest management, climate, soil nutrients, and geology may also play a role.

Acid rain also adversely affects lakes and streams, where the pH may be reduced to less than 5.0, with resultant reduced fish production. The decomposition of organic deposits contributes to lake acidity. Acidification and demineralization of soils cause higher input of toxic aluminum and other metals to lakes and streams. The condition is more apparent in a lake or groundwater when its buffering capacity and that of the surrounding soil (alkalinity and calcium) are reduced or exhausted. This leads to the release of toxic metals to water supply sources, particularly to shallow well-water supplies. There could also be accumulation in fish, as, for example, increased levels of mercury, aluminum, cadmium, and zinc of 10 to 100 times the normal range.

Control measures should start with coal desulfurization at mining sites and source reduction, such as at high-sulfur oil- and coal-burning plants, and with nitrogen oxides from motor vehicles. Further reduction can be achieved by flue gas desulfurization and the use of scrubbers and other emission control devices. The use of alternative, low-sulfur fuels, as well as hydroelectric, nuclear, and solar power, should also be considered. The application of lime or limestone to lakes and their watersheds is only a temporary measure, a long-term solution must be found.

Acid rain is only one aspect of air pollution. Other toxic stack emissions requiring control include hazardous air pollutants (HAPs) such as lead, mercury, cadmium, zinc, vanadium, arsenic, copper, selenium, and organic pollutants. These must be eliminated or reduced to innocuous levels.

SOURCES AND TYPES OF AIR POLLUTION

The sources of air pollution may be manmade, such as the internal combustion engine, or natural, such as plants (pollens). The pollutants may be in the form

of particulates, aerosols, and gases or microorganisms. Included are pesticides, odors, and radioactive particles carried in the air.

Particulates range from less than 0.01 to $1000\text{ }\mu\text{m}^*$ in size; generally they are smaller than $50\text{ }\mu\text{m}$. Smoke is generally less than $0.1\text{ }\mu\text{m}$ size soot or carbon particles. Those below $10\text{ }\mu\text{m}$ can penetrate the lower respiratory tract; particles less than $3\text{ }\mu\text{m}$ reach the tissues in the deep parts of the lung. Particles over $10\text{ }\mu\text{m}$ are removed by the hairs at front of nose. Included are dust and inorganic, organic, fibrous, and nonfibrous particles. Aerosols are usually particles $50\text{ }\mu\text{m}$ to less than $0.01\text{ }\mu\text{m}$ in size; although generally they are less than $1\text{ }\mu\text{m}$ in diameter. Gases include organic gases such as hydrocarbons, aldehydes, and ketones and inorganic gases (oxides of nitrogen and sulfur, carbon monoxide, hydrogen sulfide, ammonia, and chlorine).

Manmade Sources

Air pollution in the United States is the result of industrialization and mechanization. The major sources and pollutants are shown in Table 4.3. It can be seen that carbon monoxide is the principal pollutant by weight and that the motor vehicle is the major contributor, followed by industrial processes and stationary fuel combustion. However, in terms of hazard, it is not the tons of pollutant that is important but the toxicity or harm that can be done by the particular pollutant released. Lead has shown the most dramatic reduction, due to the use of unleaded gasoline.

Agricultural spraying of pesticides, orchard-heating devices, exhaust from various commercial processes, rubber from tires, mists from spray-type cooling towers, and the use of cleaning solvents and household chemicals add to the pollution load. Toxic pollutant emissions and their fate in the environment need further study.

Particulates, gases, and vapors that find their way into the air without being vented through a stack are referred to as *fugitive emissions*. They include uncontrolled releases from industrial processes, street dust, and dust from construction and farm cultivation. These need to be controlled at the source on an individual basis.

Wood stoves contribute significantly to air pollution. This type of pollution is a potential health threat to children with asthma and elderly people with chronic lung problems. Wood stove use may have to be limited. Stoves are being redesigned to keep the air pollution at acceptable levels.

Natural Sources

Discussions of air pollution frequently overlook the natural sources. These include dust, plant and tree pollens, arboreal emissions, bacteria and spores, gases and dusts from forest and grass fires, ocean sprays and fog, esters and terpenes from

*A micron (μm) is $1/1000$ of a millimeter, or $1/25,000$ of an inch. Particles of $10\text{ }\mu\text{m}$ and larger in size can be seen with the naked eye.

TABLE 4.3 Air Pollution According to Source and Type of Pollutant: United States, Selected Years 1970–1998

Year	All Sources	On-Road Transportation	Nonroad Engines and Vehicles	Stationary Fuel Combustion	Industrial Process	Waste Disposal and Recycling	Other
Carbon Monoxide (Millions of Short Tons)							
1970	129.4	88.0	12.0	4.6	9.8	7.1	7.9
1975	116.8	83.1	13.1	4.5	7.5	3.2	5.3
1980	117.4	78.0	14.5	7.3	7.0	2.3	8.3
1985	117.0	77.4	16.0	8.5	5.2	1.9	8.0
1987	108.4	71.2	14.5	7.0	4.9	1.9	8.9
1988	118.7	71.1	17.3	7.4	5.2	1.8	16.0
1989	106.4	66.1	17.8	7.4	5.2	1.7	8.2
1990	98.5	57.8	18.2	5.5	4.7	1.1	11.2
1991	100.9	62.1	18.6	5.9	4.6	1.1	8.7
1992	97.6	59.9	19.0	6.2	4.5	1.1	7.0
1993	98.2	60.2	19.4	5.6	4.6	1.2	7.1
1994	102.6	61.8	19.8	5.5	4.6	1.2	9.7
1995	93.4	54.1	20.2	5.9	4.6	1.2	7.3
1996	95.5	53.3	20.2	6.1	3.5	1.1	11.2
1997	94.4	51.7	20.3	5.4	3.6	1.1	12.2
1998	89.5	50.4	19.9	5.4	3.6	1.2	9.0
Nitrogen Oxides (Millions of Short Tons)							
1970	20.9	7.4	1.9	10.1	0.8	0.4	0.3
1975	22.6	8.6	2.6	10.5	0.5	0.2	0.2
1980	24.4	8.6	3.5	11.3	0.6	0.1	0.2
1985	23.2	8.1	3.9	10.0	0.8	0.1	0.3
1988	24.1	7.7	4.4	10.5	0.8	0.1	0.7
1989	23.9	7.7	4.5	10.5	0.8	0.1	0.3
1990	24.0	7.1	4.8	10.9	0.8	0.1	0.4
1991	24.2	7.5	4.9	10.8	0.7	0.1	0.3
1992	24.6	7.6	4.9	10.9	0.8	0.1	0.3
1993	25.0	7.8	4.9	11.1	0.7	0.1	0.2
1994	25.4	8.1	5.0	11.0	0.8	0.1	0.4
1995	24.9	7.8	5.1	10.8	0.8	0.1	0.3
1996	24.7	7.8	5.2	10.4	0.7	0.1	0.5
1997	24.8	7.9	5.3	10.4	0.8	0.1	0.4
1998	24.5	7.8	5.3	10.2	0.8	0.1	0.3
Volatile Organic Compounds (VOCs) (Millions of Short Tons)							
1970	31.0	13.0	1.9	0.7	3.2	2.0	10.2
1975	26.1	10.5	2.1	0.7	3.3	1.0	8.5
1980	26.3	9.0	2.3	1.0	3.5	0.8	9.7
1985	24.4	9.4	2.4	1.6	2.0	1.0	8.0
1988	24.3	8.3	2.6	1.4	2.1	1.0	9.0
1989	22.5	7.2	2.6	1.4	2.1	0.9	8.4
1990	20.9	6.3	2.5	1.0	1.8	1.0	8.3

TABLE 4.3 (continued)

Year	All Sources	On-Road Transportation	Nonroad Engines and Vehicles	Stationary Fuel Combustion	Industrial Process	Waste Disposal and Recycling	Other
1991	21.1	6.5	2.6	1.1	1.9	1.0	8.1
1992	20.7	6.1	2.6	1.1	1.9	1.0	8.0
1993	20.9	6.1	2.6	1.0	1.9	1.0	8.2
1994	21.5	6.4	2.7	1.0	1.9	1.0	8.5
1995	20.8	5.7	2.7	1.1	1.9	1.1	8.4
1996	18.7	5.5	2.7	1.0	1.4	0.4	7.7
1997	18.9	5.3	2.6	0.9	1.4	0.4	8.2
1998	17.9	5.3	2.5	0.9	1.4	0.4	7.4
Sulfur Dioxide (Millions of Short Tons)							
1970	31.2	0.4	0.1	23.5	7.1	<i>a</i>	0.1
1975	28.0	0.5	0.1	22.7	4.7	<i>a</i>	<i>a</i>
1980	25.9	0.5	0.2	21.4	3.8	<i>a</i>	<i>a</i>
1985	23.7	0.5	0.6	20.0	2.4	<i>a</i>	<i>a</i>
1988	23.1	0.6	0.7	19.8	2.0	<i>a</i>	<i>a</i>
1989	23.3	0.6	0.8	19.9	2.0	<i>a</i>	<i>a</i>
1990	23.7	0.5	0.9	20.3	1.9	<i>a</i>	<i>a</i>
1991	23.0	0.6	0.9	19.8	1.7	<i>a</i>	<i>a</i>
1992	22.8	0.6	1.0	19.5	1.7	<i>a</i>	<i>a</i>
1993	22.5	0.5	1.0	19.2	1.6	0.1	<i>a</i>
1994	21.9	0.3	1.0	18.9	1.6	0.1	<i>a</i>
1995	19.2	0.3	1.0	16.2	1.6	<i>a</i>	<i>a</i>
1996	19.1	0.3	1.0	16.3	1.4	<i>a</i>	<i>a</i>
1997	19.6	0.3	1.0	16.7	1.5	<i>a</i>	<i>a</i>
1998	19.6	0.3	1.1	16.7	1.5	<i>a</i>	<i>a</i>
PM₁₀ (Millions of Short Tons)							
1988	61.1	0.4	0.5	1.4	0.9	0.3	57.7
1989	53.1	0.4	0.5	1.4	0.9	0.3	49.7
1990	30.0	0.3	0.5	1.2	0.9	0.3	26.7
1991	29.6	0.3	0.5	1.1	0.9	0.3	26.4
1992	29.5	0.3	0.5	1.2	0.9	0.3	26.3
1993	28.0	0.3	0.5	1.1	0.8	0.3	25.0
1994	30.9	0.3	0.5	1.1	0.8	0.3	27.9
1995	27.1	0.3	0.5	1.2	0.8	0.3	24.0
1990	30.0	0.3	0.5	1.2	0.9	0.3	26.7
1991	29.6	0.3	0.5	1.1	0.9	0.3	26.4
1992	29.5	0.3	0.5	1.2	0.9	0.3	26.3
1993	28.0	0.3	0.5	1.1	0.8	0.3	25.0
1994	30.9	0.3	0.5	1.1	0.8	0.3	27.9
1995	27.1	0.3	0.5	1.2	0.8	0.3	24.0
1996	33.0	0.3	0.5	1.2	0.6	0.3	30.2
1997	34.2	0.3	0.5	1.1	0.6	0.3	31.5
1998	34.7	0.3	0.5	1.1	0.6	0.3	32.0

(continues)

TABLE 4.3 (continued)

Year	All Sources	On-Road Transportation	Nonroad Engines and Vehicles	Stationary Fuel Combustion	Industrial Process	Waste Disposal and Recycling	Other
PM_{2.5} (Millions of Short Tons)							
1990	8.0	0.3	0.4	0.9	0.5	0.2	5.6
1991	7.7	0.3	0.4	0.9	0.5	0.2	5.4
1992	7.6	0.3	0.4	0.9	0.5	0.2	5.2
1993	7.3	0.3	0.4	0.9	0.4	0.3	5.1
1994	8.0	0.3	0.4	0.8	0.5	0.3	5.7
1995	7.2	0.2	0.4	0.9	0.5	0.2	4.9
1996	8.2	0.2	0.4	0.9	0.3	0.2	6.1
1997	8.5	0.2	0.4	0.8	0.4	0.2	6.5
1998	8.4	0.2	0.4	0.8	0.4	0.2	6.4
Lead (Thousands of Short Tons)							
1970	220.9	172.0	9.7	10.6	26.4	2.2	<i>b</i>
1975	159.7	130.2	6.1	10.3	11.4	1.6	<i>b</i>
1980	74.2	60.5	4.2	4.3	3.9	1.2	<i>b</i>
1985	22.9	18.1	0.9	0.5	2.5	0.9	<i>b</i>
1988	7.1	2.6	0.9	0.5	2.3	0.8	<i>b</i>
1989	5.5	1.0	0.8	0.5	2.4	0.8	<i>b</i>
1990	5.0	0.4	0.8	0.5	2.5	0.8	<i>b</i>
1991	4.2	<i>a</i>	0.6	0.5	2.3	0.8	<i>b</i>
1992	3.8	<i>a</i>	0.6	0.5	1.9	0.8	<i>b</i>
1993	3.9	<i>a</i>	0.5	0.5	2.0	0.8	<i>b</i>
1994	4.0	<i>a</i>	0.5	0.5	2.2	0.8	<i>b</i>
1995	3.9	<i>a</i>	0.5	0.5	2.3	0.6	<i>b</i>
1996	3.9	<i>a</i>	0.5	0.5	2.3	0.6	<i>b</i>
1997	4.0	<i>a</i>	0.5	0.5	2.3	0.6	<i>b</i>
1998	4.0	<i>a</i>	0.5	0.5	2.3	0.6	<i>b</i>

^aEmissions less than 0.05 million short tons per year (less than 0.05 thousand short tons per year in the case of lead emissions).

^bNo emissions calculated.

Note: Data are calculated emissions estimates, PM₁₀, PM_{2.5} = particulate matter, particles less than 10 and 2.5 μm in diameter.

Sources: Office of Air Quality Planning and Standards, *National Air Pollutant Emission Estimates, 1900–1998*, EPA 454/R-00-002, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 2000.

vegetation, ozone and nitrogen dioxide from lightning, ash and gases (SO₂, HCl, HF, H₂S) from volcanoes, natural radioactivity, and microorganisms such as bacteria, spores, molds, or fungi from plant decay. Most of these are beyond control or of limited significance.

Ozone is found in the stratosphere at an altitude beginning at 7 to 10 miles. The principal natural sources of ozone in the lower atmosphere are lightning

discharges and, in small amount, reactions involving volatile organic compounds released by forests and other vegetation. Ozone is also formed naturally in the upper atmosphere by a photochemical reaction with UV solar radiation.

Types of Air Pollutants

The types of air pollutants are related to the original material used for combustion or processing, the impurities it contains, the actual emissions, and reactions in the atmosphere. See Table 4.3. A *primary pollutant* is one that is found in the atmosphere in the same form as it exists when emitted from the stack; sulfur dioxide, nitrogen dioxide, and hydrocarbons are examples. A *secondary pollutant* is one that is formed in the atmosphere as a result of reactions such as hydrolysis, oxidation, and photochemistry; photochemical smog is an example.

Most combustible materials are composed of hydrocarbons. If the combustion of gasoline, oil, or coal, for example, is inefficient, unburned hydrocarbons, smoke, carbon monoxide, and, to a lesser degree, aldehydes and organic acids are released.

The use of automobile catalytic converters to control carbon monoxide and hydrocarbon emissions causes some increase in sulfates and sulfuric acid emissions, but this is considered to be of minor significance. The elimination of lead from gasoline has, in some cases, led to the substitution of manganese for anti-knock purposes, with the consequent release of manganese compounds, which are also potentially toxic.

Impurities in combustible hydrocarbons (coal and oil), such as sulfur, combine with oxygen to produce SO_2 when burned. The SO_2 subsequently may form sulfuric acid and other sulfates in the atmosphere. Oxides of nitrogen, from high-temperature combustion in electric utility and industrial boilers and motor vehicles [above $1,200^\circ\text{F}$ (649°C)], are released mostly as NO_2 and NO . The source of nitrogen is principally the air used in combustion. Some fuels contain substantial amounts of nitrogen, and these also react to form NO_2 and NO . Fluorides and other fuel impurities may be carried out with the hot stack gases. (The role of sulfur and nitrogen oxides in acid rain is discussed earlier in this chapter.)

Photochemical oxidants* are produced in the lower atmosphere (troposphere) as a result of the reaction of oxides of nitrogen and volatile organics in the presence of solar radiation, as previously noted. Ozone may contribute to smog, respiratory problems, and damage to crops and forests (as previously stated).

Of the sources just noted, industrial processes are the principal source of volatile organics (hydrocarbons), with transportation the next largest contributor. Stationary fuel combustion plants and motor vehicles are the major sources of nitrogen oxides. Ozone, the principal component of modern smog, is the photochemical oxidant actually measured, which is about 90 percent of the total (see p. 9 of Ref. 23). Ozone and other photochemical products formed are usually found at some distance from the source of the precursor compounds.

*Including ozone, PANs, formaldehydes, and peroxides. Nitrogen dioxide colors air reddish-brown.

SAMPLING AND MEASUREMENT

State and local government agencies participate in the EPA national air quality monitoring system. The EPA focuses on the National Ambient Air Quality Standards—airborne particulate matter, sulfur dioxide, ozone, and lead—in over 4,000 locations across the United States.³²

Air-sampling devices are used to detect and measure smoke, particulates, acid deposition, and gaseous contaminants. The equipment selected and used and its siting are determined by the problem being studied and the purpose to be served. Representative samples free from external contamination must be collected and readings or analyses standardized to obtain valid data. Supporting meteorological and other environmental information are needed to properly interpret the data collected. Continuous sampling equipment should be selected with great care. The accuracy and precision of equipment needs to be demonstrated to ensure that it will perform the assigned task with a minimum of calibration and maintenance. Reliable instruments are available for the monitoring of ambient air parameters, such as those listed in Table 4.4. Other instruments such as for *opacity*, hydrocarbons, and sulfur are also available.

TABLE 4.4 Measurement Methods for Ambient Air Quality Parameters

Pollutant	Measurement Methods
SO ₂	Ultraviolet pulsed fluorescence, flame photometry, coulometric; dilution or permeation tube calibrators
CO	Nondispersive infrared tank gas and dilution calibration, gas filter correlation
O ₃	Gas-phase chemiluminescence ultraviolet (UV) spectrometry; ozone UV generators and UV spectrometer or gas-phase titration (GPT) calibrators
NO ₂	Chemiluminescence permeation or GPT calibration
Lead	High-volume sampler and atomic absorption analysis
PM ₁₀ ^a	Tapered-element oscillating microbalance, automated beta gauge
PM _{2.5}	Twenty-four-hour filter sampling
TSPs ^b	High-volume sampler and weight determination
Sulfates, nitrates	High-volume sampler and chemical analysis—deposit dissolved and analyzed colorimetrically
Hydrocarbons	Flame ionization and gas chromatography ^c ; calibration with methane tank gas
Asbestos and other fibrous aerosols	Induced oscillation/optical scattering, microscope, and electron microscope
Biologic aerosols	Impaction (Petri dish), incubated 24 hr and microbial colonies counted

^a10 μm or small particle.

^bTotal suspended particulates. type, size, and composition are important.

^cNot generally required to measure these if O₃ is measured.

A continuous air-quality monitoring system for the measurement of selected gaseous air pollutants, particulates, and meteorological conditions over a large geographical area can make possible immediate intelligence and reaction when ambient air quality levels or emissions increase beyond established standards. In the system, each monitoring station sends data to a data reception center, say every hour, via telephone lines or other communication network. The collected data are processed by computer and visually displayed for indicated action. Field operators who can perform weekly maintenance and calibration checks and a trained central technical staff to coordinate and scrutinize the overall daily monitoring system operation and data validation are essential for the production of usable and valid “real-time” data.³³

The air monitoring data can be used to measure ambient air quality and its compliance with state and national standards; detect major local source air quality violations; provide immediate information for a statewide air pollution episode alert warning system; provide long-term air quality data to meet public and private sector data needs, such as for environmental planning and environmental impact analysis; determine long-term air pollution concentrations and trends in a state; and provide air quality information to the public.

A continuous air quality monitoring system requires use of continuously operating analyzers of a design that measures ambient concentrations of specified air pollutants in accordance with EPA “reference methods” or “equivalent methods.”³⁴ The EPA designates air pollution analyzers after reviewing extensive test data submitted by the manufacturers for their instrumentation. Only analyzers designated as reference or equivalent methods may be used in ambient air monitoring networks to define air quality. This is necessary to ensure correct measurements and operation, thereby promoting uniformity and comparability of data used to define national ambient air quality.

The EPA has specified³⁵ a detailed ambient monitoring program for use by states, local government, and industry. Included in the program are formal data quality assurance programs, monitoring network design, probe (air intake) siting, methodology, and data reporting requirements. The EPA has specified a daily uniform air pollution index known as the pollutant standard index (or PSI) for public use in comparing air quality. The PSI values are discussed and summarized later in Table 4.7.

Types of analyzers used to measure national ambient air quality parameters are summarized in Table 4.4. Continuous analyzers utilizing “gas-phase” measurements with electronic designs, rather than “wet chemistry” measurements, are preferred as they are more accurate and reliable. However, inasmuch as not all regulatory agencies, particularly those at a local level, have the resources or need for sophisticated equipment, other devices are also mentioned here.

Particulate Sampling — Ambient Air

Measurements needing much more development are in the area of particulates, where inhalable particles sizing (less than 10^{-3} μm), identification, metals, sulfates, and nitrates are important. Particulates can also be collected and tested for

their mutagenic properties. Of all the particulate ambient air sampling devices, the high-volume sampler is the one most commonly used in the United States, although alternate continuous monitoring devices are increasingly being used. Other devices also have application for the collection of different-sized particulates.

High-volume (Hi-vol) samplers pass a measured high rate of (40–60 cfm) through a special filter paper (or fiberglass), usually for a 24-hour period. The filter is weighed before and after exposure, and the change in weight is a measure of the suspended particulate matter in (PM) in micrometers per square meter of air filtered. The particulates can be analyzed for weight, particle size (usually between 50 and $0.1\text{ }\mu\text{m}$), composition (such as benzene solubles, nitrates, lead, and sulfates), and radioactivity. Particle size selective inlets can be put on high-volume samplers, and samples can be separated into two parts using impactor principles, those in the particle size ranging above and below 2 to $3\text{ }\mu\text{m}$. There is more interest in measuring $10\text{ }\mu\text{m}$ or smaller particles (PM_{10}) since they penetrate deeper into the respiratory tract and are more likely to cause adverse health effects.

High-volume sampling is the EPA reference method. Air flow measurement is very important. An orifice with a manometer is recommended for flow measurement.

Sedimentation and settling devices include fallout or dustfall jars, settling chambers or boxes, Petri dishes, coated metal sheets or trays, and gum-paper stands for the collection of particulates that settle out. Vertically mounted adhesive papers or cylinders coated with petroleum jelly can indicate the directional origin of contaminants. Dustfall is usually reported as milligrams per centimeter squared per month. Particulates can also be measured for radioactivity.

The *automatic (tape) smoke sampler* collects suspended material on a filter tape that is automatically exposed for predetermined intervals over an extended period of time. The opacity of the deposits or spots on the tape to the transmission or reflectance of light from a standard source is a measure of the air pollution. This instrument provides a continuous electrical output that can be telemetered to give immediate data on particulates. Thus, the data are available without the delay of waiting for laboratory analysis of the high-volume filter. The equipment is used primarily to indicate the dirtiness of the atmosphere and does not directly measure the particulate total suspended particulate (TSP) ambient air quality standard.

Inertial or centrifugal collection equipment operates on the cyclone collection principle. Large particles above $1\text{ }\mu\text{m}$ in diameter are collected, although the equipment is most efficient for the collection of particles larger than $10\text{ }\mu\text{m}$.

Impingers separate particles by causing the gas stream to make sudden changes in direction in passing through the equipment. The wet impinger is used for the collection of small particles, the dry impinger for the larger particles. In the dry impinger, a special surface is provided on which the particles collide and adhere.

In the *cascade impactor*, the velocities of the gas stream vary, making possible the sorting and collection of different-sized particles on special microscopic slides. Particulates in the range of 0.7 to 50 μm are collected.

Electrostatic precipitator-type sampling devices operate on the ionization principle using a platinum electrode. Particles less than 1 μm in size collect on an electrode of opposite charge and are then removed for examination. Combustible gases, if present, can affect results.

Nuclei counters measure the number of condensation nuclei in the atmosphere. They are a useful reference for weather commentators. A sample of air is drawn through the instrument, raised to 100 percent relative humidity, and expanded adiabatically, with resultant condensation on the nuclei present. The droplets formed scatter light in proportion to the number of water droplets, which are counted by a photomultiplier tube. Concentrations of condensation nuclei may range from 10 to 10,000,000 particles/cm³.³⁶ Condensation nuclei are believed to result from a combination of natural and man-made causes, including air pollution. A particle count above 50,000 is said to be characteristic of an urban area.

Pollen samplers generally use petroleum-jelly-coated slides placed on a covered stand in a suitable area. The slides are usually exposed for 24 hours, and the pollen grains are counted with the aid of a microscope. The counts are reported as grains per centimeter squared. See Chapter 2 for ragweed control and sampling.

Gas Sampling

Gas sampling requires separation of the gas or gases being sampled from other gases present. The temperature and pressure conditions under which a sample is collected must be accurately noted. The pressure of a gas mixture is the sum of the individual gas pressures, as each gas has its own pressure. The volumes of individual gases at the same pressure in a mixture are also additive. *Concentrations of gases when reported in terms of ppm and ppb are by volume rather than by weight.** Proper sampling and interpretation of results require competency and experience, knowledge concerning the conditions under which the samples are collected, and an understanding of the limitations of the testing procedures. Automated and manual instruments and equipment for gas sampling and analysis include the following.

Pulsed Fluorescent Analyzer This instrument measures sulfur dioxide by means of absorption of UV light.³⁷ Pulsating UV light is focused through a narrow-bandpass filter that reduces the outgoing light to a narrow wavelength band of 230 to 190 nm and directs it into the fluorescent chamber. Ambient air containing SO₂ flows continuously through this chamber where the UV light excites the SO₂ molecules, which, in turn, emit their characteristic decay radiation. This radiation, specific for SO₂, passes through a second filter and

*In either metric (SI) or customary (U.S.) units.

onto a sensitive photomultiplier tube. This incoming light energy is transformed electronically into an output voltage that is directly proportional to the concentration of SO_2 in the sample air. The World Health Organization (WHO) Global Environmental Monitoring System determinations use the following methods: acidimetric titration or hydrogen peroxide, the colorimetric pararosaniline or West-Gaeke, the amperometric or coulometric, and the conductimetric.

Atomic Spectrometry In atomic spectrometry a sample solution is atomized into a flame that produces a characteristic and measurable spectrum of light wavelengths. *Gas chromatography* separates compounds that can be volatilized, while *liquid chromatography* separates compounds that are not volatile. *Mass spectrometry* identifies a separated pure component by its characteristic mass spectrum. Sampling analytical methods for the examination of toxic and hazardous organic materials include gas chromatography with flame ionization detector, gas chromatography–mass spectrometry, gas chromatography–photoionization detector, and electron capture. Calibration is accomplished through laboratory standards and certified permeation tubes.

Some continuous monitoring instruments for atmospheric measurement of pollution are quite elaborate and costly. The simplest readily available instrument should be selected that meets the required sensitivity and specificity. Power requirements, service, maintenance, calibration frequency, and time required to collect and transmit information are important considerations.

Nitrogen Oxide Chemiluminescence Analyzer Nitric oxide (NO) is measured by the gas-phase chemiluminescent reaction between nitric oxide and ozone.³⁷ This technique is also used to determine nitrogen dioxide (NO_2) by catalytically reducing NO_2 in the sample air to a quantitative amount of NO. Sample air is drawn through a capillary into a chamber held at 25 in. Hg vacuum. Ozone produced by electrical discharge in oxygen is also introduced into the chamber.

The luminescence resulting from the reaction between NO and ozone is detected by a temperature-stabilized photomultiplier tube and wavelength filter. An automatic valving system periodically diverts the sample air through a heated activated-carbon catalyst bed to convert NO_2 to NO before it enters the reaction chamber. The sample measured from the converter is called NO_x . Since it contains the original NO plus NO produced from the NO_2 conversion, the differences between the sequential NO_x and NO readings are reported as NO_x . Primary dynamic calibrations are performed with gas-phase titration using ozone and nitric oxide standards and with NO_2 permeation tubes.

Ozone Chemiluminescence Analyzer Ozone is measured by the gas-phase chemiluminescence technique, which utilizes the reaction between ethylene and ozone (O_3).³⁷ Sample air is drawn into a mixing chamber at a flow rate of 1 l/min, where it is mixed with ethylene gas and introduced at a flow rate of 25 cc/min. The luminescence resulting from the reaction of the ethylene with ambient ozone

in the air supply is detected by a temperature-stabilized photomultiplier tube. This signal is then amplified and monitored by telemetry and on-site recorders. These ozone instruments contain provision for weekly zero and span checks. Primary dynamic calibrations are periodically performed that require standardization against a known, artificially generated ozone atmosphere. Ozone is also measured by UV light instrumentation.

Carbon Monoxide Infrared (IR) Analyzer This method utilizes dual-beam photometers with detection accomplished by means of parallel absorption chambers or cells that are separated by a movable diaphragm.³⁷ The IR energy passes into each chamber—one containing the sample with CO, the other containing the reference gas. The reference gas heats up more than the ambient air sample with CO because CO absorbs more of the IR energy. This results in higher temperature and, hence, the volume–pressure in the reference chamber that is transmitted to the separating diaphragm designed to provide an electrical output to measure the CO concentration. However, it is necessary to remove water vapor interference as the humidity in ambient air absorbed by IR energy can introduce a significant error in CO readings. In one instrument (the EPA reference method), the interference due to water vapor is eliminated by first passing one portion of the ambient air sample through a catalytic converter, where CO is converted to CO₂ prior to entry into the reference chamber. The other half of the air sample containing CO passes directly into the sample chamber. This procedure cancels out the effect of moisture since both gas streams are identical except for the presence of CO.⁴² Carbon monoxide is also measured by gas-phase correlation.

Smoke and Soiling Measurement

Historically, smoke and/or opacity was measured by The *Ringelmann smoke chart*.³⁸ This consists of five* rectangular grids produced by black lines of definite width and spacing on a white background. When held at a distance, about 50 feet from the observer, the grids appear to give shades of gray between white and black. The grid shadings are compared with the pollution source (stack), and the grid number closest to the shade of the pollution source is recorded. About 30 observations are made in 15 minutes, and a weighted average is computed of the recorded Ringelmann numbers. The chart is used to determine whether smoke emissions are within the standards established by law; the applicable law is referenced to the chart. The system cannot be applied to dusts, mists, and fumes. Inspectors need training in making smoke readings. A reading of zero would correspond to all white; a reading of five would correspond to all black.

The Ringelmann chart has been replaced by a determination of the *percent opacity* of a particular emission as seen by a trained observer.[†] For example,

*Reduced to four grids or charts in the United States. The width or thickness of lines and their spacing in each grid or chart vary. A handy reduction of the Ringelmann smoke chart is the Power's Micro-Ringelmann available from Power, 33 West 42nd Street, New York, NY 10036.

†See U.S. EPA Method 9, Appendix A, 40 CFR 60, 2001.

a Ringelmann reading of 1 would correspond to an opacity of about 20 percent.

Tape Sampler – Soiling Soiling can be indicated as RUDS (reflectance units of dirt shade). One RUDS is defined as an optical reflectance of 0.01 caused by 10,000 feet of air passing through 0.786 in.² (1-in.-diameter circle) of filter paper. A vacuum pump draws the air to be sampled through the filter tape. The particles collected soil a spot on the tape. The tape is advanced automatically after a 2-hour period; the air flow rate used is 0.455 cfm. A filter is used with the light source that admits light with a wavelength of approximately 400 nm to measure the light reference; this information can be sent to a monitor. The sampling time period and air flow rate were chosen to conform with ASTM (American Society for Testing and Materials) standards.

Tape Sampler – Coefficient of Haze (COH) The tape sampler can be designed to measure light transmittance rather than reflectance. This will produce soiling measurements expressed as COH, an index of contaminant concentration, which is the EPA preferred method. The method is similar to that previously outlined except the photocell is under the tape. White light is used. It is necessary to automatically rezero the instrument near each spot to compensate for tape thickness variation. The compensation is performed by solid-state electronics.

The automated filter tape air sampler can also be used to monitor some gases. Special filter tapes are used to measure hydrogen sulfide, fluorides, and other gases. The spots produced by the gaseous pollutant are chemically treated and evaluated using the reflectance or transmission method.

Many of these measures of smoke and or opacity have been moved back to the source (smoke stack) where more enforceable standards can be applied. Industrial operation permits can require the installation of electronic opacity monitors. These monitors measure either the transmission of light from a source to a sensor across the stack (extinction) or the variability of light transmission across the stack (scintillation). Inspectors may request operation records and maintenance logs during facility inspection.

Stack Sampling

The collection of stack samples, such as fly ash and dust emissions, requires special filters of known weight and a measure of the volume of gases sampled. The sample must be collected at the same velocity at which the gases normally pass through the stack. The gain in weight divided by the volume of gases sampled corrected to 0°C (or 21°C) temperature and 760 mm Hg gives a measure of the dust and fly ash going out of the stack, usually as grains per cubic foot. When a series of samples is to be collected or measurements made, a *sampling train* is put together. It may consist of a sampling nozzle, several impingers, a freeze-out train, a weighed paper filter, dry gas meter, thermometers, and pump.

A common piece of equipment for boiler and incinerator stack sampling is the Orsat apparatus. By passing a sample of the stack gas through each of three

different solutions, the percent carbon dioxide, carbon monoxide, and oxygen constituents in the flue gas are measured. The remainder of the gas in the mixture is usually assumed to be nitrogen. Special methods are used to test for other gases and metals.

Tracer materials may be placed in a stack to indicate the effect of a pollution source on the surrounding area. The tracer may be a fluorescent material, a dye, a compound that can be made radioactive, a special substance or chemical, or a characteristic odor-producing material. The tracer technique can be used in reverse—that is, to detect the source of a particular pollutant, provided there are no interfering sources.

Measurement of Materials' Degradation

The direct effects of air pollution can be observed by exposing various materials to the air at selected monitoring stations. The degradation of materials is measured for a selected period on a scale of 1 to 10, with 1.0 representing the least degradation and 10.0 the worst, as related to the sample showing the least degradation. Materials exposed and conditions measured include steel corrosion, dyed fabric (nonspecific) for color fading, dyed fabric (NO_x sensitive), dyed fabric (ozone sensitive), dyed fabric (fabric soiling), dyed fabric (SO_2 sensitive), silver tarnishing, nylon deterioration, rubber cracking (crack depth), leather deterioration, copper pitting, and others. The samples are exposed for a selected period, such as rubber, 7 days at a time; silver, 30 days at a time; nylon, 30 or 90 days at a time; cotton, 90 days at a time; steel, 90 days and 1 year at a time; and zinc, 1 year at a time. Shrubs, trees, and other plants sensitive to certain contaminants or pollutants can also be used to monitor the effects of air pollution.

ENVIRONMENTAL FACTORS

The behavior of pollutants released to the atmosphere is subject to diverse and complex environmental factors associated with meteorology and topography. Meteorology involves the physics, chemistry, and dynamics of the atmosphere and includes many direct effects of the atmosphere on the earth's surface, ocean, and life. Topography refers to both the natural and manmade features of the earth's surface. The pollutants can be either accumulated or diluted, depending on the nature and degree of the physical processes of transport, dispersion, and removal and the chemical changes taking place. Because of the complexities of pollutant behavior in the atmosphere, it is important to distinguish between the activity of short-range primary pollutants (total suspended solids, sulfur dioxide), to which micrometeorology applies, and long-range secondary pollutants (ozone, acid rain), to which regional meteorology applies.

Within the scope of this text, the intention is not to provide a complete technical understanding of all the meteorological and topographical factors involved but to provide an insight into the relationships to air pollution of the more important processes.

Meteorology

The meteorological elements that have the most direct and significant effects on the distribution of air pollutants are wind speed and direction, solar radiation, stability, and precipitation. Therefore, it is important to have a continuing baseline of meteorological data, including these elements, to interpret and anticipate probable effects of air pollution emissions. Data on temperature, humidity, wind speed and direction, and precipitation are generally available through official government weather agencies. The National Weather Service (formerly U.S. Weather Bureau), Asheville, North Carolina, is a major source of information. Other potential sources of information are local airports, stations of the state fire weather service, military installations, public utilities and industrial complexes, and colleges and universities.

Wind Wind is the motion of the air relative to the earth's surface. Although it is three-dimensional in its movement, generally only the horizontal components are denoted when used because the vertical component is very much smaller than the horizontal. This motion derives from the unequal heating of the earth's surface and the adjacent air, which in turn gives rise to a horizontal variation in temperature and pressure. The variation in pressure (pressure gradient) constitutes an imbalance in forces so that air motion from high toward low pressure is generated.

The uneven heating of the surface occurs over various magnitudes of space, resulting in different magnitudes of organized air motions (circulations) in the atmosphere. Briefly, in descending order of importance, these are:

1. The primary or general (global) circulation associated with the large-scale hemispheric motions between the tropical and polar regions
2. The secondary circulation associated with the relatively large-scale motions of migrating pressure systems (highs and lows) developed by the unequal distribution of large land and water masses
3. The tertiary circulation (local) associated with small-scale variations in heating, such as valley winds and land and sea breezes

For a particular area, the total effect of these various circulations establishes the hourly, daily, and seasonal variations in wind speed and direction. With respect to a known source or distribution of sources of pollutants, the frequency distribution of wind direction will indicate toward which areas the pollutants will most frequently be transported. It is customary to present long-term wind data at a given location graphically in the form of a *wind rose*, an example of which is shown in Figure 4.1.

The concentration resulting from a continuous emission of a pollutant is inversely proportional to wind speed. The higher the wind speed, the greater the separation of the particles or molecules of the pollutant as they are emitted, and vice versa. This is shown graphically in Figure 4.2a. Wind speed, therefore, is an indicator of the degree of dispersion of the pollutant and contributes to the

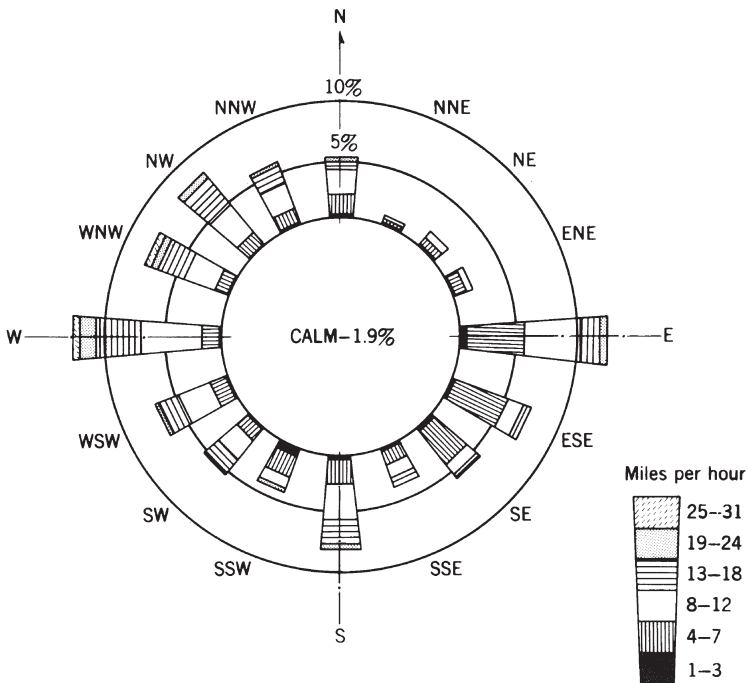


FIGURE 4.1 Example of wind rose for a designated period of time, by month, season, or year. The positions of the spokes show the direction from which the wind was blowing. The total length of the spoke is the percentage of time, for the reporting period, that the wind was blowing from that direction. The length of the segments into which each spoke is divided is the percentage of time the wind was blowing from that direction at the indicated speed in miles per hour. Horizontal wind speed and direction can vary with height.

determination of the area most adversely affected by an emission. Although an area may be located in the most frequently occurring downwind direction from a source, the wind speeds associated with this direction may be quite high so that resulting pollutant concentrations will be low as compared to another direction occurring less frequently but with lower wind speeds.

Smaller in scale than the tertiary circulation mentioned, there is a scale of air motion that is extremely significant in the dispersion of pollutants. This is referred to as the micrometeorological scale and consists of the very short term, on the order of seconds and minutes, fluctuations in speed and direction. As opposed to the “organized” circulations discussed previously, these air motions are rapid and random and constitute the wind characteristic called *turbulence*. The turbulent nature of the wind is readily evident upon watching the rapid movements of a wind vane. These air motions provide the most effective mechanism for the dispersion or dilution of a cloud or plume of pollutants. The turbulent fluctuations occur in both the horizontal and vertical directions. The dispersive effect of fluctuations in horizontal wind direction is shown graphically in Figure 4.2b.

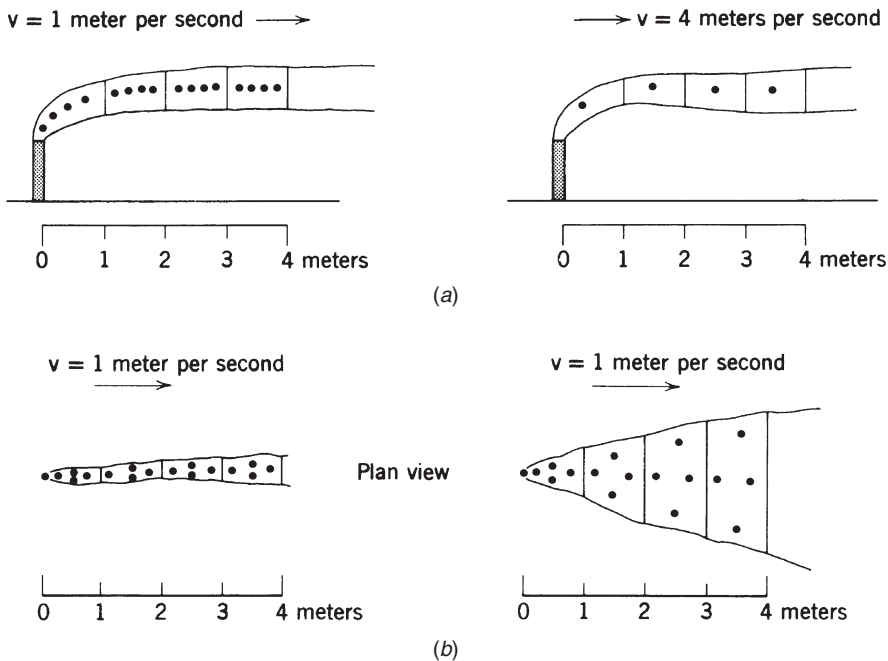


FIGURE 4.2 (a) Effect of wind speed on pollutant concentration from constant source; (b) Effect of variability of wind direction on pollutant concentration from constant source (continuous emission of 4 units/sec).

Turbulent motions are induced in the air flow in two ways: by thermal convective currents resulting from heating from below (thermal turbulence) and by disturbances or eddies resulting from the passage of air over irregular, rough ground surfaces (mechanical turbulence).

It may be generally expected that turbulent motion and, in turn, the dispersive ability of the atmosphere would be greatly enhanced during a period of good solar heating and over relatively rough terrain.

Another characteristic of the wind that should be noted is that wind speed generally increases with height in the lower levels. This is due to the decrease with height of the "frictional drag" effect of the underlying ground surface features.

Stability and Instability The stability of the atmosphere is its ability to enhance or suppress vertical air motions. Under unstable conditions the air motion is enhanced, and under stable conditions the air motion is suppressed. The conditions are determined by the vertical distribution of temperature.

In vertical motion, parcels of air are displaced. Due to the decrease of pressure with height, a parcel displaced upward will encounter decreased pressure and expand. If this expansion process is relatively rapid or over a large area so that there is little or no exchange of heat with the surrounding air or by a change of

state of water vapor, the process is dry adiabatic and the parcel of air will be cooled. Likewise, if the displacement is downward so that an increase in pressure and compression is experienced, the parcel of air will be heated.

The rate of cooling of a mass of warm dry air in a dry environment with height is the *dry adiabatic process lapse rate* and is approximately $-5.4^{\circ}\text{F}/1,000$ feet ($-1^{\circ}\text{C}/100$ m). The normal lapse rate (cooling) on the average is $-3.5^{\circ}\text{F}/1,000$ feet ($-0.65^{\circ}\text{C}/100$ m). This relationship holds true in the troposphere up to about 10 km (6 miles). Temperature increases above this level in the stratosphere.

The *prevailing* or *environmental lapse rate* is the decrease of temperature with height that may exist at any particular time and place. It can be shown that if the decrease of temperature with height is greater than $-5.4^{\circ}\text{F}/1,000$ feet, parcels displaced upward will attain temperatures higher than their surroundings. Air parcels displaced downward will attain lower temperatures than their surroundings. The displaced parcels will tend to continue in the direction of displacement. Under these conditions, the vertical motions are enhanced and the layer of air is defined as *unstable*.

Furthermore, if the decrease of temperature with height is less than $-5.4^{\circ}\text{F}/1,000$ feet, it can be shown that air parcels displaced upward attain temperatures lower than their surroundings and will tend to return to their original positions. Air parcels displaced downward attain higher temperatures than their surroundings and also tend to return to their original position. Under these conditions, vertical motions are suppressed and the layer of air is defined as “stable.”

Finally, if the decrease of temperature with height is equal to $-5.4^{\circ}\text{F}/1,000$ feet, displaced air parcels attain temperatures equal to their surroundings and tend to remain at their position of displacement. This is called *neutral stability*.

Inversions Up to this point, the prevailing temperature distribution in the vertical has been referred to as a *lapse rate*, which indicates a decrease of temperature with height. However, under certain meteorological conditions, the distribution can be such that the temperature increases with height within a layer of air. This is called an *inversion* and constitutes an extremely stable condition.

There are three types of inversions that develop in the atmosphere: radiational (surface), subsidence (aloft), and frontal (aloft).

Radiational inversion is a phenomenon that develops at night under conditions of relatively clear skies and very light winds. The earth's surface cools by reradiating the heat absorbed during the day. In turn, the adjacent air is also cooled from below so that within the surface layer of air there is an increase of temperature with height.

Subsidence inversion develops in high-pressure systems (generally associated with fair weather) within a layer of air aloft when the air layer sinks to replace air that has spread out at the surface. Upon descent, the air heats adiabatically, attaining temperatures greater than the air below.

A condition of particular significance is the subsidence inversion that develops with a stagnating high-pressure system. Under these conditions, the pressure gradient becomes progressively weaker so that the winds become very light, resulting

in a great reduction in the horizontal transport and dispersion of pollutants. At the same time, the subsidence inversion aloft continuously descends, acting as a barrier (lid) to the vertical dispersion of the pollutants. These conditions can persist for several days so that the resulting accumulation of pollutants can cause a serious health hazard.

Frontal inversion forms when air masses of different temperature characteristics meet and interact so that warm air overruns cold air.

There are many and varied effects of stability conditions and inversions on the transport and dispersion of pollutants in the atmosphere. In general, enhanced vertical motions under unstable conditions increase the turbulent motions, thereby enhancing the dispersion of the pollutants. Obviously, the stable conditions have the opposite effect.

For stack emissions in inversions—depending on the elevation of emission with respect to the distribution of stability in the lower layers of air—behavior of the plumes can be affected in many different ways. On the one hand, pollutants emitted within the layer of a surface-based (radiational) inversion by low stacks can develop very high and hazardous concentrations at the surface level. On the other hand, when pollutants are emitted from stacks at a level aloft within the surface inversion, the stability of the air tends to maintain the pollutant at this level, preventing it from reaching the surface. However, after sunrise and continued radiation from the sun resulting in heating of the earth's surface and adjacent air, the inversion is "burned off." Once this condition is reached, the lower layer of air becomes unstable and all of the pollutant that has accumulated at the level aloft is rapidly dispersed downward to the surface. This behavior is called "fumigation" and can result in very high concentrations during the period. See Figure 4.3.

Precipitation Precipitation constitutes an effective cleansing process of pollutants in the atmosphere in three ways: the washing out or scavenging of large particles by falling raindrops or snowflakes (washout), accumulation of small particles in the formation of raindrops or snowflakes in clouds (rainout), and removal of gaseous pollutants by dissolution and absorption.

The most effective and prevalent process is the washout of large particles, particularly in the lower layer of the atmosphere, where most of the pollutants are released. The efficiencies of the various processes depend on complex relationships between properties of the pollutants and the characteristics of the precipitation.

Topography

The topographic features of a region include both the natural (e.g., valleys, oceans, rivers, lakes, foliages) and manmade (e.g., cities, bridges, roads, canals) elements distributed within the region. These elements, per se, have little direct effect on pollutants in the atmosphere. The prime significance of topography is its effects on the meteorological elements. As stated previously, the variation in the distribution of land and water masses gives rise to various types of circulations.

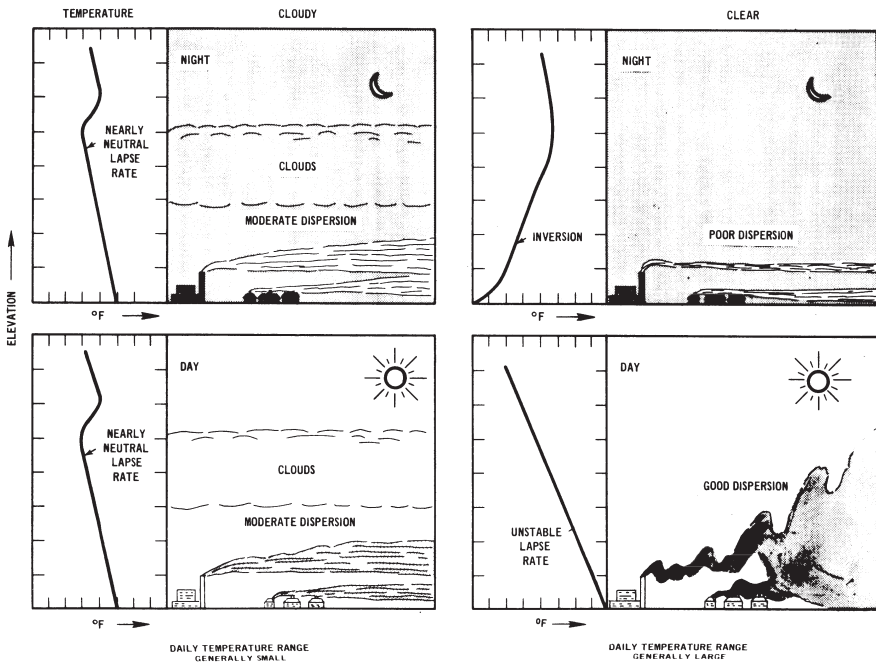


FIGURE 4.3 Diurnal and nocturnal variation of vertical mixing. (Source: M. I. Weisburd, *Field Operation and Enforcement Manual for Air Pollution*, Vol. 1: *Organization and Basic Procedures*, U.S. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, NC, 1972, p. 1.24.)

Of particular significance are the local or small-scale circulations that develop. These circulations can contribute either favorably or unfavorably to the transport and dispersion of the pollutants.

Along a coastline during periods of weak pressure gradient, intense heating of the land surface, as opposed to the lesser heating of the contiguous water surface, develops a temperature and pressure differential that generates an onshore air circulation. This circulation can extend to a considerable distance inland. At times during stagnating high-pressure systems, when the transport and dispersion of pollutants have been greatly reduced, this short-period afternoon increase in airflow may well prevent the critical accumulation of pollutants.

In valley regions, particularly in the winter, intense *surface inversions* are developed by the drainage down the slopes of air cooled by the radiationally cooled valley wall surfaces. Bottom valley areas that are significantly populated and industrialized can be subject to critical accumulation of pollutants during these periods.

The increased roughness of the surface created by the widespread distribution of buildings throughout a city can significantly enhance the turbulence of the airflow over the city, thereby improving the dispersion of the pollutants emitted.

But at the same time the concrete, stone, and brick buildings and asphalt streets of the city act as a heat reservoir for the radiation received from the sun during the day. This, plus the added heat from nighttime space heating during the cool months of the year, creates a temperature and pressure differential between the city and the surrounding rural area so that a local circulation inward to the city is developed. The circulation tends to concentrate the pollutants in the city. This phenomenon called the *urban heat island effect*.

Areas on the windward side of mountain ranges can expect added precipitation due to the forced rising, expansion, and cooling of the moving air mass with resultant release of available moisture. This increased precipitation serves to increase the removal of the pollutants.

It is apparent, then, that topographical features can have many and diverse effects in the meteorological elements and the behavior of pollutants in the atmosphere.

AIR POLLUTION SURVEYS

An air pollution survey of a region having common topographical and meteorological characteristics is a necessary first step before a meaningful air resources management plan and program can be established. The survey includes an inventory of source emissions and a contaminant and meteorological sampling network, supplemented by study of basic demographic, economic, land-use, and social factors.

Inventory

The inventory includes the location, height, exit velocity, and temperature of emission sources and identification of the processes involved; the air pollution control devices installed and their effectiveness; and the pounds or tons of specific air pollutants emitted per day, week, month, and year, together with daily and seasonal variations in production. Inventories of area sources (e.g., home heating, small dry cleaners) can be done simply through fuel use and solvent sales data. The emissions are calculated from emission tables or by material balance. An estimate can then be made of the total pollution burden on the atmospheric resources of any given air basin.³⁹ Tables have been developed to assist in the calculation of the amounts and types of contaminants released; they can also be used to check on information received through personal visits, questionnaires, telephone calls, government reports, and technical and scientific literature.⁴⁰ Additional sources of information are the complaint files of the health department, municipal and private agencies, published information, university studies, state and local chamber of commerce reports and files, and results of traffic surveys as well the Census of Housing local fuel and gasoline sales. Much of this material is now available electronically via the Internet. Data about concentration of primary pollutants, for example, are available via the Aerometric Information Retrieval System (AIRS) at www.epa.gov/airs.

Air Sampling

Air and meteorological sampling equipment located in the survey area will vary, depending on a number of factors such as land area, topography, population densities, industrial complexes, and manpower and budget availability. A minimum number of stations is necessary to obtain meaningful data.

Specific sampling sites for a comprehensive survey or for monitoring are selected on the basis of objective, scope, and budgetary limitations; accessibility for year-round operation, availability of reliable electrical power, amount and type of equipment available, program duration, and personnel available to operate stations; meteorology of the area, topography, adjacent obstructions, and vertical and horizontal distribution of equipment; and sampler operator problems, space requirements, protection of equipment and site, possible hazards, and public attitude toward the program.⁴¹ The EPA can provide monitoring and siting guidance.⁴² Careful attention must also be given to the elimination of sampling bias and variables as related to size of sample, rate of sampling, collection and equipment limitations, and analytical limitations.

Basic Studies and Analyses

Basic studies include population densities and projections; land-use analysis; mapping; and economic studies and proposals, including industrialization, transportation systems, community institutions, environmental health and engineering considerations, relationship to federal, state, and local planning, and related factors. Liaison with other planning agencies can be helpful in obtaining needed information that may already be available.

When all the data from the emission inventory, air sampling, and basic studies are collected, analyzed, and evaluated, a report is usually prepared. The analysis step should include calculations to show how the pollutants released to the atmosphere are dispersed and their possible effects under existing conditions and with future development.

Mathematical models could be developed, or commercially available modeling packages could be utilized, based on certain assumptions and the data collected, to estimate the pollution levels that might result under various emission, topographical, and meteorological conditions. A data bank and a system for the collection and retrieval of information would generally be indicated. The approximate cost to achieve selected levels of air quality (for health, aesthetic, plant, and animal considerations) and the possible effect on industrial expansion, transportation modes and systems, availability and cost of fuel, and community goals and objectives should be determined. See also "Planning and Zoning" and "Air Quality Modeling," later in this chapter.

The report would recommend air quality objectives based on EPA standards for areas in the region studied based on existing and proposed land uses. This will require consultation and coordination with state and local planning agencies.⁴³

Short- and long-term objectives and priorities should be established to achieve the desired air quality. Recommendations to reduce air pollution might include

control of pollutant emissions and limits in designated areas and under hazardous weather conditions and predictions; time schedules for starting control actions; control of fuel composition; requirement of plans for new or altered emission sources and approval of construction for compliance with emission standards; denial of certain plan approvals and prohibition of activities, or requirement of certain types of control devices; and performance standards to be met by existing and new structures and facilities.

The report is then formally submitted to the regulatory agency, board, or commission for further action. It would generally include recommendations for needed laws, rules, and regulations and administrative organization and staffing for the control of existing and new sources of air pollution.

AMBIENT AIR QUALITY STANDARDS*

Topographic, meteorological, and land-use characteristics of areas within an air region will vary. The social and economic development of an area will result in different degrees of air pollution and demands for air quality. Because of this, it is practical and reasonable to establish different levels of air purity for certain areas within a region. However, any standards adopted must ensure, at a very minimum, no adverse effects on human health.[†]

Federal Standards

The federal Air Quality Act of 1967 (Public Law 90-148) was amended in 1970, 1974, 1977, 1990, and 1997 and is now known as the Clean Air Act (CAA). The original act was passed in 1955. Emissions from stationary sources and motor vehicles are regulated under the act. Stationary sources must obtain permits that specify the amount and type of allowable emissions from the air quality regulatory agency. Modifications to an existing facility are subject to the provisions of the Act. The Act requires that the administrator of the EPA develop and issue

*“Ambient air” means that portion of the atmosphere, external to buildings, to which the general public has access.

[†]In the United States national primary and secondary ambient air quality standards were promulgated effective April 30, 1971. *Primary* ambient air quality standards are those that, in the judgment of the EPA administrator, based on the air quality criteria and allowing an adequate margin of safety, are required to protect the public health. *Secondary* ambient air quality standards are those that, in the judgment of the administrator, based on the air quality criteria, are required to protect the public welfare from any known or anticipated adverse effects associated with the presence of air pollutants in the ambient air (on soil, water, vegetation, materials, animals, weather, visibility, personal comfort, and well-being). In England (Ministry of Housing and Local Government 1966B), the standard states, in part: “No emission discharged in such amount or manner as to constitute a demonstrable health hazard in either the short or long term can be tolerated. Emissions, in terms of both concentration and mass rate of emission, must be reduced to the lowest practicable amount.” In the Soviet Union, the goal is protection from any agent in the atmosphere that can be demonstrated to produce physiological effect, even if the effect cannot be shown to be harmful.

to the states criteria of air quality for the protection of public health and welfare and further specifies that such criteria shall reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on health and welfare that may be expected from the presence of an air contaminant, or combination of contaminants, in varying quantities.

The act requires the administrator to designate interstate or intrastate air quality control regions throughout the country as considered necessary to ensure adequate implementation of air quality standards. These regions are to be designated on the basis of meteorological, social, and political factors, which suggests that a group of communities should be treated as a unit.

The federal Clean Air Act, as amended, requires that the administrator of the EPA promulgate national ambient air quality standards (NAAQSs) for sulfur oxides, particulate matter, carbon monoxide, photochemical oxidants, hydrocarbons, and nitrogen oxides. These standards are included in Table 4.5.

The act requires each state to adopt a plan that provides for the implementation, maintenance, and enforcement of such national ambient air quality standards within each air quality control region (or portion thereof) within the State (Title I, Sec. 110 (a)(1)).

States are expected to attain the national primary ambient air quality standards after approval by the administrator of the state plan. Both primary and secondary federal standards apply nationwide; however, state standards may be more stringent, except for motor vehicle emission standards, which are prescribed by law (California is exempt).

The 1977 amendments to the Clean Air Act allow each state to classify clean air areas as class I, where air quality has to remain virtually unchanged; class II, where moderate industrial growth would be allowed; or class III, where more intensive industrial activity would be permitted.

Class I areas *shall* include international parks, national wilderness areas exceeding 5,000 acres, national memorial parks exceeding 5,000 acres, and national parks exceeding 6,000 acres. This classification and designation was made by Congress.

The EPA has expanded its concerns beyond the conventional air pollutants, because of government agency and public concern and accidental toxic chemical releases, to include the regulation of some 188 chemicals and chemical categories that may be classified as hazardous air pollutants.* Chemicals may fall into an acutely hazardous category depending on their dermal, oral, and inhalation effects, which are based on the dose or concentration that will kill one-half of a group of test animals (LD₅₀ or LC₅₀). A dermal dose less than 50 ppm, an oral dose less than 25 ppm, and an inhalation dose less than 0.5 mg/l for up to 8 hrs would qualify the chemical as an acutely hazardous air pollutant.⁴⁴ Some hazardous pollutants that deserve attention are listed in Table 4.6.

Air quality issues also arise from federal legislation, especially the Resource Conservation and Recovery Act (RCRA), Comprehensive Environmental

*See the Clean Air Act of 1990.

TABLE 4.5 National Ambient Air Quality Standards (NAAQS) in Effect in 1988

Pollutant	Primary (Health Related)		Secondary (Welfare Related)	
	Average Time	Concentration ^a	Averaging Time	Concentration
PM ₁₀	Annual arithmetic mean ^b 24 hr ^b	50 µg/m ³ 150 µg/m ³	Same as primary	
PM _{2.5}	Annual arithmetic mean 24 hr	15 µg/m ³ 65 µg/m ³	Same as primary	
SO ₂	Annual arithmetic mean 24 hr ^c	0.03 ppm (80 µg/m ³) 0.14 ppm (365 µg/m ³)	Same as primary 3 hr ^c	1300 µg/m ³ (0.50 ppm)
CO	8 hr ^c 1 hr ^c	9 ppm (10 mg/m ³) 35 ppm (40 mg/m ³)	No secondary standard No secondary standard	
NO ₂	Annual arithmetic mean 1 hr	0.053 ppm (100 µg/m ³) 0.12 ppm (235 µg/m ³)	Same as primary	
O ₃	Maximum daily 8-hr average ^d	0.08 ppm (157 µg/m ³)	Same as primary	
Pb	Maximum quarterly average	1.5 µg/m ³	Same as primary	

^a Parenthetical value is an approximately equivalent concentration.

^b TSP was the indicator pollutant for the original particulate matter (PM) standards. This standard has been replaced with the new PM₁₀ standard and it is no longer in effect. New PM standards were promulgated in 1987 using PM₁₀ (particles less than 10 µm in diameter) as the new indicator pollutant. The annual standard is attained when the expected annual arithmetic mean concentration is less than or equal to 50 µg/m³; the 24-hr standard is attained when the expected number of days per calendar year above 150 µg/m³ is equal to or less than 1; as determined in accordance with Appendix K of the PM NAAQS.

^c Not to be exceeded more than once per year.

^d The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is equal to or less than 1, as determined in accordance with Appendix H of the Ozone NAAQS.

Source: National Ambient Air Quality Standards (NAAQS) 2002, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards Technical Support Division, Research Triangle Park, NC, March 2002. Available: www.epa.gov/airs/criteria.html.

TABLE 4.6 Some Hazardous Air Pollutants

Acrylonitrile	Ethylene oxide
Arsenic	Formaldehyde
Benzene	Methylene chloride
1,3-Butadiene	Nickel
Cadmium	Perchloroethylene
Carbon tetrachloride	Polycyclic organic matter
Chloroform	Radionuclides
Chromium	Trichloroethylene
Ethylene dichloride	Glycol ethers

Response, Compensation, and Liability Act (CERCLA or Superfund), and the Emergency Planning and Community Right-to-Know Act, also called Superfund Amendments and Reauthorization Act Title III (SARA Title III). Of these, SARA Title III has the most dramatic and far-reaching impact on industry regarding the control of toxic chemicals in air. In addition, the EPA has proposed standards limiting emissions of volatile organic pollutants from process vents and equipment leaks at new and existing hazardous waste transfer, storage, treatment, and disposal facilities. These regulations will impose additional air monitoring and emission control responsibilities on RCRA-permitted facilities. Current air quality aspects of RCRA apply to hazardous waste incinerators and land treatment and disposal facilities as well as to remedial action to clean designated sites.

Clean Air Act of 1990

The Clean Air Act amendments of 1990 have added significantly to potential ambient air quality improvement. Some of the major features follow.

Title I deals with the attainment of ambient air quality standards. The EPA may establish geographical boundaries and grade nonattainment areas that exceed standards for carbon monoxide, ozone, and particulate matter. States must reduce overall emissions, and the EPA can impose sanctions (loss of funds for highways and construction) against states and cities for noncompliance.

Title II deals with mobile sources of air pollution. Stricter tailpipe emission limits are established for oxides of nitrogen, hydrocarbons, and carbon monoxide. Cleaner fuel and vehicles will be required in certain cities having ozone, smog, or carbon monoxide problems.

Title III deals with the reduction and regulation of 188 toxic air emissions from commercial and industrial sources and municipal incinerators. The “maximum achievable control technology” will be required at existing, new, or modified sources.

Title IV deals with the control of acid deposition, commonly referred to as acid rain, primarily from plants burning fossil fuels. Reductions in sulfur dioxide emissions will be required on an EPA-phased-time basis, taking into consideration

location of sources and existing emissions. Emissions of nitrogen oxides are to be reduced, and standards are to be issued by the EPA. Continuous monitoring of sulfur dioxide, nitrogen oxides, and opacity will be required. Utilities may save, buy, or sell pollution emission allowances.

Title V deals with the development and requirement of a permit system by the EPA similar to the National Pollutant Discharge Elimination System used under the Clean Water Act. All sources of toxic air pollutants will be required to obtain an operating permit valid for up to five years. The permit will list the compliance requirements; the program will be administered by the states.

Title VI deals with the phasing out of ozone-depleting chemicals, including CFCs, halons, HCFCs, carbon tetrachloride, and methyl chloroform. Under the law, CFCs, halons, and carbon tetrachloride are to be phased out by the year 2000. Methyl chloroform is to be phased out in 2002 and HCFCs by 2030. Recycling of refrigerants from motor vehicle air-conditioning units is required. The Act requires that assistance be provided to developing countries.

Title VII deals with enforcement. Corporations and corporate officials are subject to civil and criminal liabilities. The EPA may issue administrative penalties of up to \$200,000 and field citations up to \$5,000. Also, private citizens or groups may take action against violators.

Title VIII deals with the study of visibility impairment, regulation of air pollution from outer continental shelf activities, monitoring of carbon dioxide emissions by utilities, and grants for air pollution planning and control programs.

Title IX requires that the EPA conduct a research program that includes sampling, measurement, monitoring, analysis, and modeling of air pollution.

Title X requires that the EPA ensure, to the extent possible, that 10 percent of research funding be made available to disadvantaged business concerns.

Title XI authorizes a training and benefits program for workers who become unemployed because of the Act.

Clean Air Act Amendments of 1997

In 1997, the EPA proposed more restrictive NAAQSs for ozone and particulate matter. A new standard for particulate matter was drafted that regulated particulates less than $2.5\text{ }\mu\text{m}$ in diameter. These fine particulates are implicated in respiratory distress because of their ability to penetrate deep into the lungs. The proposed ozone standard reduced the permissible concentration to an 8-hour average of 0.080 ppm. This is in contrast to the previous 12-hour 0.120-ppm standard. The EPA estimated these standards would affect 125 million people, including 35 million children in the United States. The proposed rules were challenged in court in 1997 and remained in litigation until the Supreme Court of the United States and subsequently the District of Columbia Circuit Court sided with the EPA in 2002. The standards will should have a significant effect on the number of communities that will have to address ground-level ozone issues. Mobile sources of $\text{PM}_{2.5}$, such as heavy-duty diesel trucks, may also be significantly affected by these amendments.

Pollutant Standards Index (PSI)

The pollutant standards index is a uniform method recommended* to classify and report urban air quality. Five criteria pollutants are judged for the amount and adverse effects on human health, as shown in Table 4.7. On that basis, the air quality evaluated is designated as presenting “hazardous conditions” if the PSI is greater than 300; “very unhealthful conditions” if the PSI is between 200 and 300; “unhealthful conditions” if the PSI is between 100 and 200; “moderate” if the PSI is 50 to 100; and “good” if the PSI is between 0 and 50. The PSI for one day rises above 100, that is, to the “Alert” level or higher, when any one of the five criteria pollutants reaches a level that may be judged to have adverse effects on human health.

CONTROLS

Air pollution involves a source such as a power-generating plant burning heavy fuel oil; a production byproduct or waste such as particulates, vapors, or gases; release of pollutants into the atmosphere, such as smoke or sulfur dioxide; transmission by airflows; and receptors who are affected, such as people, animals, plants, structures, and clothing. Controls can be applied at one or more points between the source and the receptor, starting preferably at the source. The application of control procedures and devices is more effective when supported by public information, raw-material or production and process revision, and installation of proper air-cleaning equipment. Regulatory persuasion and, if necessary, legal action would follow.

Source Control

Processes that are sources of air pollution include chemical reaction, evaporation, crushing and grinding, drying and baking, and combinations of these operations.

For stationary combustion installations, such as fossil-fuel-fired electric generating stations and plants generating steam for space heating or processes, the amounts and types of pollutants can be kept to a minimum using a fuel with less air pollution potential. Some examples of the types and amounts of contaminants from different types of fuels are given in Table 4.8. As can be seen, sulfur dioxide is a major pollutant in all fuels. Its removal for health and environmental (acid rain) reasons has a high priority.

Processes can also be designed and modified to reduce waste and the pollutants produced at the source. This has been a fundamental step in the reduction of industrial wastewater pollution and can certainly be applied to air pollution control.

*Recommendation of task force consisting of the Council on Environmental Quality, the EPA, Department of Commerce, National Oceanic and Atmospheric Administration, and the National Bureau of Standards.

TABLE 4.7 Comparison of PSI Values with Pollutant Concentrations and Health Effects

Index Value	Air Quality Level	Pollutant Levels					Health Effect Descriptor	General Health Effects	Cautionary Statements
		PM _{2.5} , 24 hr (µg/m ³)	SO ₂ , 24 hr (ppm)	CO, 8 hr (ppm)	O ₃ , 8 hr (ppm)	NO ₂ , 1 hr (ppm)			
500	Significant harm	500	1.004	50.4	—	2.04	Hazardous	Premature death of ill and elderly. Healthy people will experience adverse symptoms that affect their normal activity.	All persons should remain indoors, keeping windows and doors closed. All persons should minimize physical exertion and avoid traffic.
400	Emergency	350	0.804	40.4	—	1.64	Hazardous	Premature onset of certain diseases in addition to significant aggravation of symptoms and decreased exercise tolerance in healthy persons.	Elderly and persons with existing diseases should stay indoors and avoid physical exertion. General populations should avoid outdoor activity.

300	Warning	250	0.604	30.4	0.374 ^a	1.24	Very unhealthful	Significant aggravation of symptoms and decreased exercise tolerance in persons with heart or lung disease, with widespread symptoms in the healthy population.	Elderly and persons with existing heart or lung disease should stay indoors and reduce physical activity.
200	Alert	150.4	0.304	15.4	0.124	0.65	Unhealthful	Mild aggravation of symptoms in susceptible persons, with irritation symptoms in the healthy population.	Persons with existing heart or respiratory ailments should reduce physical exertion and outdoor activity.
100	Moderate	40.4	0.144	9.4	0.084	^b	Moderate		
50	Good	15.4	0.034 ^c	4.4	0.064	^b			

^aWhen 8-hr O₂ concentrations exceed 0.374 ppm, air quality index (AQI) values of 301 or higher must be calculated with 1-hr O₃ concentrations.

^bNO₂ has no short-term NAAQS and can generate an AQI only above AQI value of 200.

^cAnnual primary National Ambient Air Quality Standards (NAAQS); see Table 4.5.

Source: Guideline for Public Reporting of Daily Air Quality—Pollutant Standards Index (PSI). EPA 454/R-99-010, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards (OAQPS), Research Triangle Park, NC, 1999, Table 7, p. 13.

TABLE 4.8 Uncontrolled Contaminant Emissions (lb/10⁶ Btu of Fuel)^a

Contaminant	Bituminous Coal ^b	Anthracite Coal	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas
Solids	0.39 (A) ^c	0.39 (A)	0.112	0.085	0.018
SO ₂	1.52 (S) ^d	1.52 (S)	1.046 (S)	1.120 (S)	0.006
NO ₂	0.82	0.70	0.439	0.365	0.200
Organics, volatile organic carbon	0.003	0.003	0.020	0.021	0.020
Organic acids	1.150	0.595	0.714	0.765	0.003
Aldehydes	<0.001	<0.001	0.007	0.014	0.005
NH ₃	0.078	0.040	0.047	0.050	0.020
CO	0.023	0.023	0.001	0.014	0.004

^aTypical fuel values:Bituminous coal=25.629 m × 10⁶ Btu/tonAnthracite coal=25.721 m × 10⁶ Btu/tonResidual fuel oil=149.7 m × 10⁶ Btu/10⁶ galDistillate fuel oil=138.7 m × 10⁶ Btu/10⁶ galNatural gas=1029 Btu/ft³^bUtility.^cContaminant emission in pounds=0.0630 × (A), where (A) is ash content in percent.^dContaminant emission in pounds=1.407 × (S), where (S) is sulfur content in percent.

Source: From E. W. Davis, Division of Air Resources, New York State Department of Environmental Conservation, Albany, personal communication, 1990. An extensive collection of emission factors is available from the EPA AP-42 at <http://www.epa.gov/ttn/chief/ap42/index.html>.

The internal combustion engine is a major producer of air pollutants. A change from gasoline to another fuel or a major improvement in the efficiency of the gasoline engine would attack that problem at the source. Inspection of cars and light trucks for compliance with exhaust emissions standards can significantly reduce hydrocarbon and carbon monoxide levels in the ambient air. Heavy-duty gasoline trucks also add a large percentage of carbon monoxide and hydrocarbons; however, their reduction will require phasing out old trucks and catalytic converter installation on new trucks. Reducing the lead content of gasoline and capturing gasoline evaporation during handling from filling stations, petroleum storage tanks, auto tanks, and carburetors are other means of source control. Improved mass transit, use of bus lanes, reduced travel by personal car, better traffic control for faster vehicle travel, and less stop-and-go are other means to reduce emissions.

Significant air pollution control can be achieved by process and material changes, recovery and recycling of waste materials, or product recovery, as by collection of combustion product particles of value.

Proper design of basic equipment, provision of adequate solid waste collection service, elimination of open burning, and the upgrading or elimination of inefficient apartment house, municipal, institutional, and commercial incinerators also attack the problem at the source.

Proper operation and maintenance of production facilities and equipment will often not only reduce air pollution but also save money. For example, air–fuel ratios can determine the amount of unburned fuel going up the stack, combustion temperature can affect the strain placed on equipment when operated beyond rated capacity, and the competency of supervision can determine the quantity and type of pollutants released and the quality of the product.

Emission Control Equipment

Municipal waste incinerators can emit hazardous levels of dioxins and other organic chemicals, metals, and acid gases if not regulated. In view of this, the EPA is requiring strict controls on air emissions from such facilities.⁴⁵ In addition to dioxins, the organics include furans, chlorobenzenes, chlorophenols, formaldehyde, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls. The metals are arsenic, beryllium, cadmium, chromium, lead, and mercury. The EPA believes that proper incinerator combustion, acid gas scrubber, and particulate removal can achieve 99 percent or greater reduction of dioxins and furans, 95 percent or greater reduction of organics, 90 percent or greater reduction of hydrogen chloride, and 97 to 99 percent reduction of metals.

Emission control equipment is designed to remove or reduce particulates, aerosols (solids and liquid forms), and gaseous byproducts from various sources and, in some instances, emissions resulting from inefficient design and operation.

Here are four operating principles of aerosol collection equipment:

1. Inertial entrapment by altering the direction and velocity of the effluent
2. Increasing the size of the particles through conglomeration or liquid mist entrainment to subject the particles to inertial and gravitational forces within the operational range of the control device
3. Impingement of particles on impact surfaces, baffles, or filters
4. Precipitation of contaminants in electrical fields or by thermal convection.⁴⁶

The collection of gases and vapors is based on the particular physical and chemical properties of the gases to be controlled.

Particulate Collectors and Separators

Some of the more common collectors and separators are identified in this section. These have application in mechanical operations for dust control such as in pulverizing, grinding, blending, woodworking, and handling flour as well as at power stations, incinerators, cement plants, heavy metallurgical operations, and other dusty operations. In general, collector efficiencies increase with particle size and

from a low efficiency with baffled settling chambers, increasing with cyclones, electrostatic precipitators, spray towers, scrubbers, and baghouses, depending also on design, operation, and combinations of collectors used.

Settling chambers cause velocity reduction, usually to slower than 10 fps, and the settling of particles larger than $40\text{ }\mu\text{m}$ in diameter in trays that can be removed for cleaning. Special designs can intercept particles as small as $10\text{ }\mu\text{m}$.

Cyclones impose a downward spiraling movement on the tangentially directed incoming dust-laden gas, causing separation of particles by centrifugal force and collection at the bottom of the cone. Particle sizes collected range from 5 to $200\text{ }\mu\text{m}$ at gas flows of 30 to $25,000\text{ ft}^3/\text{min}$. Removal efficiency below $10\text{ }\mu\text{m}$ particle size is low. Cyclones can be placed in series or combined with other devices to increase removal efficiency. See Figures 4.4 and 4.5.

Sonic collectors can be used to facilitate separation of liquid or solid particles in settling chambers or cyclones. High-frequency sound pressure waves cause particles to vigorously vibrate, collide, and coalesce. Collectors can be designed to remove particles smaller than $10\text{ }\mu\text{m}$.

Filters are of two general types: the baghouse and cloth screen. The filter medium governs the temperature of the gas to be filtered, particle size removed, capacity and loading, and durability of the filter. Filter operating temperatures

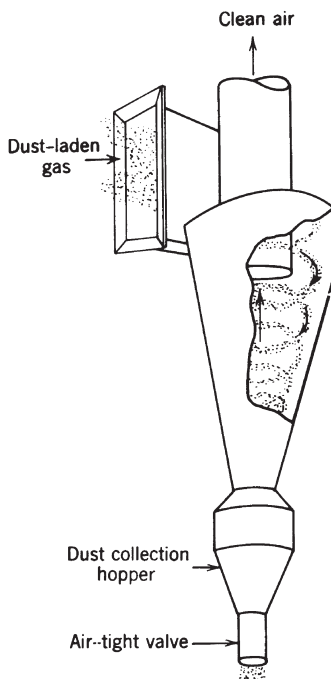


FIGURE 4.4 Flow of dust through cyclone. (Source: Adapted from *Air Pollution Control Field Operations Manual*, PHS Pub. No. 937, Department of Health, Education, and Welfare, Washington, DC, 1962.)

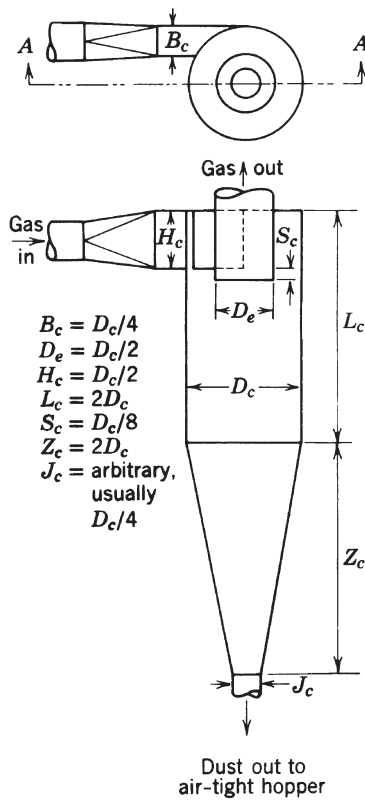


FIGURE 4.5 Diagram of cyclone separator. (Source: *Air Pollution Control Field Operations Manual*, PHS Pub. No. 937, Department of Health, Education, and Welfare, Washington, DC, 1962.)

vary from about 200°F (93°C) for wool or cotton to 450° to 500°F (232°–260°C) for glass fiber.

A *baghouse filter* is shown in Figure 4.6. The tubular bags are 5 to 18 inches in diameter and from 2 to 30 feet in length. The dust-laden gas stream to be filtered passes through the bags where the particles build up on the inside and, in so doing, increase the filtering efficiency. Periodic shaking of the bags (tubes) causes the collected dust to fall off and restore the filtering capacity. The baghouse filter has particular application in cement plants, heavy metallurgical operations, and other dusty operations. Efficiencies exceeding 99 percent and particle removal below 10 μm in size are reported, depending on the major form and buildup. Baghouses are usually supplemented by scrubber systems.

Cloth-screen filters are used in the smaller grinding, tumbling, and abrasive cleaning operations. Dust-laden air passes through one or more cloth screens in series. The screens are replaced as needed. Other types of filters use packed fibers, filter beds, granules, and oil baths.

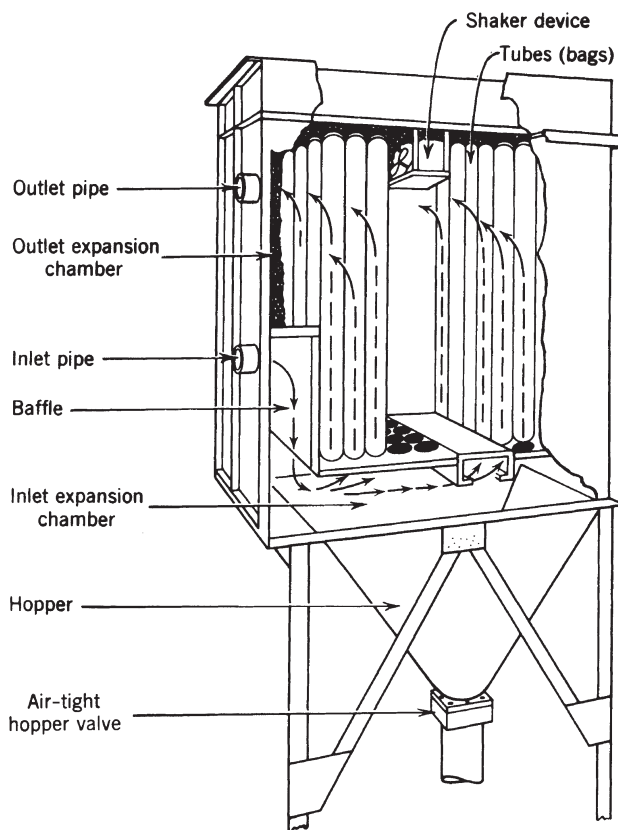


FIGURE 4.6 Simplified diagram of a baghouse. (Source: *Air Pollution Control Field Operations Manual*, PHS Pub. 937, Department of Health, Education, and Welfare, Washington, DC, 1962.)

Electrostatic precipitators have application in power plants, cement plants, and incinerators as well as in metallurgical, refining, and heavy chemical industries for the collection of fumes, dusts, and acid mists. Particles, in passing through a high-voltage electrical field, are charged and then attracted to a plate of the opposite charge where they collect. The accumulated material falls into a hopper when vibrated. See Figure 4.7.

The gases treated may be cold or at a temperature as high as 1,100°F (593°C), but 600°F (316°C) or less is more common, typically 280° to 300°F (138°–149°C). Precipitators are efficient for the collection of particles less than 0.5 μm in size; hence, cyclones and settling chambers, which are better for the removal of larger particles, are sometimes used ahead of precipitators. Single-stage units operate at voltages of 25,000 V or higher; two-stage units (used in air conditioning) operate at 12,000 V in the first or ionizing unit and at 6,000 V in the second collection unit.

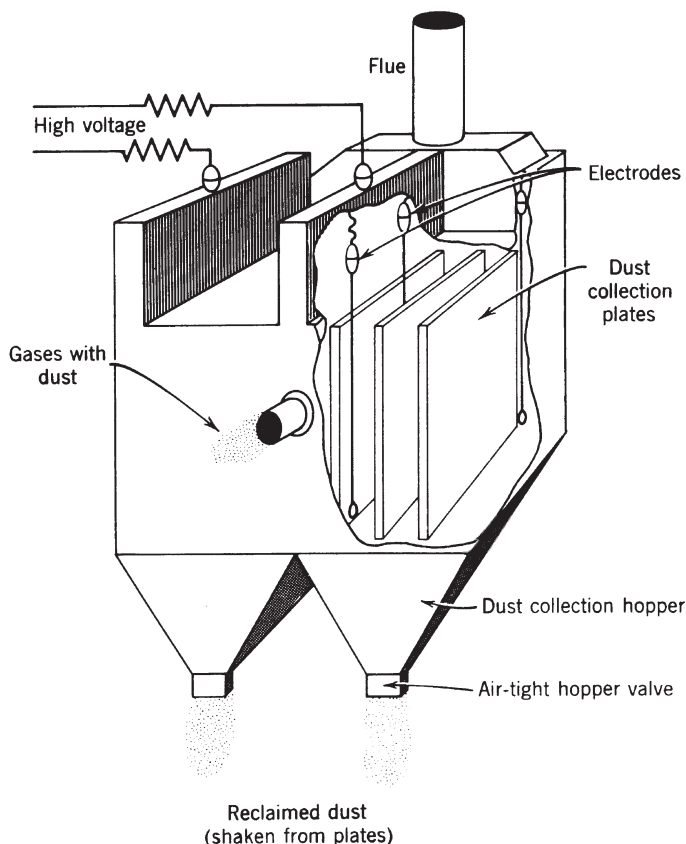


FIGURE 4.7 Diagram of plate-type electrostatic precipitator used to collect catalyst dust. (Source: Adapted from *Air Pollution Control Field Operations Manual*, PHS Pub. 937, Department of Health, Education and Welfare, Washington, DC, 1962.)

Electrostatic precipitators are commonly used at large power stations and incinerators to remove particulates from flue gases. Particulate removal of at least 98 to 99 percent can be achieved. They are considered one of the most effective devices for this purpose. Flue gases may be cooled by water spray, air cooling, or passage through a boiler.

Scrubbers are of different types, selected for specific applications. They include spray towers, ejector venturists, venturi scrubbers, and packed-bed, plate, moving-bed, centrifugal, impingement, and entrainment types. See Figures 4.8 and 4.9.

Wet collectors are generally used to remove gases such as hydrogen chloride, nitrous oxides, and sulfur dioxide and particles that form as a dust, fog, or mist. A high-pressure liquid spray is applied to the gas passing through the washer, filter, venturi, or other device. In so doing, the gas is cooled and cleaned. Although

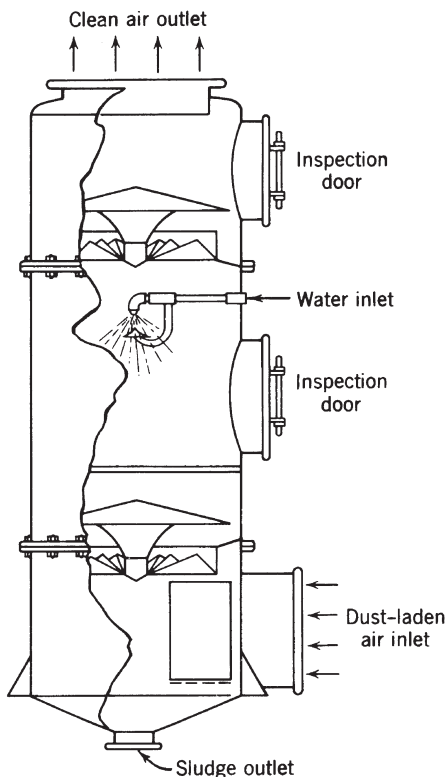


FIGURE 4.8 Centrifugal wash collector. (Source: *Air Pollution Control Field Operations Manual*, Department of Health, Education, and Welfare, Washington, DC, 1962.)

water is usually used as the spray, a caustic may be added if the gas stream is acidic. Where the spray water is recirculated, corrosion of the scrubber, fan, and pump impeller can be a serious problem. Particle size collected may range from $40\text{ }\mu\text{m}$ to as low as $1\text{ }\mu\text{m}$ with efficiency as high as 98 to 99 percent, depending on the collector design. Required removal efficiencies for hydrogen chloride, sulfur dioxide, and hydrogen fluoride can usually be met.

Controls for sulfur dioxide emissions include wet and dry flue gas desulfurization and fuel switching and physically cleaning coal. Nitrogen oxide emissions can be controlled by special burners or by catalytic or selective noncatalytic reduction. A *duct injection* technology (dry scrubber) is being emphasized by the Department of Energy (DOE) to reduce sulfur dioxide emissions from existing coal-fired power plants: "Lime is sprayed into existing ductwork located just after the combustion chamber. Fly ash in the exhaust stream reacts with the small pieces of lime, then with sulfur oxides and is finally captured by a filter fabric."⁴⁷

For every ton of sulfur removed, 3 to 6 tons of sludge from wet scrubbers will require safe disposal.

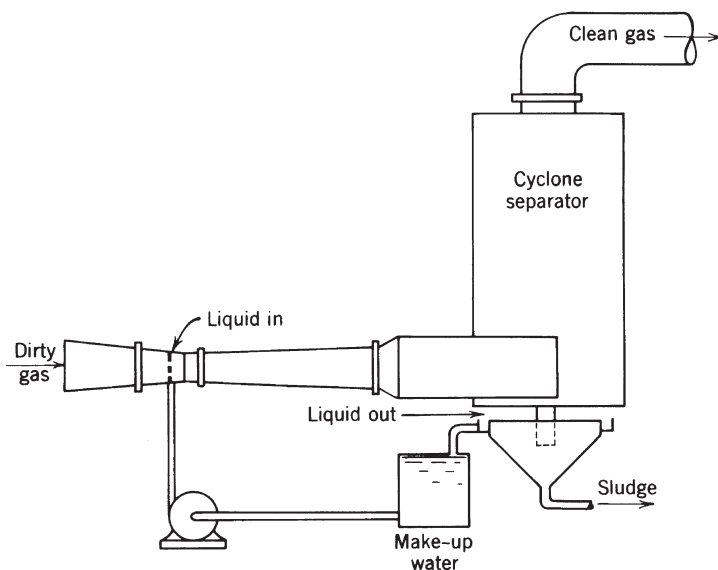


FIGURE 4.9 Venturi scrubber. (Source: *Air Pollution Control Field Operations Manual*, PHS Pub. 937, Department of Health, Education, and Welfare, Washington, DC, 1962.)

Gaseous Collectors and Treatment Devices

The release of gases and vapors to the atmosphere can be controlled by combustion, condensation, absorption, and adsorption. Combustion devices include thermal afterburners, catalytic afterburners, furnaces, and flares.

Thermal afterburners are used to complete the combustion of unburned fuel, such as smoke and particulate matter, and to burn gaseous hydrocarbons and odorous combustible gases. Apartment house and commercial incinerators and meat-packing plant smokehouses are examples of smoke and particulate emitters. Rendering, packing house, refinery, and paint and varnish operations; fish processing; and coffee roasting are examples of odor-producing operations. Afterburners usually operate at around 1200°F (649°C) but may range from 900° to 1600°F (482°–871°C), depending on the ignition temperature of the contaminant to be burned.

Catalytic afterburners may be used for the burning of lean mixtures of combustible gaseous air contaminants. They are also used to reduce nitrous oxides, with ammonia injection.

Condensers are best used to remove vapors by condensation, generally prior to passage to other air pollution control equipment, thus reducing the load on this equipment. Condensers are of the surface and contact types. In the surface condenser, the vapor comes into contact with a horizontal cool surface and condenses to form liquid droplets with a pure saturated vapor or, more commonly,

a film. In the contact condenser, the coolant, vapors, and condensate are all in intimate direct contact.

Adsorbers are of the fixed-bed stationary or rotating type, in horizontal or vertical cylinders, usually with activated-carbon beds or supported screens, through which the gas stream passes. In adsorption, the molecules of a fluid such as a gas, liquid, or dissolved substance to be treated are brought into contact with the adsorbent, such as activated carbon, aluminas, silicates, char, or gels that collect the contaminant in the pores or capillaries. The material adsorbed is called the adsorbate. In some cases, the adsorbent, such as activated carbon, is regenerated by superheated steam at about 650°F (343°C); the contaminant is condensed and collected for proper disposal. In other cases, the adsorbent and adsorbate are separated from the fluid and discarded. Solid adsorbents have very large surface-to-volume ratios and different adsorptive abilities, depending on the particular adsorbate. The life of an activated-carbon adsorption bed is reduced if particulate matter is not first removed.

In *absorption*, the gaseous emission to be treated is passed through a packed tower, spray or plate tower, and venturi absorbers, where it comes in contact with a liquid absorbing medium or spray that selectively dissolves or reacts with the air contaminants to be removed. For example, oxides of nitrogen can be absorbed by water; hydrogen fluoride, by water or an alkaline water solution. Absorption is generally also used to control emissions of sulfur dioxide, hydrogen sulfide, hydrogen chloride, chlorine, and some hydrocarbons. Lime injection controls acid gas emissions from incinerators.

Vapor conservation equipment is used to prevent vapors escaping from the storage of volatile organic compounds such as gasoline. A storage tank with a sealed floating roof cover or a vapor recovery system connected to a storage tank is used. Vapors that can be condensed are returned to the storage tank.

Dilution by Stack Height

Since wind speed increases with height in the lower layer of the atmosphere, the release of pollutants through a tall stack enhances the transport and diffusion of the material. The elevated plume is rapidly transported and diffused downwind. This generally occurs at a rate faster than that of the diffusion toward the ground. The resulting downwind distribution of pollutant concentrations at the ground level is such that concentrations are virtually zero at the base of the stack, increase to a maximum at some downwind distance, and then decrease to negligible concentrations thereafter. This distribution and the difference due to stack height are shown schematically in Figure 4.10. This applies to uncomplicated weather and level terrain. Obviously, if the plume is transported to hill areas, the surfaces will be closer to the center of the plume and hence will experience higher concentrations.

Meteorological conditions will determine the type of diffusion the pollutant plume will follow. See Figure 4.3. With heavy atmospheric turbulence associated with an unstable lapse rate, the plume will “loop” as it travels downwind. With

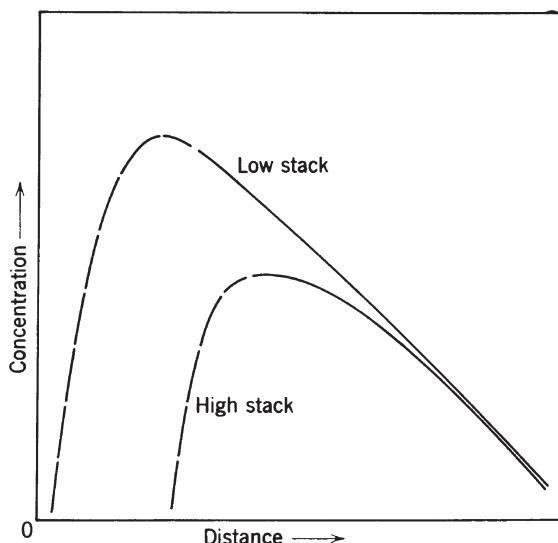


FIGURE 4.10 Variation of ground-level pollutant concentration with downwind distance. (The distance may be hundreds of miles.)

lesser turbulence associated with a neutral lapse rate, the plume will form a series of extended, overlapping cones called *coning*. With stable air conditions and little turbulence associated with an inversion, the plume will “fan” out gradually. With the discharge of a plume below an inversion, the plume will be dispersed rapidly downward to the ground surface, causing *fumigation*. With the discharge of a plume within the inversion layer, the plume will spread out horizontally as it moves downwind with little dispersion toward the ground. Erratic weather conditions can cause high concentrations of pollutants at ground level if the plume is transported to the ground.

It has been general practice to use high stacks for the emission of large quantities of pollutants, such as in fossil-fueled power production, to reduce the relatively close-in ground-level effects of the pollutants. Stacks of 250 to 350 feet in height are not unusual, and some are as high as 800 to 1,250 feet. It should be recognized, however, that there is a practical limit to height beyond which cost becomes excessive and the additional dilution obtained is not significant. There may also be legal permitting restrictions on the maximum stack height.

Although local conditions are improved where a tall stack is used, adverse environmental effects continue to be associated with the distant (long-range) transport of pollutants. For example, the pollutants contribute to acid rain, heavy-metal particle deposition, and toxic metal dissolution from surrounding or downwind soils and rocks into surface and groundwaters, which adversely affect the flora and fauna hundreds or more miles away (as previously noted). Therefore, emphasis should be placed on reduction of emission concentrations,

rather than on dispersion from a tall stack, to improve ambient air quality. The EPA is also considering requiring pollution control devices on tall stacks and limiting tall stacks for emission dispersion by requiring removal instead.

Planning and Zoning

The implementation of planning and zoning controls requires professional analysis and the cooperation of the state and regional planning agencies and the local county, city, village, and town units of government.

The local economic, social, and political factors may limit what can realistically be achieved in many instances. For example, a combination of factors, including planning and zoning means, should be considered in locating a new plant. These means could include plant siting downwind from residential, work, and recreational areas, with consideration given to climate and meteorological factors, frequency of inversions, topography, air movement, stack height, and adjacent land uses. Additional factors are distance separation, open-space buffers, designation of industrial areas, traffic and transportation control, and possible regulation of plant raw materials and processes. All these controls must recognize the present and future land use and especially the air quality needed for health and comfort, regardless of the land ownership.

The maintenance of air quality that meets established criteria requires regulation of the location, density, and/or type of plants and plant emissions that could cause contravention of air quality standards. This calls for local and regional land-use control and cooperation to ensure that the permitted construction of plants would incorporate practices and control equipment that would not emit pollution that could adversely influence the air quality of the community in the airshed. See Tables 4.6 and 4.7 and “Ambient Air Quality Standards,” later in this chapter.

Monitoring of the air at carefully selected locations would continually inform and alert the regulatory agency of the need for additional source control and enforcement of emission standards. Conceivably, under certain unusually adverse weather conditions, a plant may have to take previously planned emergency actions to reduce or practically eliminate emissions for a period of time.

Air zoning establishes different air quality standards for different areas based on the most desirable and feasible use of land. As discussed earlier in this chapter, the 1977 amendments to the Clean Air Act allow each state to classify air areas as either class I, II, or III. Class I areas would remain virtually unchanged and class III could permit intensive industrial activity. Specific standards are established for each classification level. In all levels, however, protection of the public health is paramount. Insofar as air zoning is concerned, an industry should be able to choose its location and types of emission controls provided the air quality standards are not violated.

Although air zoning provides a system or basis for land use and development, sound planning can assist in greatly minimizing the effects of air pollution. A WHO Expert Committee suggests seven steps:⁴⁸

1. The siting of new towns should be undertaken only after a thorough study of local topography and meteorology.
2. New industries using materials or processes likely to produce air contaminants should be so located as to minimize the effects of air pollution.
3. Satellite (dormitory) towns should restrict the use of pollution-producing fuels.
4. Provision should be made for greenbelts and open spaces to facilitate the dilution and dispersion of unavoidable pollution.
5. Greater use should be made of hydroelectric and atomic power and of natural gas for industrial processes and domestic purposes, thereby reducing the pollution resulting from the use of conventional fossil fuels.
6. Greater use should be made of central plants for the provision of both heat and hot water for entire (commercial or industrial) districts.
7. As motor transport is a major source of pollution, traffic planning can materially affect the level of pollution in residential areas.

It is apparent that more needs to be learned and applied concerning open spaces, bodies of water, and trees and other vegetation to assist in air pollution control. For example, parks and greenbelts appear to be desirable locations for expressways because vegetation, in the presence of light, will utilize the carbon dioxide given off by automobiles and release oxygen. In addition, highway designers must give consideration to such factors as road grades, speeds and elevations, natural and artificial barriers, interchange locations, and adjacent land uses as means of reducing the amounts and effects of automobile noise and emissions.

Air Quality Modeling

It is possible to calculate and predict, *within limits*, the approximate effects of existing and proposed air pollution sources on the ambient air quality.⁴⁹ A wide variety of models are used to estimate the air quality impacts of sources on receptors, to prepare or review new industrial and other source applications, and to develop air quality management plans for an area or region.

Air quality models can be categorized into four classes:

1. *Gaussian*: Most often used for estimating the ground-level impact of non-reactive pollutants from stationary sources in a smooth terrain.
2. *Numerical*: Most often used for estimating the impact of reactive and non-reactive pollutants in complex terrain.
3. *Statistical*: Employed in situations where physical or chemical processes are not well understood.
4. *Physical*: Involves experimental investigation of source impact in a wind tunnel facility.

Because of the almost limitless variety of situations for which modeling may be employed, no single model can be considered “best.” Instead, the user is encouraged to examine the strengths and weaknesses of the various models available and select the one best suited to the particular job at hand.

The EPA has made a number of models available to the general public through its User’s Network for Applied Modeling of Air Pollution (UNAMAP). These models can be obtained from the National Technical Information Service (NTIS).

The information needed to use an air quality model includes source emission data, meteorological data, and pollutant concentration data.

Source Emission Data Sources of pollutants can generally be classified as point, line, or area sources. Point sources are individual stacks and are identified by location, type and rate of emission, and stack parameters (stack height, diameter, exit gas velocity, and temperature). Line sources are generally confined to roadways and can be located by the ends of roadway segments. Area sources include all the minor point and line sources that are too small to require individual consideration. These sources are usually treated as a grid network of square areas, with pollutant emissions totaled and distributed uniformly within each grid square.

Meteorological Data The data needed to represent the meteorological characteristics of a given area consist of (as a minimum) wind direction, wind speed, atmospheric stability, and mixing height. The representativeness of the data for a given location will depend on the proximity of the meteorological monitoring site to the area being studied, the period of time during which data are collected, and the complexity of terrain in the area. Local universities, industries, airports, and government agencies can all be used as sources of such data.

Pollutant Concentration Data In order to assess the accuracy of a model for a particular application, predicted concentrations must be compared against observed values. This can be done by obtaining historical pollutant concentration data from air quality monitors located in the study area. Air quality data from monitors located in remote areas should also be obtained to determine if a background concentration should be included in the model. Data should be verified using appropriate statistical procedures.

The accuracy of the model used depends on the following factors:

1. How closely do the assumptions upon which the model is based correspond to the actual conditions for which the model is being used? For example, a model that assumes that the area being modeled is a flat plain of infinite extent may work well in Kansas but not in Wyoming.
2. How accurate is the information being used as input for the model? Of particular importance here is verifying the accuracy of source emission data. Some points to consider are as follows:

- a. Should the source emission data be given in terms of potential, actual, or allowable emissions? "Actual" emissions should always be used for model verification.
- b. Does emission rate vary by time of day or time of year?
- c. What level of production, percent availability, and so on should be assumed for each emission source? The emission rates for industrial sources will often decline significantly during periods of economic recession. Similarly, stationary fuel combustion sources (for space heating) will vary according to the severity of the winter.
- d. Are stack parameters correct? Are there nearby structures or terrain features that could influence the dispersion patterns of individual sources?
- e. Is the source location correctly identified?
- f. How reliable is the pollution control equipment installed on each emission source?

The user will often find that the job of verifying the input data are the most difficult and time-consuming part of the modeling process.

As the cost of computer services continues to decline, it is expected that air quality modeling will become an available technology for smaller agencies such as local health and planning departments. The person who performs this modeling will have to be knowledgeable not only in traditional air pollution control engineering but also in the fields of air pollution meteorology and computer programming.

PROGRAM AND ENFORCEMENT

General

A program for air resources management should be based on a comprehensive areawide air pollution survey including air sampling, basic studies and analyses, and recommendations for ambient air quality standards. The study should be followed by an immediate and long-term plan to achieve the community air quality goals and objectives, coupled with a surveillance and monitoring system and regulation of emissions.

MacKenzie proposes six conclusions and decisions for the implementation of a study:⁴³

1. Select air quality standard, possibly with variations in various parts of the area.
2. Cooperate with other community planners in allocating land uses.
3. Design remedial measures calculated to bring about the air quality desired. Such measures might include several or all of the following: limitations on pollutant emissions, variable emission limits for certain weather conditions and predictions, special emission limits for certain areas, time schedules for

commencing certain control actions, control of fuel composition, control of future sources by requiring plan approvals, prohibition of certain plan approvals, prohibition of certain activities or requirements for certain types of control equipment, and performance standards for new land uses.

4. Outline needs for future studies pertaining to air quality and pollutant emissions and design systems for collection, storage, and retrieval of the resultant data.
5. Establish priorities among program elements and set dates for implementation.
6. Prepare specific recommendations as to administrative organization needed to implement the program, desirable legislative changes, relationships with other agencies and programs in the area and adjoining areas and at higher governmental levels, and funds, facilities, and staff required.

As in most studies, a continual program of education and public information supplemented by periodic updating is necessary. People must learn that air pollution can be a serious hazard and must be motivated to support the need for its control. In addition, surveys and studies must be kept current; otherwise, the air resources management activities may be based on false or outdated premises.

International treaties, interstate compacts or agreements, and regional organizations are sometimes also needed to resolve air pollution problems that cross jurisdictional boundaries. This becomes more important as industrialization increases and as people become more concerned about the quality of their environment.

It becomes apparent that the various levels of government each have important complementary and cooperative roles to play in air pollution control.

The federal government role includes research into the causes and effects of air pollution, as well as the control of international and interstate air pollution on behalf of the affected parties. It should also have responsibility for a national air-sampling network, training, preparation of manuals and dissemination of information, and assisting state and local governments. In the United States, this is done primarily through the EPA. Other federal agencies making major contributions are the U.S. Weather Service; the Nuclear Regulatory Commission, in relation to the effects of radioactivity; the Department of Agriculture, in relation to the effects of air pollution on livestock and crops; the Department of Interior; the Department of Commerce, including the National Bureau of Standards; and the Civil Aeronautics Administration.

The state role is similar to the federal role. It would include, in addition, the setting of statewide standards and establishment of a sampling network, the authority to declare emergencies and possession of appropriate powers during emergencies, the delegation of powers to local agencies for control programs, and the conducting of surveys, demonstration projects, public hearings, and special investigations.

The role of local government is that delegated to it by the state and could include complete program implementation and enforcement.

Organization and Staffing

Organization and staffing will vary with the level of government, the legislated responsibility, funds provided, government commitment, extent of air pollution, and other factors. Generally, air pollution programs are organized and staffed on the state, county, large-city, and federal levels. In some instances, limited programs of smoke and nuisance abatement are carried out in small cities, towns, and villages as part of a health, building, or fire department program. Because of the complexities involved, competent direction, staff, and laboratory support are needed to carry out an effective and comprehensive program. A small community usually cannot afford—and, in fact, might not have need for—a full staff, but it could play a needed supporting role to the county and state programs. In this way, uniform policy guidance and technical support could be provided and local on-the-spot assistance utilized. The local government should be assigned all the responsibilities it is capable of handling effectively.

An organization chart for an air resources management agency is shown in Figure 4.11. There are many variations.

Regulation and Administration

A combination of methods and techniques is generally used to prevent and control air pollution after a program is developed, air-quality objectives established, and problem areas defined:

- Public information and education
- Source registration
- Plan review and construction operation approval
- Emission standards
- Monitoring and surveillance
- Technical assistance and training
- Inspection and compliance follow-up
- Conference, persuasion, and administrative hearing
- Rescinding or suspension of operation permit
- Legal action—fine, imprisonment, misdemeanor, injunction

Effective administration requires the development and retention of competent staff and the assignment of responsibilities. In a small community, the responsibilities would probably be limited to source location and surveillance, data collection, smoke and other visible particulate detection, complaint investigation, and abatement as an arm of a county, regional, or state enforcement unit.

Regulatory agencies usually develop their own procedures, forms, and techniques to carry out the functions just listed. Staffing, in addition to the director of air pollution control, may include one or more of the following: engineers, scientists, sanitarians, chemists, toxicologists, epidemiologists, public information

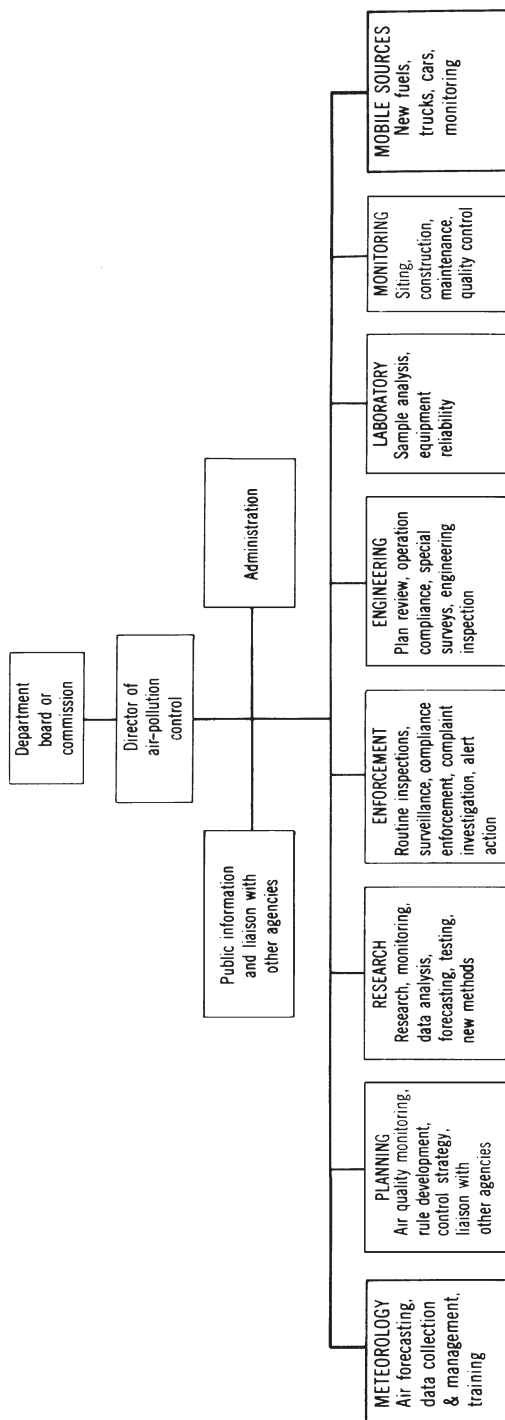


FIGURE 4.11 Air resources management functional organization chart.

specialists, technicians, inspectors, attorneys, administrative assistants, statisticians, meteorologists, electronic data processing specialists, and personnel in supporting services.

Important in regulation is the development of working relationships and memoranda of agreements with various public and private agencies. For instance, government construction, equipment, and vehicles could set examples of air pollution prevention. The building department would ensure that new incinerators and heating plants have the proper air pollution control equipment. The police would enforce vehicular air pollution control requirements. The fire department would carry out fire prevention and perhaps boiler inspections. The planning and zoning boards would rely on the director of air pollution control and the director's staff for technical support, guidance, and testimony at hearings. Equipment manufacturers would agree to sell only machinery, equipment, and devices that complied with the emission standards. The education department would incorporate air pollution prevention and control in its environmental health curriculum. Industry, realty, and chain-store management would agree to abide by the rules and police itself. Cooperative training and education programs would be provided for personnel responsible for operating boilers, equipment, and other facilities that may contribute to air pollution. These are but a few examples. With ingenuity, many more voluntary arrangements can be devised to make regulation more acceptable and effective.

NOISE CONTROL

One of the most important tasks of architects, builders, acoustic engineers, urban planners, industrial hygiene engineers, equipment manufacturers, and public health personnel is to ensure that noise and vibration are kept to an acceptable level in the general environment, in the workplace, and inside dwellings. Noise is of special concern in occupational health where hearing loss has been documented.

The discussion that follows will touch on some of the fundamentals of noise and its effects, measurement, reduction, and control. Special problems should involve experts such as acoustical consultants.

Definitions and Explanation of Selected Terms and Properties of Sound

Sound Sound and, therefore, all noise, is physically a rapid alteration of air pressure above and below atmospheric pressure. Basically, all sounds travel as sound pressure waves from a vibrating body such as a human larynx, radio, TV, record player speaker, or vibrating machine.

A sound that contains only one frequency is a *pure tone*, which is expressed in Figure 4.12 as a sine curve. Most sounds contain many frequencies. In general, the waves travel outward from the source in three dimensions. The *pitch* of a sound is determined primarily by frequency: vibrations per second. The amplitude or magnitude of sound is the *sound pressure*.

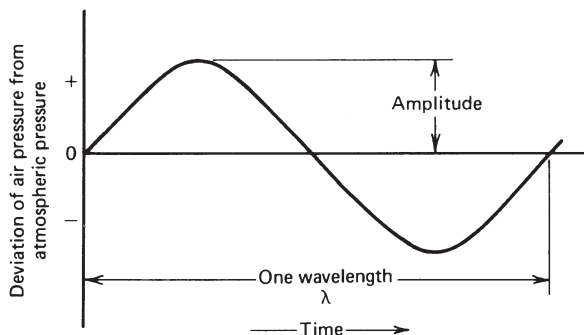


FIGURE 4.12 Pure tone, sine wave.

The distance that a sound wave travels in one cycle or period is the wavelength of the sound. This is illustrated in Figure 4.12. Wavelength is given by the equation

$$\lambda = \frac{c}{f}$$

where

λ = wavelength, ft

f = frequency, Hz (cycles/sec)

c = speed of sound, ft/sec

Sound travels through gases, liquids, and solids but not through a vacuum. The speed with which sound travels through a particular medium is dependent on the compressibility and density of the medium. Our own voice reaches us primarily through the bony structures in our head. Most sound reaches us through the air and less frequently through solids and liquids. The speed of sound through various media is given in Table 4.9.

As sound travels through a medium, it loses energy or amplitude in two ways: molecular heating and geometric spreading. For example, drapes absorb sound, releasing the energy as heat to the surrounding air. Air itself also absorbs sound to a smaller degree because it is not perfectly elastic. Plane waves emitted from a large distant source travel in a plane or front perpendicular to their direction of travel. There is no geometric spreading or energy loss in plane waves, neglecting molecular heating. Spherical waves, resulting from a small vibrating sphere in close proximity, spread in three dimensions. They lose energy according to the inverse square law, given by

$$I_{\text{ave}} = \frac{W}{4\pi r^2}$$

where

I = sound intensity, watts/cm²

r = distance to the source, cm

W = total source power, watts

TABLE 4.9 Speed of Sound in Various Media

Media	Speed	
	m/s	fps
Air, 69.8°F (21°C)	344	1,129
1,213°C)	331	1,086
Alcohol	1,213	3,980
Lead	1,220	4,003
Hydrogen, 32°F (0°C)	1,269	4,164
Water, fresh	1,480	4,856
Water, salt, 69.8°F (21°C), at 3.5% salinity	1,520	4,987
Human body	1,558	5,112
Plexiglas	1,800	5,906
Wood, soft	3,350	10,991
Concrete	3,400	11,155
Fir timber	3,800	12,468
Mild steel	5,050	16,570
Aluminum	5,150	16,897
Glass	5,200	17,061
Gypsum board	6,800	22,310
Copper	3,901	12,800
Brick	4,176	13,700

Source: A. J. Schneider, *Noise and Vibration Rocket Handbook*, Bruel & Kjaer, Cleveland. OH. p. 18; *IAC Noise Control Handbook*, Industrial Acoustics Co., New York, 1982, p. A-6.

For every doubling of distance, the intensity is reduced by a factor of four, or 6 dB. The sound from an infinite line source spreads geometrically in two dimensions so that energy is halved, or loses 3 dB, when the source distance doubles. When reflecting objects are near, a more complex sound field results.

Noise Noise is unwanted sound. It may be unwanted for a variety of reasons: causing hearing loss, interfering with communication, causing loss of sleep, adversely affecting human physiology, or causing just plain annoyance.

Noise Pollution Noise pollution is the condition in which noise has characteristics and duration injurious to public health and welfare or unreasonably interferes with the comfortable enjoyment of life and property in such areas as are affected by the noise.

Ambient Noise Ambient noise is the total noise in a given situation or environment.

Noise Level Noise level is the weighted sound pressure level in dBA* obtained by the use of an approved type [American National Standards Institute (ANSI)]

*The A-weighted scale approximates the frequency response of the human ear.

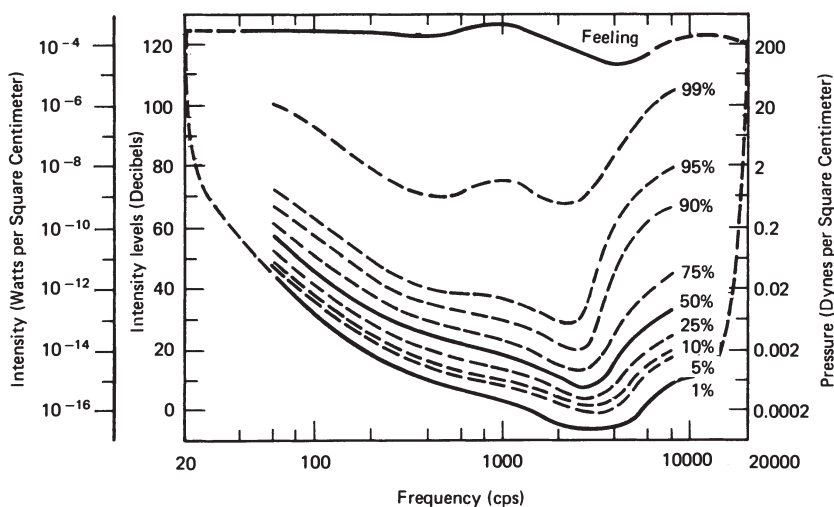


FIGURE 4.13 Absolute auditory threshold for a typical group of Americans. Curves are labeled by percent of group that could hear tones below the indicated level. (*Source: Toward a Quieter City*, A report of the Mayor's Task Force on Noise Control, New York, 1970.)

sound-level meter. See "Decibel" and "Sound Pressure," as well as "Sound-Level Meter," later in this chapter.

Frequency Frequency of sound is the number of times a complete cycle of pressure variation occurs in 1 second, both an elevation and a depression below atmospheric pressure. The frequency of a sound determines its *pitch*. Frequency is expressed in hertz (Hz), which is the metric unit for cycles per second (cps). For example, sounds with a frequency of 30 Hz are considered very low pitch; sounds with a frequency of 15,000 Hz are very high pitch. A young, healthy ear can detect frequencies over a range of about 20 to 20,000 Hz, but the most common sensitive hearing range is between 1,000 and 6,000 Hz. Normal speech is in the range of 250 to 3,000 Hz. However, the audibility of sound is dependent on both frequency and sound pressure level. This is illustrated in Figure 4.13 for a typical group of Americans. Since most sounds are made up of several frequencies, a narrow-band analyzer is used to determine the various frequencies in a sound. Most sounds are in the sonic frequency range of 20 to 20,000 Hz. Ultrasonic range is 20,000 Hz and above; infrasonic range is 20 Hz and below. See "Sound Analyzer" and "Octave-Band Analyzer" later in this chapter.

Decibel Decibel (dB) is a dimensionless unit to express physical intensity or sound pressure levels. The starting or reference point for noise-level measurement is 0 dBA, the threshold of hearing for a young person with very good hearing. The threshold of pain is 120 dBA. The decibel is one-tenth of the bel, a unit using common logarithms named for Alexander Graham Bell.

Sound Pressure The sound pressure level of a noise source is expressed by this relationship:

$$\text{Sound pressure level (SPL) in dB} = 20 \log_{10} \frac{P}{P_0}$$

where

P = pressure of measured sound, micropascals (μPa)

P_0 = sound pressure reference level of $20 \mu\text{Pa}$ *; for measurements in air, this is the threshold of human hearing at 1,000 Hz

A change in sound pressure level with distance from a source can be determined by

$$P_2 = P_1 - 20 \log \frac{d_2}{d_1}$$

where

P_1 = sound pressure level at location 1, dB

P_2 = sound pressure level at location 2, dB

d_1 = distance from noise source to location 1

d_2 = distance from noise source to location 2

The sound pressure level is measured by a standard sound-level meter. The meter has built-in electrical characteristics or weighting that simulates the way the ear actually hear sound.

Pascal (Pa) is a unit of pressure corresponding to a force of 1 N acting uniformly upon an area of 1 m^2 ; $1 \text{ Pa} = 1 \text{ N/m}^2$.

Newton (N) is the force required to accelerate 1 kg mass at 1 m/s^2 . It is approximately equal to the gravitational force on a 100 g mass. The A-weighting, which simulates the frequency bias of the human ear, is most commonly used in measurements regarding impact on humans and the sound levels are read in dBA. The B, C, and D scales are normally used only for special occasions. For example, the D scale is used to measure and compare the effect of airplane noise on the human ear. The C scale is used for very loud sounds and the B scale for moderately loud sounds. See "Sound-Level Meter" for further discussion.

Table 4.10 shows the calculated sound pressure levels in decibels for selected sound pressure values.

To add sound-level values, it is first necessary to convert each decibel reading to sound intensity using these formulas:

$$\begin{aligned} \text{Sound intensity level in dB} &= 10 \log_{10} \frac{I}{I_0} \\ &= 10 \log_{10} \frac{I_1 + I_2}{I_0} \end{aligned}$$

*Equals 10^{-12} W for sound power and 10^{-12} W/m^2 for intensity, also 0.0002 dyn/cm^2 , or $0.0002 \mu\text{bar}$, or 0.00002 N/m^2 or $20 \mu\text{N/m}^2$.

TABLE 4.10 Sound Pressures for Selected Decibel Values

Sound Pressure ^a		Sound Pressure Level (dB) ^b
μbar	μPa	
0.0002	20	0 ^c
0.00063	63	10
0.002	200	20
0.0063	630	30
0.02	2,000	40
0.063	6,300	50
0.2	20,000	60
0.63	63,000	70
1.0	100,000	74
2.0	200,000	80
6.3	630,000	90
20	2,000,000	100
63	6,300,000	110
200	20,000,000	120
2,000	200,000,000	140

^a0.0002 microbars (μbar) for sound pressure in air = 20 μPa = 0.00002 N/m² (20 μN/m²) = 2.9 × 10⁻⁹ psi = 0.0002 dyn/cm².

^bRelative to 20 μPa or 0.0002 μbar = standard reference value.

^c0 dB = 2.9 × 10⁻⁹ psi = 10¹⁶ W/cm² = 10⁻¹² W/m² for sound intensity = threshold of human hearing.

where

- I = unknown sound intensity, watts/m²
- I_0 = sound intensity reference base = 10⁻¹² W/m²
- I_1 = sound intensity from source 1
- I_2 = sound intensity from source 2

All sound intensities are added and then the sum is converted to a resultant decibel reading. A similar procedure is followed to subtract the numbers of decibels. For example, to add two sound levels dB₁ and dB₂, find the I_1 , corresponding to dB₁; find I_2 corresponding to dB₂ and add to I_1 yielding I ; then reconvert to decibels using the formulas just given. This rather complex process is much simplified by use of Table 4.11. For example, consider the summation of a 50-dB sound with a 56-dB sound. For a difference of 6 dB, we find from Table 4.11 that 1 dB is added to the higher of the two sounds. The combined sound level is 57 dB. In adding several sound levels, start with the lowest.

Consider another example involving three noise sources. An industrial safety engineer wants to compute the total sound pressure level in a work area from the machinery nearby. An air compressor, a drill press, and ventilation fans contribute 85, 81, and 75 dB sound pressure levels, respectively. Starting with the lowest, according to Table 4.11, an 81-dB level and a 75-dB level sum to 82 dB. The 82-dB level and the 85-dB level sum to 86.8 dB. Note that if the 75-dB level were missing, the total would have been 86.5 dB, almost the same.

TABLE 4.11 Approximate Increase When Combining Two Sound Levels

Difference between Levels (dB)	Decibels to Be Added to Higher Level
0	3.0
1	2.6
2	2.1
3	1.8
4	1.5
5	1.2
6	1.0
7	0.8
8	0.6
10	0.4
12	0.3
14	0.2
16	0.1

Source: A. C. Hosey (Ed.), *Industrial Noise, A Guide to Its Evaluation and Control*, PHS Pub. No. 1572, Department of Health, Education, and Welfare, Washington, DC, 1967.

A noise contribution less than 10 dB lower than the other noise contributions can usually be neglected.

It should be noted that in using the previous formula the following generalization can be made: Any two *identical* sound levels will have the effect of increasing the overall level by 3 dB and any three will increase the overall level by 4.8 dB.

Intensity Intensity of a sound wave is the energy transferred per unit time (in seconds) through a unit area normal to the direction of propagation. It is commonly measured in W/m^2 or W/cm^2 . For a pure tone (single frequency), there is a one-to-one correspondence between loudness and intensity. However, almost all sound contains multiple frequencies. The relationship is not simple because of the interference effects of the sound waves.⁵⁰ For example, increasing the sound pressure level by 3 dB is equivalent to increasing the intensity by a factor of 2. Increasing the sound pressure level by 10 dB is equivalent to increasing the intensity by a factor of 10, and increasing the sound pressure level by 20 dB is equivalent to increasing the intensity by a factor of 100. Expressed in another way, whereas 10 dB is 10 times more intense than 1 dB, 20 dB is 100 times (10×10) more intense, and 30 dB 1,000 times ($10 \times 10 \times 10$) more intense.

Loudness Loudness, or amplitude, of sound is the sound level or sound pressure level as perceived by an observer. The apparent loudness varies with the sound pressure and frequency (pitch) of the sound. This is illustrated in Figure 4.14. It is specified in sones or phons. For a pure tone, each time the sound pressure level increases by 10 dB, the loudness doubles (sones increase

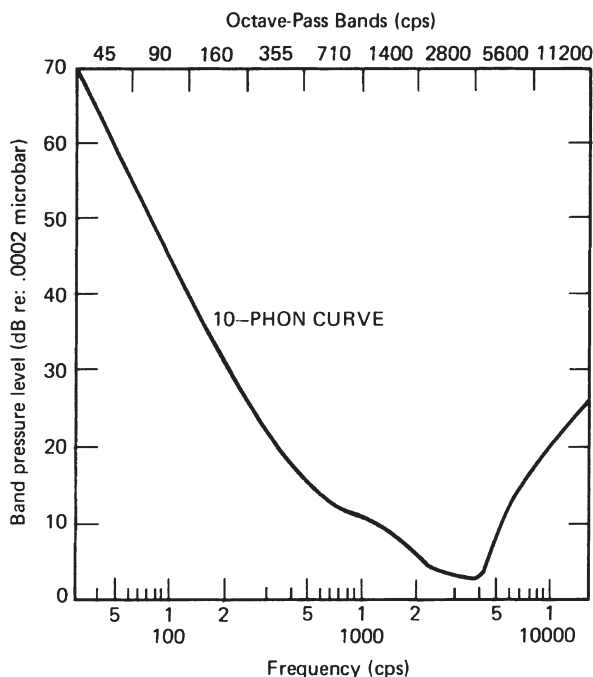


FIGURE 4.14 Equal loudness contour. (Source: *Toward a Quieter City*, A report of the Mayor's Task Force on Noise Control, New York, 1970.)

by a factor of 2). Sound levels of the same intensity may not sound the same since the ear does not respond the same to all types of sound.

A 1,000-Hz pure tone 40 dB above the listener's hearing threshold (0 dB) produces a loudness of 1 *son*, which is a unit of loudness.⁵¹ This loudness of 1 *son* is equal to 40 phons. Loudness levels are usually expressed in phons. For practical purposes, each doubling of the *sones* increases the phons by 10—that is, 1 *son* = 40 phons; 2 *sones* = 50 phons; 4 *sones* = 60 phons. Also for pure tones, a 10-dB increase in sound level would be perceived as a 10-phon increase in loudness by a person with good hearing in the frequency range of 600 to 2,000 Hz.

For example, take a human listener with normal hearing who hears a 100-Hz pure tone with a SPL of 90 dB. What loudness does the listener perceive?

From Figure 4.14, a SPL of 40 dB at approximately 100 Hz equals a loudness of 10 phons. Since a 50-dB increase in SPL is equivalent to a 50-phon increase in loudness, the tone's loudness is 60 phons, or 4 *sones*.

Noys Noys is a measure of the perceived noise level (PNL) (in decibel) in relation to the noisiness or acceptability of a sound level. Although similar to loudness, the ratings by observers when tested were different.

Procedures for the calculation of loudness and noisiness are given in standard texts.⁵²

Day–Night Average Sound Level (DNL) System The day–night average sound level is the 24-hour average sound level, expressed in decibels, obtained after the addition of a 10-dB penalty for sound levels that occur at night between 10 p.m. and 7 a.m. It is recorded as L_{dn} . The DNL system has been adopted by the EPA, the Department of Defense, the Department of Housing and Urban Development (HUD), and the Federal Aviation Administration (FAA), specifically for describing environmental impacts for airport actions.⁵³

Effects of Noise – A Health Hazard

Noise pollution is an environmental and workplace problem. Excessive noise can cause permanent or temporary loss of hearing. Loud sounds affect the circulatory and nervous systems, although the effects are difficult to assess. It interferes with speech, radio, and TV listening; disturbs sleep and relaxation; affects performance as reduced work precision and increased reaction time; and causes annoyance, irritation, and public nuisance. There is a hearing loss with age, particularly at the higher frequencies, and in younger people who have been exposed to loud noises. Occupation-related hearing loss has been documented since the sixteenth century and is still a serious problem. An estimated \$835 million compensation was paid workers from 1978 to 1987.⁵⁴ Sonic booms can cause physical damage to structures. David G. Hawkins, assistant EPA administrator reported the following:⁵⁵

A poll conducted by the U.S. Bureau of the Census showed that noise is considered to be the most undesirable neighborhood condition—more irritating than crime and deteriorating housing.

Criteria for hearing protection and conservation have been established primarily for the worker. The major factors related to hearing loss are intensity (sound pressure levels in decibels), frequency content, time duration of exposure, and repeated impact (a single pressure peak incident). In measuring the potential harm of high-level noise, frequency distribution as well as intensity must be considered. Continuous exposure to high-level noise is more harmful than intermittent or occasional exposure. High- and middle-frequency sounds at high levels generally are more harmful than low-frequency sounds at the same levels. Greater harm is done with increased time of exposure.

Individuals react differently to noise depending on age, sex, and socioeconomic background. The relation of noise to productivity or performance is contradictory and not well established.

For workers, a sound level over 85 dBA calls for study of the cause. A level above 90 dBA should be considered unsafe for daily exposure over a period of months and calls for noise reduction or personal ear protection if this is practical.

An EPA report identified a 24-hour exposure level of 70 dBA as the level of environmental noise that will prevent any measurable hearing loss over a lifetime. Levels of 55 dBA outdoors and 45 dBA indoors are identified as preventing

annoyance and not interfering with spoken conversation and other activities such as sleeping, working, and recreation.⁵⁶ Some common sound levels and human responses are noted in Table 4.12.

Other effects of noise are reduced property values; increased compensation benefits and possible accidents, inefficiency, and absenteeism; and increased building construction costs.

Sources of Noise

Transportation, industrial, urban, and commercial activities are the major sources of noise, plus the contributions made by household appliances and equipment.

TABLE 4.12 Sound Levels and Human Response

Sources	Noise Level (dBA)	Response
Carrier deck, jet operation	140	Painfully loud
Live rock music	130	Limits amplified speech
Jet takeoff (200 ft)	120	Maximum vocal effort
Discotheque	115	
Rock band (10 ft)	115	
Auto horn (3 ft) loud	110	
Riveting machine	110	
Jet takeoff (2000 ft)	110	
Garbage truck, snowmobile	100	
Power lawn mower (operator)	95	
New York subway station	90	Very annoying
Heavy truck (50 ft)	90	Hearing damage (8 hr)
Food blender	90	
Pneumatic drill (50 ft)	85	
Diesel truck, 40 mph (50 ft)	85	
Dishwasher	80	
Alarm clock	80	Annoying
Garbage collection	80	
Freeway traffic (50 ft)	70	Telephone use difficult
Vacuum cleaner	70	
Normal speech	60	
Air-conditioning unit (20 ft)	60	Intrusive
Light auto traffic (100 ft)	50	Quiet
Living room	40	Quiet
Bedroom	40	
Public library	35	
Soft whisper (15 ft)	30	Very quiet
Broadcasting studio	20	
Breathing	10	Just audible
	0	Threshold of hearing

Sources: *Sound Levels and Human Responses*, Office of Planning Management, U.S. Environmental Protection Agency, Washington, DC, July 1973; *MMWR*, March 1986, p. 185.

The major sources of transportation noise are motor vehicles, including buses and trucks, aircraft, motorcycles, and snowmobiles.

Industrial, urban, and commercial noises emanate from factories, equipment serving commercial establishments, and construction activities. Construction equipment sources are power tools, air compressors, earthmovers, dump trucks, garbage collection trucks, diesel cranes, pneumatic drills, and chain saws. Compactor trucks manufactured after October 1, 1980, may not exceed a noise level of 79 decibels and may not exceed 76 decibels after July 1, 1982, measured on the A-weighted scale 7 m from the front, side, and rear of the vehicle while empty and operating.

Residential noise is associated with dishwashers, garbage disposal units, air conditioners, power lawn mowers, and home music amplifier units.

Measurement of Noise

Noise measurement equipment selection depends on the task to be performed. For an initial survey, a sound-level meter is adequate for a rapid evaluation and identification of potential problem areas. To study and also determine the characteristics of a noise problem area, a sound-level meter, frequency analyzer, and recorder are needed to determine sound pressure distribution with frequency and time. More sophisticated equipment would be needed for research or solution of special noise problems.

Sound-Level Meter A sound-level meter is used to measure the sound pressure level; it is the basic instrument for noise measurement.

Meters are available to cover the range of 20 to 180 dB. The specifications usually refer to the American National Standards Institute (ANSI) and particularly to the standard *Specification for Sound Level Meters*, ANSI S1.4-1971. Three weighting networks, A, B, and C, are provided to give a number that best approximates the total loudness level for a particular situation, with consideration of the sound frequency, intensity, and impact levels. There are three types of meters. Type I is highest quality; type III is lowest quality and not suitable for public health professionals. Type II is the most common type used by public health officials. Most noise laws and regulations permit either type I or II but not type III meters.

The B and C networks are no longer normally used. The A-weighted scale is most commonly used. It discriminates against frequencies below 500 Hz and most nearly encompasses the most sensitive hearing range of sound—that is, 1,000 to 6,000 Hz. The symbol dBA is used to designate the A-weighted decibel scale, which combines both frequency and pressure levels; it measures environmental noise and should be supplemented by the time or duration to determine the total quantity of sound affecting people. The sound level meter provides the total quantity of sound affecting people. The sound-level meter provides settings for “F” (fast time response) and “S” (slow time response).

The most important part of the equipment is a calibrator that generates a known decibel standard. Without a calibration before and after a measurement, the measurement is suspect.

Noise Dosimeter The noise dosimeter will measure the amount of potentially injurious noise to which an individual is exposed over a period of time. A dosimeter can be set to the desired level and will then total the exposure time to noise above the set level. The noise dosimeter does not, however, identify noise sources. Therefore, if a study is being conducted to determine noise exposure and culpability, it is imperative that the dosimeter be coupled with a frequency analyzer or better still with a human observer to record noise source identities.

Sound Analyzer A frequency analyzer may be necessary to measure complex sound and sound pressure according to frequency distribution. It will supplement readings obtained with a sound-level meter. Noise analyzers cover different frequency bands. The octave-band analyzer is the most common. The impact noise analyzer is used to measure the peak level and duration of impact noise. Examples of impact noises are drop hammer machines and gun fire.

Cathode-Ray Oscillograph This makes possible observing the wave form of a noise and pattern. The magnetic tape recorder makes possible the collection of noise information in the field and subsequent analysis of the data in the office or laboratory. Environmental noise monitors are now available that can be located in a community and will retain noise levels in a memory.

Octave-Band Analyzer This has filters that usually divide a noise into eight possible frequency categories. Each category is called an octave band, with frequency ranges of 45 to 90, 90 to 180, 180 to 355, 355 to 710, 710 to 1,400, 1,400 to 2,800, 2,800 to 5,600, and 5,600 to 11,200 Hz (or cps). The bands are identified by their center or midfrequencies: 63, 125, 250, 500, 1,000, 2,000, 4,000, and 8,000 Hz. With center-frequency bands at 31.5 and 16,000 Hz, the audible frequency range of 20 to 20,000 Hz is then covered with 10 octave bands.

Background Noise Background noise is noise in the absence of the sound being measured that may contribute to and obscure the sound being measured. A rough correction could be made by applying the correction factors given in Table 4.13. However, such subtractions typically introduce significant error in the final result. The message to be obtained from Table 4.13 is that the background noise should be at least 10 dB lower than the noise being measured. This will introduce negligible error (less than 0.5 dB) due to interfering background.

Methods for Noise Control

Noise can be controlled at the source, in its path of transmission (through a solid, air, or liquid), or where it is received. Sometimes, because no one method

TABLE 4.13 Correction for Background Noise

Total Noise Level Less Background Level (dB)	Decibels to Subtract from Total Noise Level to Get Noise Level Due to Source
10	0.5
9	0.6
8	0.7
7	1.0
6	1.2
5	1.6
4	2.2
3	3.0
2	4.3
1	6.9

Source: H. H. Jones, "Noise Measurement," *Industrial Environment. . . Its Evaluation and Control*, PHS Pub. No. 614, Department of Health, Education, and Welfare, Washington, DC, 1958, p. B-21.

is sufficiently effective, controls are instituted at two or at all three steps in the path of noise travel from the source to the receptor. In general, it is best to reduce the noise at the source. This should include establishment of clear, reasonable, and enforceable noise design objectives for manufacturers and installers.

Noise control generally involves adoption and effective enforcement of reasonable and workable regulations; protection of workers from hazardous occupational noise levels; building quieter machines, use of vibration isolators, new product regulation, and product labeling for consumer information; improved building construction and use of rubber sleeves, gaskets, paddings, linings, seals, and noise barriers; compatible land-use planning and zoning; and informing the public of harmful effects of noise and methods to reduce noise to acceptable levels. Regulations may encompass ambient noise in general and industrial noise, motor vehicle noise, and aircraft noise as well as building and construction codes, housing occupancy codes, sanitary codes, and nuisance codes.

A WHO Expert Committee⁵⁷ suggests the following preventive measures to control noise and vibration:

- General measures such as locating noisy industrial plants, airports, landing fields for helicopters, railway stations and junctions, superhighways, and so on, outside city limits
- Improving technical processes and industrial installations with a view to reducing noise and vibration and installing noise suppressors (mufflers) on automobiles, motorcycles, and so on
- Improving the quality of surface highways and urban streets (also tire tread designs)
- Creating green spaces in each neighborhood district
- Perfecting procedures for acoustic insulation

- Adopting administrative regulations with a view to limiting the intensity of background noise within the urban environment

The committee recommends close international collaboration and close cooperation between metropolitan planners and environmental health personnel to reduce noise and vibration to a minimum.

Control of Industrial Noise

Noise control should start in the planning of a new plant or when planning to modernize an existing plant. Consideration should be given at that time to minimizing the effects of noise on the workers, office personnel, and nearby residents. The control of an existing noise problem first requires suitable noise standards and an identification of the location, extent, and type of noise sources. This would be followed by the application of needed noise-control measures to achieve the required or desired levels.

Eight factors are considered in industrial noise control:⁵⁸

1. Select building site that is isolated or an area where there is a high background noise level. Topography and prevailing winds should be considered, as well as the use of landscaping and embankments, to reduce the noise travel where it may cause a nuisance.
2. Building layout should separate and isolate noisy operations from quiet areas.
3. Substitute low-noise-level processes for noisy operations, such as welding instead of riveting, metal pressing instead of rolling or forging, compression riveting instead of pneumatic riveting, and belt drives in place of gears.
4. Select new equipment with the lowest possible noise level (also modification of existing equipment with better mufflers).
5. Reduce noise at its source through maintenance of machinery, covers and safety shields, and replacement of worn parts; reduction of driving forces; reduction of response of vibrating surfaces; intake and discharge sound attenuation and flexible connections or collars; use of total or partial enclosures, with sound-absorbing materials (also coatings or sound-absorbing materials on metals to dampen vibration noise); and isolation of vibration and its transmission. See "Noise Control" and "Noise Reduction," earlier in this chapter.
6. Use acoustic absorption materials to prevent noise reflections.
7. Control noise in ventilation ducts or conveyor systems.
8. Use personnel shelters.

Sometimes the only practical and economical method of noise control is through the use of personal protective devices. These may also be a supplement to the applied engineering, worker, and education controls. Personal ear protector

types include properly fitted and sized earplugs, earmuffs, and helmets providing a good seal around the ear. They should meet established criteria for comfort, tension, sound attenuation (at least 15 dBA), simplicity, durability, and so on. To be effective, however, *the worker must cooperate by wearing the protective device* where needed. Dry cotton plugs do not provide significant sound attenuation.

Control of Transport Noise

Noise from various forms of transport and its transmission into the home may be reduced as follows:⁵⁹

- At the source, that is, by controlling the *emission* of noise
- By means of town and country planning and traffic engineering, that is, by controlling the *transmission* of noise
- In the home, that is, by controlling the *reception* of noise by the occupants

Eight specific measures can be used to reduce the effect of highway noise:

1. Enclose highways going through residential areas.
2. Use wider rights-of-way, that is, separation or buffer zone between the source and the receptor.
3. Design walls to deflect or absorb noise (earth berms covered with vegetation are more effective).⁶⁰
4. Change highway alignment and grade to avoid sensitive areas, minimizing stop-and-go traffic, and shifting to low gears.
5. Set lower speed limits for certain sections of a highway.
6. Use adjacent barriers, nonresidential buildings in sound transmission path, earth embankments or berms, and elevation or depression of highways. It is reported, however, that barriers provide little attenuation of low-frequency sounds and that a thick band of deciduous trees 200 to 300 ft in width is relatively ineffective in cutting down traffic noises, reducing them only on the order of 4 or 5 dB.⁶¹ Separation distance is most effective in reducing noise from highways.
7. Establish alternate truck routes.
8. Write building codes to require building insulation to limit interior transmission of noise. Additional measures are masonry walls, elimination of windows, use of double windows or glazing, soundproofing of ceilings, thick carpeting, overstuffed furniture, and heavy drapes.

Noise Reduction

Sound Absorption The amount of sound energy a material can absorb (soak up) is a function of its absorption coefficient (α) at a specified frequency. The

sound absorption coefficient is the fractional part of the energy of an incident sound wave that is absorbed by a material. A material with an absorption coefficient of 0.8 will absorb 80 percent of the incident sound energy. A material that absorbs all incident energy, such as an open window, has an absorption coefficient of 1. The sound absorption of a surface is measured in sabins. A surface having an area of 100 ft² made of material having an absorption coefficient of 0.06 has an absorption of 6 sabin units (100 × 0.06). To determine the noise reduction in a room, the floor, walls, and ceiling surface areas multiplied by the absorption coefficient of each surface, at a given frequency, before and after treatment, must be added to obtain the total room surface absorption in sabin units.

The *noise reduction* (NR) in decibels at a given frequency of a surface before and after treatment can be determined by the following equation:

$$NR = 10 \log_{10} \frac{A_2}{A_1}$$

where

A_2 = total room surfaces absorption after treatment, sabins

A_1 = total room surfaces absorption before treatment, sabins

Incremental noise reduction from a piece of machinery can be obtained by a rigid, sealed enclosure, plus vibration isolation of a machine from the floor using spring mounts or absorbent mounts and pads, plus acoustical absorbing material on the inside of the enclosure, plus mounting the enclosure on vibration isolators and enclosing, without contact, in another enclosure having inside acoustical absorbing material. If machinery air cooling and air circulation are needed, provide baffled air intakes. Insert a flexible connector, if a physical pipe or duct connection is needed between the machinery and other building piping or duct work, to reduce noise transmission.

However, sound energy can go around or through a particular material (around corners) or pass through openings (cracks, windows, ducts) and thereby nullify the sound absorption as well as transmission reduction efforts. For example, 1 in.² of opening transmits as much sound as about 100 ft² of a 40-dB wall.⁶² This emphasizes the importance of sealing all cracks, pipe and conduit sleeves, electrical receptacles, or openings with nonsetting caulking compound.

Sound-absorptive materials include rugs, carpets with felt pads, heavy drapes, stuffed furniture, and ceiling and wall acoustical materials designed to absorb sound. These materials absorb high-frequency sounds much more effectively than low frequency. Sound absorptive materials are most effective to the occupant when used in and near the areas of high-level noise. These materials can control interior noise, sound reflection, and reverberation*; however, noise easily passes through. Hard, smooth, impervious materials reflect sound. Some absorption coef-

*The sound that persists in an enclosed space after the sound source has stopped, which is reflected by the wall, floor, or ceiling.

ficients at 1000 Hz are plate glass 0.03; brick wall 0.01 to 0.04; linoleum, asphalt, or rubber tile on concrete 0.03; smooth plaster on brick or hollow tile 0.03; $\frac{3}{8}$ -in. plywood paneling 0.09; felt-lined carpet on concrete 0.69; velour (14 oz/yd²) 0.75; painted concrete block 0.07; and unpainted concrete block 0.29.

Sound Transmission Sound transmission loss (TL) is the ratio of the energy passing through a wall, floor, or ceiling to the energy striking it—that is, how effective a material is in stopping the passage of sound. The sound transmission varies with the frequency of the sound, the weight or mass, and the stiffness of the construction. Hence, any reduction of noise transmission from outside to inside a building is accomplished through control of the design, thickness, and weight of wall, floor, door, window, and ceiling materials. Improved design of building equipment and its installation, noise and vibration isolation, and discontinuance or gaps in structural members are interior factors also to be considered. The transmission loss increases as the frequency increases. Hollow doors readily transmit sound; solid wood or solid core doors do not.

Mechanical equipment, household appliances, and other stationary sources of noise should be isolated from the floors or walls or on mountings by means of rubber or similar resilient pads to absorb vibration and prevent or reduce sound transmission to the structure, as noted previously under “Sound Absorption.” Small-diameter pipe carrying water at high velocity causes noise to travel long distances. Air chambers on pipelines may also be needed to prevent water hammer.

Sound transmission class (STC) loss ratings for various types of materials are given in decibels in design handbooks, texts, and standards such as the National Bureau of Standards, Building Materials and Structures Report BMS 144 for “Insulation of Wall and Floor Construction.” For example, 4-inch cinder block weighing 25 lb/ft² has an average approximate STC loss rating of 25 dB; if the block is plastered on one side, its rating is 40 dB. A 4-inch brick wall weighing 40 lb/ft² has a rating of approximately 45 dB. A 4-inch concrete slab with a resiliently suspended ceiling has a rating of 55 dB. A quarter-inch plywood sheet nailed to studs has an STC rating of 24 dB; half-inch gypsum board on studs has a rating of 32 dB. The frequency of the sound affects the sound transmission loss. In general, the sound transmission loss rating increases with frequency increase. Theoretically, transmission loss increases at the rate of 6 dB per doubling of the weight of the construction. Some building codes recognize the need to prevent sound transmission between apartments in a multiple dwelling or in row houses. A double *separated* wall with two layers of insulation is effective. A sound-pressure-level reduction of about 50 dB in the normal speaking range (250–3000 Hz) is suggested.

Since a room floor, wall, and ceiling are usually constructed of different materials, an average transmission coefficient must be calculated taking into consideration the coefficient for each material (including doors, windows, and vents) and its area to determine the room noise insulation factor in decibels. The total noise reduction level accomplished by a wall or other divider is a function of the

wall transmission loss, the room absorption characteristics, and the absorption in the rooms separated. It is determined by measuring the difference in sound levels in the rooms. The types of windows (single or double-hung) and doors can have a major effect on the overall noise insulation factor. For example, opening a window can double the interior noise.

Numerous sample calculations for sound and vibration control situations are given in various texts, including the *ASHRAE Guide and Data Book, Systems, 1970*.⁶³

Mechanical noises such as high-velocity noises require proper design of ventilation systems and plumbing systems to reduce flow velocity. Hammering noise in a plumbing system is usually due to a quick-closing valve in the plumbing system, which requires installation of an air chamber on the line or a pressure or vacuum-breaker air-relief valve to absorb the pressure change created when the momentum of the flowing water suddenly stops.

Separation distance between the sound source and receptor should be emphasized and not overlooked in the planning stages as a practical noise reduction method. In general, if there are no sound-reflecting surfaces in the vicinity, a sound pressure level will be reduced approximately 6 dB for each doubling of the distance. Doubling the air space between panels increases the transmission loss by about 5 dB. When a sound barrier, such as a wall, is erected between a source and a receptor, some sound is reflected back toward the source, some is transmitted through the barrier, and some is diffracted over and around the barrier. With a partition close to the source, part of the sound is absorbed, part is reflected back, and part is transmitted through.

Federal Regulations

Maximum acceptable or permissible noise levels are established for certain categories by federal or state regulations or by local ordinances. Some guides are given in Table 4.14.

In May 1969 the Department of Labor issued the first federal standards for occupational exposure to noise. The Occupational Safety and Health Administration (OSHA) sets and enforces regulations, under the Occupational Safety and Health Act of 1970, for the protection of workers' hearing. These standards have been made more stringent over the years as more human hearing loss research has become available. Table 4.15 shows the year 2000 American Conference of Governmental Hygienists suggested daily durations and sound pressure levels. The federal regulatory approach is to start control at the point of manufacture.

The Federal Highway Act of 1970 led to design noise levels related to land use as a condition to federal aid participation. If the design noise levels shown in Table 4.16 are exceeded, noise abatement measures are required in the highway design. Federal highway funds may also be used to abate noise on previously approved highway projects.

The Noise Control Act of 1972 [Public Law (PL) 92-574] directed the EPA to promote an environment for all Americans free from noise that jeopardizes

TABLE 4.14 Some Guides for Maximum Acceptable Sound Levels

Space	Sound Level (dBA)	
	Maximum	Design
Auditoriums	30–45	25–30
Drafting rooms	55	35–50
Hospital rooms	40	25–35
Hotel rooms	45	30–40
Indoor recreational areas		30–45
Libraries	40–45	30–40
Manufacturing, light machinery		45–70
Movie theaters	35–45	30–35
Private offices	40–45	30–40
Residences, rural or suburban		20–30
Residences, urban		25–35
Restaurants	50	35–45
School rooms	30–40	30–40
Secretarial offices	55–60	35–50
Small conference rooms	35–40	25–35
Sports arenas		30–40
Stores, department and supermarkets		35–50

their health and welfare. It is required to set limits on noise emission, and the Act requires manufacturers to warrant product performance and label products. Regulation of noise from a broad range of sources and products is required. The EPA and the Department of Transportation (DOT) have been given the responsibilities to implement the law. The EPA estimates that 16 million people are exposed to aircraft noise levels with effects ranging from moderate to very severe.

The Aviation Safety and Noise Abatement Act of 1979 requires the FAA to develop a single system for measuring noise at airports and under certain conditions to prepare and publish noise maps. The Noise Abatement Criteria established by the Federal Highway Administration for residential areas, schools, parks, hospitals, and other sensitive areas is 67 dBA equivalent steady state and 72 dBA for commercial land use.*

The FAA, in the Department of Transportation, has primary authority for aircraft noise regulations and standards. The FAA has adopted noise emission standards for new aircraft and has a plan to retrofit older aircraft.

The Quiet Communities Act of 1978 amended the Noise Control Act of 1972 to encourage noise control programs at the state and community levels.

*A. Charabegian, "GIS/CAD Enhance Traffic Noise Study," *Public Works*, November 1990, pp. 61–62.

TABLE 4.15 Sound Pressure Levels as Suggested by American Conference of Governmental Industrial Hygienists for Permissible Noise Levels at Various Durations of Exposure^a

Duration per Day	Sound Pressure Level (dBA) ^b	Duration per Day	Sound Pressure Level (dBA) ^b
24 hr	80	28.12 sec	115
16 hr	82	14.06 sec	118
4 hr	88	7.03 sec	121
2 hr	91	3.52 sec	124
1 hr	94	1.76 sec	127
30 min	97	0.88 sec	130
15 min	100	0.44 sec	133
7.50 min ^c	103	0.22 sec	136
3.75 min ^c	106	0.11 sec	139
1.88 min ^c	109		
0.94 min ^c	112		

^a2000 TLVs and BEIs, American Conference of Governmental Industrial Hygienists. No exposure to continuous, intermittent, or impact noise in excess of a peak C-weighted level of 140 dB.

^bSound level in decibels is measured on a sound-level meter, conforming as a minimum to the requirements of the American National Standards Institute Specification for Sound Level Meters, S1.4 (1983)⁽²⁾ Type S2A, and set to use the A-weighted network with slow meter response.

^cLimited by the noise source, not by administrative control. It is also recommended that a dosimeter or integrating sound-level meter be used for sounds above 120 dB.

TABLE 4.16 Design Noise Level–Land Use Relationships

Design Noise Level (dBA)	Description of Land-Use Category
60 (exterior)	Areas such as amphitheaters, certain parks, or open spaces in which local officials agree serenity and quiet are of extraordinary significance
70 (exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, recreational areas
75 (exterior)	Developed land, properties, or activities not included in above two categories
55 (interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, auditoriums

Source: U.S. Department of Transportation, Policy Procedure Memorandum 90-2 Appendix B, Transmittal 279, February 8, 1973.

The Housing Act of 1949 (PL 81-171), among other things, sets forth the national goal of “a decent home and suitable living environment for every American family.” This goal was affirmed by the Housing and Urban Development Act of 1968 (PL 89-117).⁶⁴

TABLE 4.17 Noise Levels for Sleeping Quarters in New Structures

Exterior	Interior
Does not exceed 45 dBA for more than 30 min per 24 hr (Acceptable)	Not greater than 55 dBA for more than an accumulation of 60 min in any 24-hr day
Does not exceed 65 dBA for more than 8 hr per 24 hr (normally acceptable)	Not greater than 45 dBA for more than 30 min during nighttime sleeping hr 11 p.m. to 7 a.m. and not greater than 45 dBA for more than an accumulation of 8 hr in any 24-hr day

Note: Not greater than 30 dBA preferred for bedrooms.

Source: Department of Housing and Urban Development, Circular 1390, amended September 1, 1971.

The Department of Housing and Urban Development has criteria for the sound insulation characteristics of walls and floors in row houses, nursing homes, and multifamily housing units. These criteria must be met by housing of this type in order to qualify for HUD mortgage insurance.

The National Bureau of Standards and the National Science Foundation are concerned with research in noise control and abatement in factories, homes, offices, and commercial work areas.

The EPA has issued noise control regulations for interstate trucks, interstate railroad carriers, new medium and heavy-duty trucks, and new air compressors. The EPA and DOT regulations establish a maximum noise level of 90 dBA for interstate trucks and buses over 10,000 lb in speed zones over 35 mph and 86 dBA at 35 mph or less, measured 50 feet from the center line of the lane of travel. New trucks over 10,000 lb must achieve a sound level no higher than 83 dBA.

The EPA program for certain noise-emitting and noise-reducing products requires a noise rating giving the number of decibels (dBA) a product emits and a noise reduction rating. Noise emissions from new products (including portable air compressors) are not to exceed 76 dBA at 23 feet (7 m).

The HUD noise levels for new sleeping quarters are given in Table 4.17.

State and Local Regulations

New York State enacted a state highway antinoise law in 1965 and California followed in 1967. Chicago put into effect a comprehensive noise control program in July 1971. Regulations require reduced noise levels after 1979 for vehicles, construction machinery, home-powered equipment, and like-manufactured equipment. St. Louis County has a noise code that limits noise in residential areas to 55 dBA and in industrial areas to 80 dBA. New Jersey enacted comprehensive noise legislation January 1972. Most states in the snow belt have established a maximum noise level for snowmobiles of 78 dBA at 50 ft. Some 12,000 states

and municipalities have noise control legislation, but enforcement has been weak and spotty.

Local regulations consistent with federal and state laws and enforced locally are encouraged as being more practical for enforcement. Model noise control ordinances are available to assist local communities in the development of a local program.^{71*}

Maximum acceptable sound levels for different situations are given in Tables 4.14, 4.16, and 4.17. Maximum permissible sound levels for workers in industrial plants and factories regulated by the Occupational Safety and Health Act are given in Table 4.15.

REFERENCES

1. EPA Section 812 Cost Benefit Analysis of the Clean Air Act: 1970–1990, EPA, Washington, DC, October 1997.
2. D. Zmirou, A. Deloraine, F. Balducci, C. Boudet, and J. Dechenaux. "Health Effects Costs of Particulate Air Pollution," *J. Occup. Environ. Med.*, **41** (10), (October 1999): 847–856.
3. W. W. Heck, C. S. Furiness, E. B. Cowling, and C. K. Sims, "Effects of Ozone on Crop, Forest, and Natural Ecosystems: Assessment of Research Needs," *EM: Air Waste Manage. Assoc. Mag. Environ. Managers*, October 1998, pp. 11–22.
4. Associated Press, Prague, Czechoslovakia, May 30, 1970.
5. C. D. Cooper and F. C. Alley, *Air Pollution Control*, Waveland Press, Prospect Heights, IL, 1994, Chapter 1.
6. "The Effects of Air Pollution," Air Pollution Control Orientation Course, Office of Air Programs, Air Pollution Training Institute, EPA, Washington, DC, 1972, p. 86.
7. D. Rind, "A Character Sketch of Greenhouse," *EPA J.*, (January/February 1989): 4–7.
8. C. Flavin, *Slowing Global Warming: A Worldwide Strategy*, Worldwatch Paper 91, Worldwatch Institute, Washington, DC, 1989.
9. J. T. Houghton, L. G. Meirafilho, B. Lim, K. Treanton, I. Mamaty, Y. Bonduki, D. J. Griggs, B. A. Callendar, *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency, UK Meteorologica Office, Bracknell, England.
10. P. Shabecoff, "Bush Wants Billions of Trees for War Against Polluted Air," *New York Times*, January 28, 1990, p. 25; R. J. Moulton and K. Andrasko, "Reforestation," *EPA J.*, (March/April 1990): 14–16.
11. T. Takeshita, Y. Uchiyama, K. Ito, and H. Hayashibe, "Life Cycle Analysis of World Electricity in the 21st Century Using the World Energy LCA Model," *International J. of Global Energy Issues* **1**, (1998): 42–50.

*The EPA maintains up-to-date compilation of city and state noise control ordinances.

12. J. T. Houghton, Y. Ding, D. J. Griggs M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, C. A. Johnson (Eds.), *Climate Change 2001: The Scientific Basis*, Cambridge University Press, New York, 2001; R. Alley, T. Berntsen, N.L. Bindoff, et al., *Climate Change 2007: The Physical Science Basis*, Intergovernmental Panel on Climate Change, Climate Change 2007: The Physical Science Basis.
13. S. H. Schneider, "The Global Warming Debate: Science or Politics?" *Environ. Sci. Technol.* (April 1990): 432–435; P. Roger, "Climate Change and Global Warming," *Environ. Sci. Technol.* (April 1990): 428–430.
14. A. B. Robinson et al., "Environmental Effects of Increased Atmospheric Carbon Dioxide," *Journal of American Physicians and Surgeons*, **12** (2007): 79–90.
15. S. Balianas, "Kyoto Science Just Doesn't Add Up," Can West Interactive, *Calgary Herald*, Calgary, Alberta, Canada, May 27, 2002, p. A13.
16. "Environmental Indicators: Ozone Depletion," *EPA Bulletin*, Washington, DC, 2002, available www.epa.gov/ozone/science/indicat.
17. Charles Stewart Mott Foundation and the Conservation Foundation, *State of the Environment: A View Toward the Nineties*, Conservation Foundation, Washington, DC, 1987, p. 82.
18. *Environmental News Digest*, Food Service and Packaging Institute, Fall 1989, p. 3.
19. A. K. Naj, "Bromines May Be Harming Ozone Layer as Much as Fluorocarbon, Report Says," *Wall Street Journal* (August 30, 1988), sec. 1, p. 10; J. W. Bow, "Containers Easy on the Ozone Layer," *New York Times*, May 21, 1991 sec. A, p. 20.
20. M. McFarland, "Chlorofluorocarbons and Ozone," *Environ. Sci. Technol.* (October 1989): 1203–1207.
21. I. M. Mintzer and A. S. Miller, "The Ozone Layer," *Environ. Sci. Technol.* (December 1987): 1167–1169.
22. W. Glaze, "ES&T Currents," *Environ. Sci. Technol.* (August 1989): 909.
23. *Ozone in the Lower Atmosphere: A Threat to the Health and Welfare*, EPA-86-010, EPA, Washington, DC, December 1986, p. 1.
24. N. R. Glass, G. E. Glass, and P. J. Rennie, "Effects of Acid Precipitation," *Environ. Sci. Technol.* (November 1979): 1350–1354.
25. "Latest Findings on National Air Quality: 2001 Status and Trends," U.S. EPA, September 2002, available www.epa.gov/air/aqtrnd01.
26. J. Heritage (Ed.), *Acid Rain: An EPA Journal Special Supplement*, EPA, Office of Public Affairs, Washington, DC, June–July 1986, pp. 13–23.
27. M. A. Benarde, "Health Effects of Acid Rain: Are There Any?" *J. R. Soc. Health*, **4**, (1987): 139–145.
28. D. L. Ray, "Acid Rain—What to Do?" *Environ. Sci. Technol.* (April 1988): 348.
29. J. N. Woodman and E. B. Cowling, "Airborne Chemicals and Forest Health," *Environ. Sci. Technol.*, **21**, 2 (1987).
30. R. A. Olson, "The Impacts of Acid Deposition on N and S Cycling," *Environ Exp Botany*, **23**, 3, (1983): 211.
31. W. K. Stevens, "Researchers Find Acid Rain Imperils Forests Over Time," *New York-Times*, December 31, 1989, pp. 1, 22.
32. EPA Aerometric Information Retrieval System, available www.epa.gov/air/data/info.html, 2002.

33. Environmental Protection Agency, *Quality Assurance Handbook for Air Pollution Measurement Systems*, Vols. I–III, Doc. EPA 600/9-76-005, EPA, Environmental Monitoring Systems Laboratory, Research Triangle Park, NC, 1984 .
34. National Exposure Research Laboratory, Human Exposure & Atmospheric Sciences Division (MD-46), EPA, Research Triangle Park, NC, www.epa.gov/ttn/amtic/criteria.html.
35. *Fed. Reg.* 40 CFR Part 58, 2001 .
36. A. Rihm, “Air Pollution,” in N. Irving Sax (Ed.), *Dangerous Properties of Industrial Materials*, Van Nostrand Reinhold, New York, 1969.
37. *New York State Air Quality Report*, Annual 1978 DAR-79-1, Division of Air, New York State Department of Environmental Conservation, Albany, NY, September 1979, pp. 240–243.
38. Bureau of Mines, Bureau of Mines Information Circular No. 8333 (revision of IC 7718), Publications Distribution Section, U.S. Dept. of Interior, Pittsburgh, PA, 1967.
39. H. Power and J. M. Baldasano (eds.), *Air Pollution Emissions Inventory*, Computational Mechanics Inc.; Billerica, MA, 1998.
40. H. H. Hovey, A. Risman, and J. F. Cunnann, “The Development of Air Contaminant Emission Tables for Nonprocess Emissions,” *J. Air Pollut. Control Assoc.*, **16** (July 1966): 362–366.
41. *Quality Assurance Handbook for Air Pollution Measurement Systems*, Vol. II: Ambient Air Specific Methods, Doc. EPA-600/4-77-027a, Environmental Monitoring Systems Laboratory, Research Triangle Park, NC, July 1984 .
42. *Quality Planning and Standards Report No. 1.2-012, Supplement A*, September 1975, and related reports; F. L. Ludwig, “Siting Air Monitoring Stations,” *Environ. Sci. Technol.* (July 1978): 774–778.
43. V. G. MacKenzie, “Management of Our Air Resources,” paper presented at the Growth Conference on Air, Land, and Water Resources, University of California at Riverside, October 7, 1963 .
44. R. M. Dowd, “Hazardous Air Pollution Control,” *Environ. Sci. Technol.* (February 1986): 122.
45. J. Heritage (Ed.), “Update,” *EPA J.* (July/August 1987): 36.
46. *Air Pollution Control Field Operations Manual*, PHS Pub. 937, DHEW, Washington, DC, 1962.
47. R. Voelker, “Power without Acid,” *Civil Eng.*, ASCE, July 1989, pp. 45–47.
48. World Health Organization Expert Committee on Environmental Health Aspects of Metropolitan Planning and Development, “Environmental Health Aspects of Metropolitan Planning and Development,” *WHO Tech. Rep. Ser.*, **297**, 1965.
49. M. Smith, *Recommended Guide for the Prediction of the Dispersion of Airborne Effluents*, American Society of Mechanical Engineers, New York, 1968; A. C. Stern, H. C. Wohlers, R. W. Boubel, and W. P. Lowry, *Fundamentals of Air Pollution*, Academic, New York, 1973, pp. 274–287; R. E. Munn, “Air Pollution Meteorology,” in M. J. Suess and S. R. Craxford, (Eds.), *Manual on Urban Air Quality Management*, WHO Regional Publication European Series No. 1, Copenhagen, Denmark, 1976, pp. 101–126; A. T. Rossano and T. A. Rolander, “The Preparation of an Air Pollution Source Inventory,” in M. J. Suess and S. R. Craxford (Eds.), *Manual on Urban Air Quality Management*, WHO Regional Publication European Series No. 1, Copenhagen, Denmark, 1976, pp. 127–152.

50. M. I. Davis, *Air Resources Management Primer*, ASCE, New York, August 1973.
51. C. D. Jaffe, "Sound and Noise," in *The Industrial Environment . . . Its Evaluation and Control*, PHS Pub. 614, U.S. Government Printing Office, Washington, DC, 1958, pp. B-20, 2.
52. *Environmental Health Criteria 12, Noise*, WHO, Geneva, 1980, pp. 24–25.
53. *The Noise Guidebook*, HUD-953-CPD, HUD, Washington, DC, March 1985, p. 3.
54. "Self-Reported Hearing Loss among Workers Potentially Exposed to Industrial Noise—United States," *MMWR* (March 1986): 185–188, and (March 18, 1988): 158–167.
55. "E.P.A., Battling Noise Pollution, Tells of Extent of Damage to Ears," United Press International, *New York Times*, November 11, 1979.
56. *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety*, EPA/550/9-74-004, EPA, Washington, DC, March 1974.
57. "Environmental Health Aspects of Metropolitan Planning and Development," *WHO Tech. Rep. Ser.*, **297** (1965): 52.
58. H. H. Jones, "Principles of Noise Control," in A. D. Hosey and C. H. Powell (Eds.), *Industrial Noise, a Guide to Its Evaluation and Control*, PHS Pub. 1572, DHEW, Washington, DC, 1967, pp. N-10-1 to N-10-5; *Guidelines to the Department of Labor's Occupational Noise Standards*, Bulletin 334, OSHA, Washington, DC, 1971; M. Witt (Ed.), *Noise Control*, OSHA 3048, U.S. Department of Labor, Office of Information, Washington, DC, 1980.
59. *Health Hazards of the Human Environment*, WHO, Geneva, 1972, p. 265.
60. *Engineering Times* (June 1989): 11 .
61. J. E. Heer, Jr., D. J. Hagerty, and J. L. Pavoni, "Noise in the Urban Environment," *Public Works* (October 1971): 60–64.
62. J. N. Boaz (Ed.), *Architectural Graphic Standards*, Wiley, New York, 1970, pp. 504–512.
63. "Sound and Vibration Control," in *ASHRAE Guide and Data Book, Systems*, 1970, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA, Chapter 33.
64. National Environmental Health Association, "A Model for Community Noise Control," *J. Environ. Health* (July/August 1977): 24–44; National Institute of Municipal Law Officers, *Model Community Noise Control Ordinance*, Doc. EPA 550/9; 76-003. EPA, Research Triangle Park, NC, 1975.

BIBLIOGRAPHY

Air Pollution

- "Air Pollution," *WHO Monograph Series 46*, Columbia University Press, New York, 1961.
- Cost Benefit Analysis of the Clean Air Act: 1970 to 1990, EPA Section 812, EPA. October 1997.
- Danielson, J. A. (Ed.), *Air Pollution Engineering Manual*, Pub. AP-40, EPA, Office of Air Quality Planning and Standards, Research Triangle Park, NC, May 1973.

- Davis, M. L., *Air Resources Management Primer*, ASCE, New York, 1973.
- Godish, T., *Air Quality*, Lewis Publishers, Chelsea, MI, 1985.
- Guideline for Public Reporting of Daily Air Quality—Pollutant Standards Index (PSI)*, EPA 454/R-99-010, Office of Air Quality Planning and Standards, EPA, Research Triangle Park, NC, 1999, Table 7, p. 13.
- D. Harrop, *Air Quality Assessment and Management: A Practical Guide*, Spon Press, New York, 2002.
- Heck, W. W., C. S., Furiness, E. B. Cowling, and C. K. Sims, "Effects of Ozone on Crop, Forest, and Natural Ecosystems: Assessment of Research Needs," *EM: Air Waste Manag. Assoc. Mag. Environ. Managers*, October 1998, pp. 11–22.
- Houghton, J. T., L. G. Meir, FILHO, P. Lim, K. Treanton, I. Mamaty, Y. Bonduki, D. J. Griggs, and B. A. Callendar, *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency, Bracknell Meteorologica Office, England, 1997.
- Hus, M., K. Kosutic, and S. Lulic, "Radioactive Contamination of Wood and Its Products," *J. Environ. Radioactivity*, **55**(2), (2001): 179–186.
- Interim Guidelines on Air Quality Models*, Office of Air Quality Planning and Standards Pub. 1.2–080, EPA, Research Triangle Park, NC, October 1977.
- National Exposure Research Laboratory, Human Exposure & Atmospheric Sciences Division (MD-46), EPA, Research Triangle Park, NC, www.epa.gov/ttn/amtic/criteria.html.
- "Research into Environmental Pollution," *WHO Technical Report Series 406*, WHO, Geneva, 1968.
- Rytoma, T., "Ten Years after Chernobyl," *Ann. Med.*, **28**(2), (April 1996): 83–87.
- Smith, M. E. (Ed.), *Recommended Guide for the Prediction of the Dispersion of Airborne Effluents*, American Society of Mechanical Engineers, New York, May 1968.
- Stern, A. C. (Ed.), *Air Pollution*, Academic, New York. Vol. I: *Air Pollutants, Their Transformation, and Transport*, 1976; Vol. II: *The Effects of Air Pollution*, 1977; Vol. III: *Measuring, Monitoring, and Surveillance of Air Pollution*, 1976; Vol. IV: *Engineering Control of Air Pollution*, 1977; Vol. V: *Air Quality Management*, 1977.
- Stern, A. C., H. C. Wohlers, R. W. Boubel, and W. P. Lowry, *Fundamentals of Air Pollution*, Academic, New York, 1973.
- Subcommittee on Environmental Improvement, *Cleaning Our Environment—A Chemical Perspective*, American Chemical Society, Washington, DC, 1978.
- Suess, M. J., and S. R. Craxford, *Manual on Urban Air Quality Management*, WHO, Regional Office for Europe, Copenhagen, Denmark, 1976.
- Takeshita, T., Y. Uchiyama, K. Ito, and H. Hayashibe, "Life Cycle Analysis of World Electricity in the 21st Century Using the World Energy LCA Model." *International Journal of Global Energy Issues*, **11** (1), (1998): 42–50.
- Vesilind, P. A., and J. Jeffrey Peirce, *Environmental Engineering*, Ann Arbor Science, Ann Arbor, MI, 1982.
- Weisburd, M. I., and S. Smith Griswold (Eds.), *Air Pollution Control Field Operations Manual*, PHS Pub. 937, DHEW, Washington, DC, 1962.
- WHO Expert Committee, *Air Quality Criteria and Guides for Urban Air Pollutants*, WHO Technical Report Series, No. 506, WHO, Geneva, 1972.
- Zmirou, D., A. Deloraine, F. Balducci, C. Boudet, and J. Dechenaux, "Health Effects Costs of Particulate Air Pollution," *J. Occup. Environ. Med.*, **41** (10), (October 1999): 847–856.

Noise Control

- National Environmental Health Association Noise Committee, "A Model for Community Noise Control," *J. Environ. Health* (July/August 1977), pp. 25–44.
- Berendt, R. D., E. L. R. Corliss, and M. S. Ojalvo, *Quieting: A Practical Guide to Noise Control*, U.S. Department of Commerce, National Bureau of Standards, U.S. Government Printing Office Washington, DC, July 1976.
- Burns, W., *Noise and Man*, J. B. Lippincott, Philadelphia, PA, 1973.
- Crocker, M. J., and A. J. Price, *Noise and Noise Control*, Vols. 1 and 2, CRC Press, Cleveland, OH.
- Environmental Health Criteria 12*, Noise, WHO, Geneva, 1980.
- "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," EPA 550/9-74-004, EPA, Washington, DC, March 1974.
- Local Noise Ordinance Handbook*, Bureau of Noise Control, Division of Air Resources, New York State Department of Environmental Conservation, Albany, NY, October 1977.
- Peterson, A. P. G., and E. E. Gross, Jr., *Handbook of Noise Measurement*, General Radio Company, Concord, MA, 1974.
- The Industrial Environment—Its Evaluation & Control*, DHEW, PHS, CDC, NIOSH, U.S. Government Printing Office, Washington, DC, 1973.
- The Noise Guidebook*, HUD-953-CPD, HUD, Washington, DC, March 1985.
- Witt, M. (Ed.), *Noise Control*, U.S. Department of Labor, Office of Information, OSHA 3048, U.S. Government Printing Office, Washington, DC, 1980.

CHAPTER 5

SURVEYING AND MAPPING FOR ENVIRONMENTAL ENGINEERING

KURT W. BAUER, PE, RLS, AICP

Executive Director Emeritus, Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin

INTRODUCTION

The practice of environmental engineering often entails the use of maps and map-based land information systems and the conduct of related surveying operations. Accordingly, this chapter is intended to set forth certain basic surveying and mapping concepts, the understanding of which is required for the practice of environmental engineering. Historically, surveying and mapping constituted a highly specialized branch of civil engineering, just as city and regional planning once did. And, historically, university civil engineering curriculums included extensive course work in surveying and mapping, and textbooks in surveying and mapping were often authored by practicing civil engineers. The American Society of Civil Engineers maintains a division of surveying and mapping—a field now known as *geomatics*—and annually awards a prize for notable achievement in the field. Surveying and mapping have, however, increasingly become a discipline separate from civil and environmental engineering, and some branches—such as land surveying, which could once be practiced by licensed engineers—are now practiced by a separately licensed profession. Some universities no longer include any courses in surveying and mapping as a part of the civil and environmental engineering curriculum. Nevertheless, the practice of environmental engineering will inevitably involve the use of maps, and, in some cases, the conduct of related surveying operations. Therefore, an understanding of the basic concepts underlying surveying and mapping is essential to the competent practice of environmental engineering. Accordingly, this chapter sets forth these basic concepts in summary—and in some cases greatly simplified—form.

IMPORTANCE OF MAPS

The most efficient and effective way of not only presenting, but of integrating, information about a number of factors that must be considered in any environmental engineering effort, is through the preparation of good maps designed specifically for engineering application. Good maps serve at least two important purposes in environmental engineering: (1) to provide a graphic representation of the geographic area concerned; and (2) to relate pertinent data to geographic location. Before considering the specific map requirements for environmental engineering, a review of some of the basic concepts and definitions involved in the preparation and use of maps is in order.

BASIC DEFINITIONS AND CONCEPTS

A map may be defined as a flat, true-scale, graphical representation of a portion of the earth's surface. In this respect, it should be recognized that the spherical surface of the earth cannot be presented on a flat surface without some distortion. Map scale may be defined as the relationship that exists between a distance on a map and the corresponding distance on the surface of the earth. Map scale may be expressed as an equivalence, a ratio, or a graph.

Foundational Elements for Creation of Maps

The creation of a map requires three foundational elements. The first of these is a system for accurately locating features on the surface of the earth. The system used consists of spherical coordinates expressed as latitude in degrees, minutes and seconds north or south of the equatorial plane, and longitude expressed in degrees, minutes and seconds east or west of the prime meridian through Greenwich, England.

The topographic surface of the earth constitutes the physical entity upon which the measurements of latitude and longitude, and indeed all survey measurements, are made. The surface of the earth is an irregular, roughly spherical surface; flattened at the poles and elongated through the equatorial plane. The latitude of a point on this surface is given as the angular distance north or south of the equator, and can be determined by direct astronomic observation as, for example, by observation of the angular elevation of the pole star—using a transit or sextant. The longitude of a point on this surface can be determined by observation of the time difference between the meridian of longitude concerned, east or west of a reference meridian—or prime—meridian—the longitude of Greenwich, England, being the reference meridian in universal use today. See Figures 5.1 and 5.2.

The geoid is defined as a surface everywhere perpendicular to the direction of gravity—conceptually equivalent to the surface that would be assumed by mean

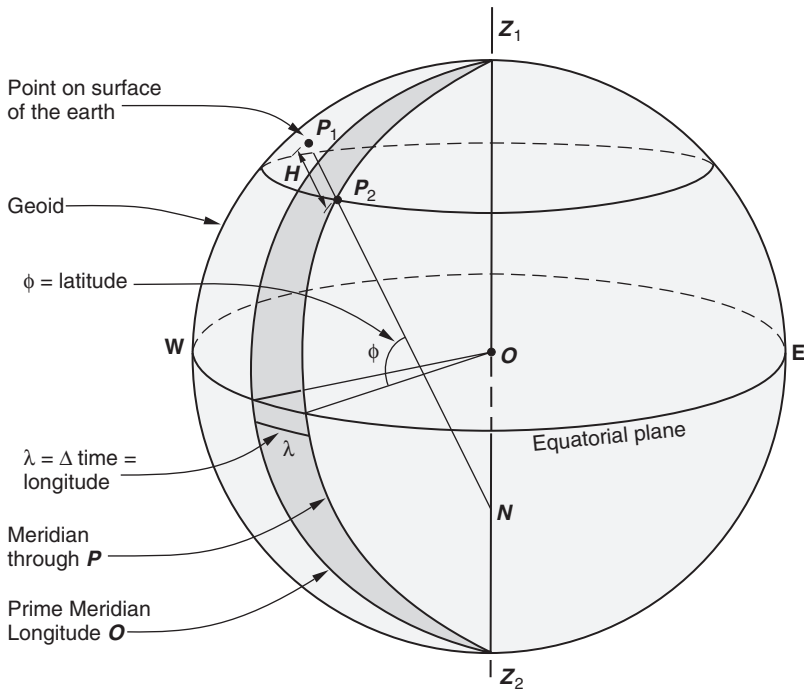


FIGURE 5.1 Ellipsoid latitude (ϕ), longitude (λ), and the orthometric height (H) of a point P_1 .

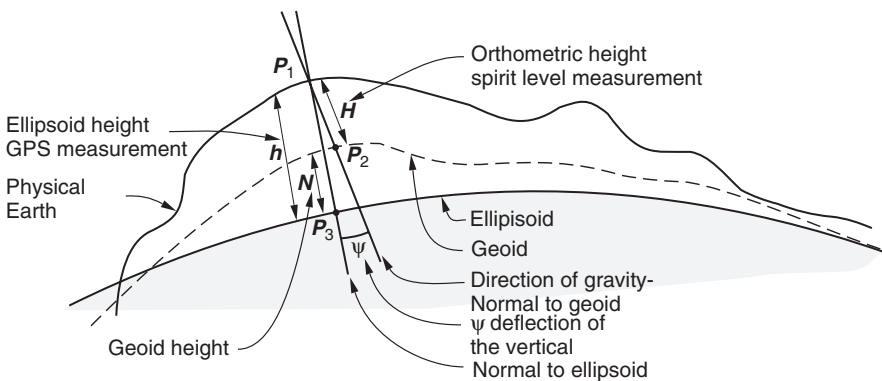


FIGURE 5.2 Relationships between the topographic surface of the earth, the geoid, and a reference ellipsoid.

sea level if the seas extended under the continents. The geoid is the figure to which all survey measurements are referenced and to which surveying instruments are oriented through the use of spirit level vials or plumb lines. The geoid is, however, an irregular, undulating surface.

Since it is impossible to make survey computations on the irregular surface of the geoid, a mathematical surface is substituted that closely approximates the geoid. This surface is created by rotating a two-dimensional ellipse about its semiminor axis to create a three-dimensional, mathematically defined surface, known as the ellipsoid.

Geographic locations and relationships—distances and directions—are expressed as though they were located on the ellipsoid. Historically, a number of ellipsoids have been used as a basis for surveying and mapping operations. Within the continental United States, the historically most widely used ellipsoid is known as the Clark spheroid of 1866. This ellipsoid was adopted for use in geodetic surveying and in hydrographic mapping operations in the continental United States by the U.S. Coast and Geodetic Survey—now known as the National Geodetic Survey—and for use in topographic mapping operations by the U.S. Geological Survey in the later part of the nineteenth century. This ellipsoid is the basis for the North American Datum of 1927 (NAD-27), and for the older State Plane Coordinate Systems still in use within the United States. The grid coordinate values under these older systems are expressed in U.S. survey feet. The newer State Plane Coordinate Systems in use within the United States are based on the Geodetic Reference System of 1980. This spheroid is the basis for the North American Datum of 1983 (NAD-83), and for the revised State Plane Coordinate Systems. The grid coordinate values under these newer systems are expressed in meters.

Map Projections

The second of the foundational elements required for the creation of a map is a map projection. A map projection typically consists of a set of mathematical equations for converting the spherical surface of the earth to a flat surface upon which maps may be constructed. Map projections thus serve to convert the spherical geometry of the mapping ellipsoid to the plane geometry of the flat mapping surface. A number of projection systems are in use for surveying and mapping.

Tangent Plane Projection

The tangent plane projection was the most common form of projection once used by land surveyors and civil engineers. It is the basis for “plane” surveying procedures, the procedures usually taught in introductory courses in surveying. This projection is applicable only to the surveying and mapping of small areas and is being replaced by more sophisticated projections and attendant mapping surveying procedures. Many land surveyors and civil engineers engaged in the application of plane surveying may not even be aware that they are using this type of projection in the preparation of maps and plats attendant to their work. In application, the surveyor selects a point in, or near, the area to be surveyed and mapped, at which point the survey is oriented to some form of directional control that is recoverable. The directional control may be provided by magnetic observation; celestial observation; or by the direction of a line defined by two

monumented U.S. Public Land Survey system one-quarter section corners. The surveyor then measures the angles formed by the lines of the survey and the central direction. This is very different from independently measuring a magnetic or astronomic direction for each line as is the case in projection-less mapping. The angles so measured may then be drawn to scale on the map. Bearings shown on tangent projection maps do not represent the astronomic or geodetic bearings of the survey lines. The curvature of the earth and convergence of the meridians are ignored. The distances are measured as, or reduced to, horizontal distances. The distances are assumed to be measured at the mean elevation of the area surveyed, and are horizontal and not level distances. No adjustments are made for differences between distances as measured on the surface of the earth and these same distances on the flat plane of the projection. The map—often termed a *plat*—derived from the measured angles and distances is, in effect, a projection of the curved surface of the earth onto a flat plane.

The principal advantage of this system is its simplicity. Straight lines are considered to have a constant bearing; parallel straight lines are considered to have the same bearing; level surfaces are considered to be flat planes; and plumb lines are considered to be parallel. The errors introduced by these assumptions become noticeable when the areas concerned exceed about 75 square miles, and then approximate 0.05 foot and 0.1 second of arc. Individually compiled maps cannot be coordinated and become diagrams rather than true maps. Other surveys conducted in the same manner will disagree in the lengths and directions of common lines, and directions between identical points on adjacent parcels will have different values. This means that discrepancies, gaps, and overlaps will not be apparent from mere review of plats of survey of adjacent parcels. Resurveys are entirely dependent on recovery of survey markers or monuments set during the original work.

Tangent plane projection surveys are of limited use to comprehensive planners and to civil and environmental engineers concerned with areawide projects. The lack of a common reference system makes the task of relating individual parcels to each other difficult or impossible. Indeed, existing municipal maps compiled from plats of survey are often no more than representations of the compilations of paper records, so poorly done as to make their use in planning and engineering difficult and costly, and the use of such plan implementation devices as official mapping legally questionable.

The need to identify real property boundaries permanently and precisely, and the need for large-scale, areawide planning and engineering has led to the use of projection systems that eliminate the disadvantages of the tangent plane system.

Lambert Projection

The Lambert conformal conic projection conceptually uses a cone passed through two parallels of the ellipsoid—known as standard parallels—to develop the spherical surface into a plane surface. See Figures 5.3, 5.4, and 5.5. Meridians of longitude are represented on the projection by converging straight lines; and parallels of latitude are represented as arcs of circles with a common center.

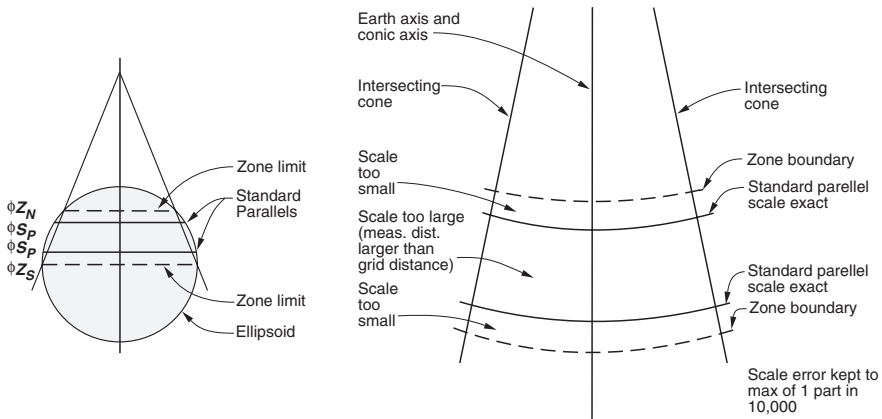


FIGURE 5.3 Concepts underlying creation of a conic projection.

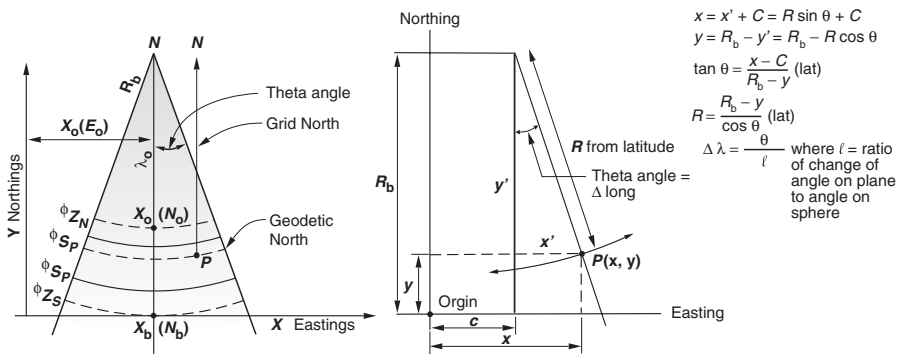


FIGURE 5.4 Concepts underlying creation of a State Plane Coordinate System grid from conic projection.

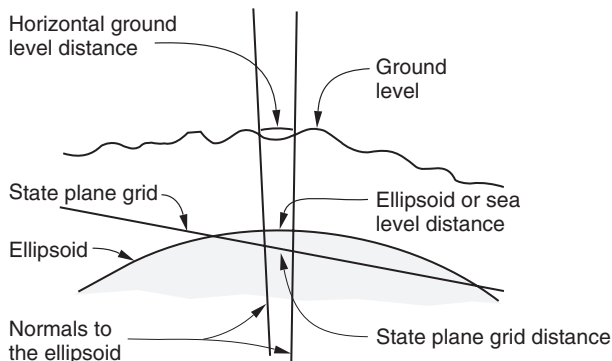


FIGURE 5.5 Relationship of ground level distances to state plane grid distances.

Angles are correctly represented on this projection. The scale is exact only along the standard parallels, and is continuously changing along the meridians. Since more than one cone may be fitted to the ellipsoid to create projection zones, the projection concerned is also known as the Lambert conformal polyconic projection.

With respect to projections, the term *conformal* has a special meaning. Since it is impossible to develop a spherical surface onto a plane, all maps will contain distortions according to the projection used in their compilation. The distortions may relate to scale; area; angles; or to the shape of figures. The unique properties of a conformal projection include the following:

- All figures on the surface of the earth retain their shape on the map.
- Angles measured on the map approximate their true values on the surface of the earth.
- The map scale at any point is uniform in all directions.

These properties are important to all who use grid coordinates in their work, including surveyors, engineers, and planners. The Lambert conformal conic projection is typically used as the basis for the State Plane Coordinate Systems in states having the greatest dimension in the east–west direction.

Mercator Projection

The Mercator projection is a projection that conceptually uses a cylinder tangent to the ellipsoid at the equator to develop the spherical surface of the earth into a plane surface. The equator is represented as a straight line true to scale; meridians of longitude are represented as straight lines perpendicular to the equator; and parallels of latitude are represented by straight lines parallel to the equator. The scale is exact only along the equator and expands along the meridians north and south of the equator. A line of constant bearing—called a *rhumb line*—appears as a straight line on this projection. Therefore, the course between two points can be scaled from the map, a useful characteristic for mariners. This will not, however, be the shortest distance between the two points concerned.

Transverse Mercator Projection

The transverse Mercator projection is equivalent to a Mercator projection rotated 90 degrees. Neither meridians of longitude—except for the central meridian—nor parallels of latitude appear as straight lines. This projection is used as a basis for the State Plane Coordinate Systems in states having the greatest dimension in a north–south direction.

Other Projections

There are a number of other projections in use for various mapping purposes, including the Universal Transverse Mercator (UTM) projection system. This is

a system devised for military purposes, but is used for some civil purposes. It divides the entire earth into 62 zones, much larger than the zones used for the State Plane Coordinate System. The later systems are to be preferred for use in most public planning, engineering, surveying, and large-scale mapping efforts. Unlike the Transverse Mercator projection used as a basis for the state plane coordinate systems, which is a tangent projection, the transverse Mercator projection used as a basis for the UTM projection is a secant projection.

The State Plane Coordinate System

The State Plane Coordinate System converts the spherical coordinates—latitude and longitude—of the projection, as measured in degrees, minutes and seconds, to rectangular grid coordinates measured in feet. The x axis values are known as *eastings*, the y axis values are known as *northings*. See Figure 5.4. The State Plane Coordinate Systems permit the conduct of surveys using plane surveying methods, while accounting for the curvature of the earth, and maintaining distortions within specified limits.

In the use of the State Plane Coordinate System, it is important to determine whether the system concerned is the older system based on the North American Datum of 1927, in which the grid coordinate values and related distances are expressed in U.S. survey feet; or is the newer system based on the North American Datum of 1983, in which the grid coordinate values and related distances are expressed in meters. It is also important to understand the relationship of ground level distances to State Plane Coordinate distances; see Figure 5.5. The following definitions may be helpful in examining Figure 5.4, and are essential to the proper understanding and use of the State Plane Coordinate Systems. The term *scale factor* is defined as the state plane coordinate distances divided by the ellipsoidal, or sea level, distances. The term *sea level reduction factor* is defined as the ellipsoidal, or sea level, distances, divided by the horizontal ground level distances. The combination *scale and sea level reduction factor* is defined as the product of the scale factor and the sea level reduction factor so that State Plane Coordinate grid distances are equal the horizontal ground level distances multiplied by the combination factor.

Survey Control Networks

The third fundamental element required for the creation of a map is a system of survey control that makes manifest on the surface of the earth the map projection used, and makes it possible to accurately relate the measurements involved in surveying and mapping to the map projection. A survey control network consists of a framework of monumented points, or stations, the locations of which, on the surface of the earth, are accurately known—either relatively or absolutely. The control survey stations are used to locate, orient, and adjust local surveys, to provide a means of verification and check for such surveys, and in the use of surveys in the preparation of maps. Survey control networks are of two types:

horizontal, in which the locations of the monumented stations are given either in terms of latitude and longitude, or in terms of State Plane Coordinates; and vertical in which the orthometric heights—elevations—of the monumented stations (called *bench marks*) are given in feet above the geoid—mean sea level configuration—of the earth.

There are, in fact, two horizontal survey control networks in place and used within much of the United States: (1) the geodetic control survey network created by the federal government through the National Geodetic Survey, formerly known as the U.S. Coast and Geodetic Survey; and (2) the U.S. Public Land Survey System, also created by the federal government through the Bureau of Land Management and its predecessor agencies. The National Geodetic Survey also provides a vertical control network complimentary to the horizontal control network. The geodetic control survey system provides the basis for all federal topographic mapping efforts, and for the preparation of all nautical and aeronautical charts within the continental United States, including Alaska.

The U.S. Public Land Survey System provides the basis for all real property boundary surveys and mapping in much, but not all, of the continental United States. The states in which the Public Land Survey System has been established include the 30 states that were created out of the public domain—that is, out of the lands originally ceded to, and owned by, the federal government. These states are Alabama, Alaska, Arizona, Arkansas, California, Colorado, Florida, Idaho, Illinois, Indiana, Iowa, Kansas, Louisiana, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Ohio, Oregon, South Dakota, Utah, Washington, Wisconsin, and Wyoming.

The National Geodetic Survey Control System

As already noted, the national geodetic survey control system actually consists of two networks: a horizontal survey control network and a complimentary vertical survey control network. The system is a scientific system designed to provide, as already noted, the basic control for all federal topographic mapping and hydrographic and aeronautical charting operations.

The horizontal survey control network consists of thousands of monumented points whose positions on the surface of the earth—expressed in terms of latitude and longitude—were established to known high orders of accuracy by the U.S. Coast and Geodetic Survey (USC and GS), now National Geodetic Survey. The positions were established by high-order triangulation and traverse surveys. The stations are relatively widespread, being typically located on topographic high points, and are often relatively inaccessible. The use of the stations requires knowledge and skill in the use of geodetic survey techniques and equipment, knowledge, and skills, not generally historically available to public works engineers and land surveyors.

In order to make the national horizontal survey control network more readily available to and usable by local surveyors, the USC and GS in 1933 devised the State Plane Coordinate System. As already noted, the State Plane Coordinate

System, as originally developed, is based on the Clark Spheroid of 1866 and the attendant North American Datum of 1927 (NAD-27). The State Plane Coordinate grid values are expressed in U.S. survey feet. Also as noted, the system translates the spherical coordinates—latitude and longitude—of the primary federal survey control stations into rectangular coordinates on a plane surface mathematically related to the ellipsoid on which the spherical coordinates have been determined. The State Plane Coordinate System is designed so that the effect of the distortion inherent in the projection of the curved surface of the ellipsoid onto the plane used for the rectangular grid is not more than one part in 10,000. The State Plane Coordinate System, thus, permits local engineers and surveyors to connect surveys by simple, well established plane surveying techniques tied to the extensive network of precisely located triangulation and traverse stations of the national geodetic control survey network.

If the location of a point is defined by stated coordinates on the State Plane Coordinate System grid, then the location of that point is also known by its corresponding latitude and longitude. Thus, the precise location on the surface of the earth of all survey stations and landmarks established in local engineering and land surveys can be accurately described by stating their coordinates referred to the common origin of the State Plane Coordinate System grid. Once plane coordinates are established for any survey station or landmark, these coordinates may become the best available evidence for the original positions concerned, should physical monuments be lost. Computations relating to the lengths and bearings of lines and to related coordinate values using the State Plane Coordinate System are simple, being made with the well-established formulas of plane surveying.

The National Geodetic Survey (NGS) readjusted the horizontal survey control network in 1983, creating the North American Datum of 1983 (NAD-83). This datum has been further refined in some areas of the United States, such refined datums being identified by a suffix attached to the notation NAD-83. For example, in Wisconsin the refined datum is indicated as NAD-83(91). As already noted, NAD-83 is based on the Geodetic Reference System ellipsoid of 1980. The attendant State Plane Coordinate values are given in meters. The shifts in latitude and longitude values between the two datums can be significant. For example, in Southeastern Wisconsin, the maximum shift in latitude between NAD-27 and NAD-83(91) approximates 11 feet; while the maximum shift in longitude approximates 39 feet. Although these shifts are important globally, affecting courses and distances between intercontinental locations, the shifts do not significantly affect the relative bearings and distances between monumented points and control stations within local areas.

The vertical survey control network of the national geodetic control system consists of a network of monumented benchmarks, the elevations—orthometric heights—of which have been determined by the USC and GS through differential spirit level surveys. The original vertical datum is known as National Geodetic Vertical Datum of 1929 (NGVD-29). This datum was also known as Mean Sea Level Datum. The national level net concerned was based on 26 tide stations

located along the coasts of the United States and Canada, interconnected by high-order-accuracy differential spirit level surveys.

The NGS readjusted the level network in 1988 to produce a new vertical datum known as the North American Vertical Datum of 1988 (NAVD-88). The differences in elevations on the two datums can be significant. For example, in Southeastern Wisconsin, the difference between NGVD-29 and NAVD-88 elevations ranges from 0.08 to 0.32 foot.

Some local vertical control survey datums are still in use. These can present significant problems when engineering efforts requiring an areawide approach—such as the hydrologic and hydraulic studies that are required to be conducted on a watershed bases—are involved. The use of the national datums and the conversion of local datums to the national datums is to be encouraged.

U.S. PUBLIC LAND SURVEY SYSTEM

After the Revolutionary War and Louisiana Purchase, the newly created federal government found itself to be the owner of a vast wilderness area stretching westward from the original 13 colonies. Subsequent additions of territory through treaty and purchase greatly expanded this already vast area. In order to facilitate the sale of the public lands and their development through private ownership, it was necessary to provide a convenient and certain method of land description and identification. To this end, the U.S. Public Land Survey (USPLSS) system was devised, and the federal lands were surveyed and monumented by the federal government before sale. The USPLSS is a brilliantly devised system providing a simple means of writing short, unique legal descriptions for each and every parcel of land to be conveyed in the vast area concerned. However, the system depends, as a control survey system, on being able to identify, in the field, the location of the original monuments established by the government surveyors. This is a significant weakness in an otherwise virtually ideal system for real property boundary description and field location identification.

The scheme of subdivision can be summarized as follows (see Figure 5.6): The primary unit of subdivision is the survey township, a nominally 36-square-mile area. The secondary unit of subdivision is the section, a nominally one-square-mile, or 640-acre, area. These units are located with respect to a set of coordinate axes consisting of an initial point, a principal meridian through that point, and a base line, surveyed as a parallel of latitude and therefore a curved line on the surface of the earth, through that point. A set of standard lines, consisting of standard parallels, or correction lines, and guide meridians are used to control for the convergence of the meridional lines. The subdivision of areas enclosed by standard lines into survey townships is accomplished by running range lines (meridional lines) and township lines (latitudinal lines). It should be noted that in the identification system it is the ranges and tiers of townships that are numbered and not the lines. The townships are subdivided into 36 sections as shown and numbered in Figure 5.6. The sections can be further subdivided

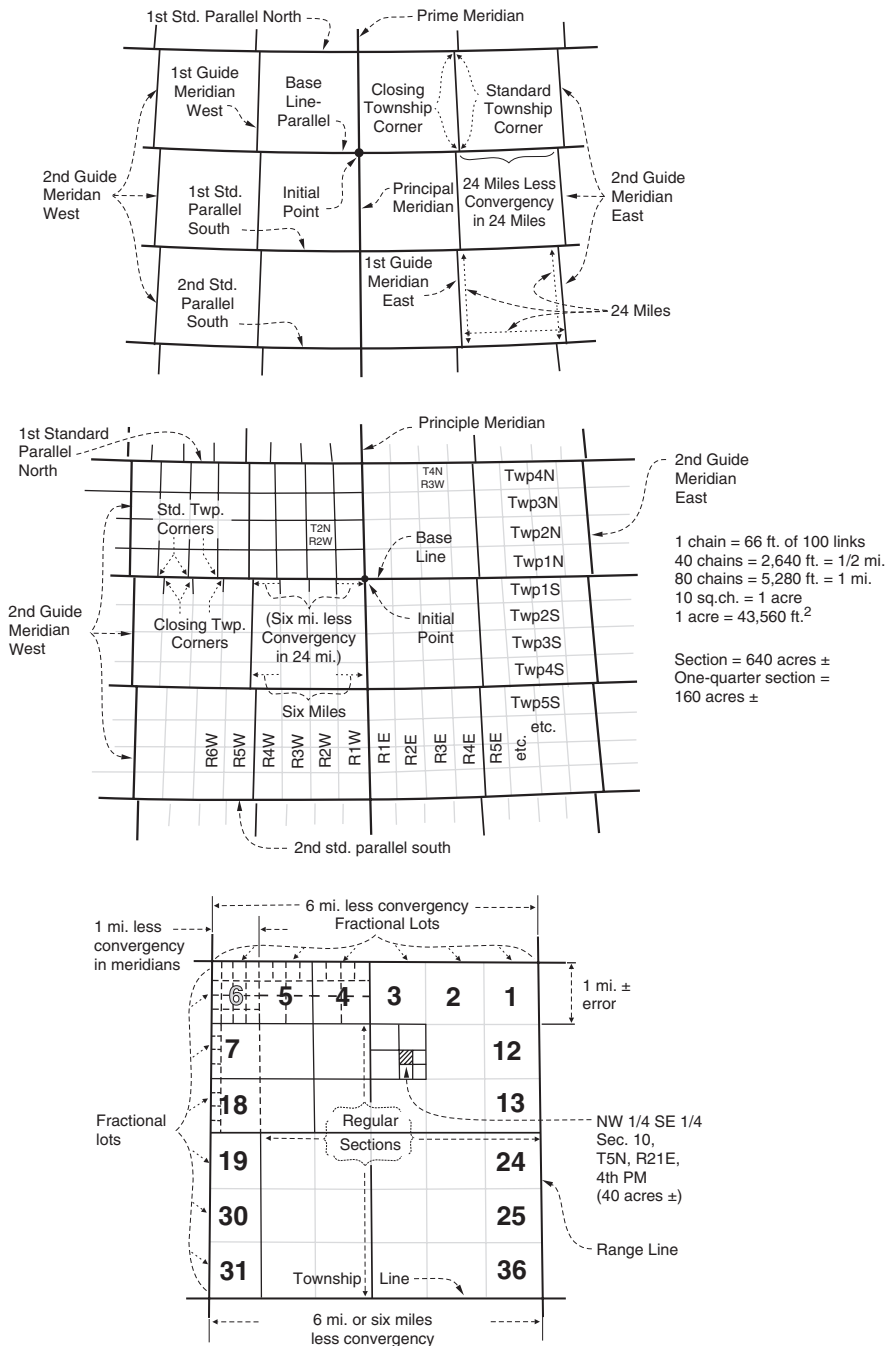


FIGURE 5.6 Standard lines, township and range lines, and township subdivisions.

into one-quarter sections—nominally 160 acre areas, and smaller areas such as 80, 40, 20, 10 and 5 acre areas—by simple descriptions.

A typical legal description might read: NE 1/4 of SE 1/4 of Section 10, Township 5 North, Range 21 East of the Fourth Principle Meridian. Often, the reference to the numbered meridian is dropped and a county and state location substituted. In this example, a nominally 40-acre tract is simply and unambiguously identified. This type of description can readily identify parcels down to a nominal 5 acre size.

The U.S. Public Land Survey System not only provided a simple, unambiguous means for describing and locating real property boundaries for, but also provided the first maps and natural resource inventories of the vast areas covered by the survey system. The instructions to the government surveyors provided that, as the township, range, and section lines were run, notes had to be kept indicating where such lines crossed streams, together with the width of the streams shown and the direction of flow, intersected lake shores, which were then meandered, where wetlands were entered and left, and where woodlands were entered and left. The government surveyors also had to make notations concerning the types of trees in the woodlands, the types and potential fertility of the soils encountered, and the potential presence of gravel, stone, and other mineral deposits. The survey data, when assembled on township plats, provided the first maps of the area surveyed, and the first resource inventory. The survey notes can be used to readily construct an accurate map of the surface water system, wetlands, woodlands, and prairies as they existed at the time of settlement by Europeans.

It should be noted that the two control systems—topographic and real property boundary line—are not on a common datum. This was not critical when topographic maps were compiled by field survey methods, but is critical today when topographic maps are compiled photogrammetrically.

MAP REQUIREMENTS FOR PLANNING AND ENVIRONMENTAL ENGINEERING

The proper planning and design of land development projects and of supporting public works facilities and the proper conduct of environmental studies and assessments require constant attention to two factors: The land itself with its topography and other physical characteristics; and the boundaries of real property ownership. Definitive information about these two factors is essential if land is to be properly developed, if supporting public works are to be soundly conceived and effectively executed, and if environmental studies and assessments are to be properly completed. The need to provide this information, in turn, generates the need for a control survey network, both as a basis for the production of adequate maps and as a basis for the cost-effective execution of land and engineering surveys that can be properly integrated on an areawide basis.

Two basic types of maps are required to adequately meet municipal planning and engineering and environmental study and assessment needs:

1. *Large-scale topographic maps.* Such maps accurately show the configuration and elevation of the ground (hypsometry); stream and watercourse lines, and other natural and cultural (manmade) features of the land and cityscapes (planimetry). The desirable scale of such maps for planning and engineering purposes may range from one inch equals 50 feet to one inch equals 200 feet, with vertical contour intervals ranging from 1 to 2 feet.

The maps should be prepared on a map projection to National Map Accuracy Standards (i.e., all horizontal control survey stations and all map projection tick markers should be plotted to an accuracy of 0.01 inch on the map sheet). All well-defined planimetric features should be plotted to an accuracy of $1/30^{th}$ of an inch; 90 percent of all contour lines should be accurate to within one-half contour interval; and all spot elevations should be accurate to within one-quarter of a contour interval.

2. *Large-scale cadastral maps.* Such maps accurately show the location, arrangement, and dimensions of all real property boundary lines, including all street and other public rights-of-way. The cadastral maps should be prepared on the same map projection and at the same scale as the topographic maps. The use of a common map projection is essential so that the data presented on the cadastral maps can be readily and precisely correlated with the data presented on the topographic maps by simple “overlay” processes—that is, so that the two types of maps can be readily and accurately integrated by analog or digital means.

These two types of maps, if properly prepared, are not only useful in the conduct of day-to-day planning and engineering functions, but can provide the basis for the economical preparation of a number of other maps such as zoning district maps and official maps, and to create planning base maps. The latter show specific types of fundamental information—such as, for example, real property lines, copies of which can then be utilized to display other information. Importantly, these two types of maps, if carefully designed and constructed on a common map projection, can be used to create automated, parcel-based, land information systems.

Topographic maps should be prepared by photogrammetric methods. Cadastral maps will normally be prepared by conventional plotting techniques that require the interpretation of the legal descriptions of real property boundaries. As already noted, the maps should be prepared on a common map projection. All horizontal control survey stations and all map projection grid tick marks should be shown with an accuracy of 0.01 inch on the map sheet; all real property boundary lines should be plotted to an accuracy of 2.5 feet, and all gaps and overlaps of 2.5 feet or more should be shown; all smaller gaps and overlaps should be annotated. A peculiar feature of cadastral maps that is not in accord with the basic definition of a map is that the dimensions and bearings of real property boundary lines are typically shown on the maps. However, the dimensions given are ground-level

figures and are not reduced to sea level and grid values. This introduces small differences in the values concerned, usually less than 0.01 foot in 100 feet.

Desirable Control Survey and Mapping System

It is essential that the control survey system meet two basic design criteria if the maps based on it are to be effective planning and engineering tools. First, the control survey system must facilitate the accurate correlation of real property boundary line maps with topographic maps. Second, the control survey network must be monumented on the ground so that lines on the maps can be correctly reproduced in the field when planned land-use development and supporting public works projects reach the construction stage. That is, the control survey system should provide not only the foundation for the preparation of maps that accurately reflect topographic and cadastral conditions, but also maps the lines of which can be readily and accurately reproduced on the ground as well. The topographic and cadastral maps should be prepared at scales large enough not only for use in comprehensive planning, but also for use in site-development planning, preliminary engineering, and environmental studies and assessments. Importantly, the topographic and cadastral maps should be based on a common control survey network so that the two types of maps can be accurately correlated.

In areas covered by the U.S. Public Land Survey System, the control survey network should entail the relocation and monumentation of all U.S. Public Land Survey section and quarter section corners, including the centers of sections, and the use of these corners as stations in high-order surveys tied to the national horizontal control survey and national vertical control survey systems. The horizontal control surveys should establish the grid lengths and grid bearings of all quarter section lines, as well as the geographic positions in the form of state plane coordinates, of the U.S. Public Land Survey corners; while the vertical control surveys should establish orthometric heights—elevations—for the monuments marking the U.S. Public Land Survey corners and of certain accessories thereto.

The adopted control survey system provides the desirable common system of control for real property boundary line, as well as for topographic mapping, and for the conduct of both land and engineering surveys. Since all new land subdivision plats must typically, in states covered by the U.S. Public Land Survey System, by state law be tied to corners established in that system, and since the accuracy of these plats can be controlled by state and local land subdivision regulations, the cadastral maps can be readily and accurately updated and extended into newly developed areas. By locating and monumenting the U.S. Public Land Survey System corners and accurately placing those corners on the State Plane Coordinate System, it becomes at once possible to prevent the future loss of these corners and to make the use of the State Plane Coordinate System practical for land and engineering surveys.

The ability to accurately correlate topographic and real property boundary line data by simple overlay techniques—analog or digital—can provide great savings in research time during the planning and design phases of municipal public

projects and in the conduct of environmental engineering studies and environmental assessments. Such correlated information makes possible the consideration and analysis of many alternative configurations for such public works facilities as drainage and flood control works, trunk sewers, water transmission mains and major traffic ways, and thereby of many alternative solutions to drainage, flooding, sewerage, water supply, and transportation problems. The control survey system and attendant maps also facilitate the preparation, calibration, and validation of the hydrologic and hydraulic simulation models essential to drainage and flood control, sanitary sewerage, and water supply system planning and engineering.

The control survey system provides a common bearing basis for all surveys and plats and permits elevations to be referenced to a common datum. The system places a monumented recoverable control survey station accurately located on both the U.S. Public Land Survey System and on the State Plane Coordinate System, and an attendant monumented reference benchmark at approximately one-half-mile intervals throughout the area covered so that a user is never more than about one-quarter mile from a monumented control survey station of known location on the two control survey systems concerned and of known elevation. The system thus facilitates the conduct of surveys required for certain types of environmental engineering efforts such as, among others, the delineation of floodlands, wetlands, woodlands, wildlife habitat, and contaminated areas, and facilitates the preparation of maps displaying the delineated areas.

The system permits lines drawn on maps—whether marking the limits of land to be reserved for various public and private uses, the limits of regulatory districts, or the selection and alignment (horizontal and vertical) of proposed public works to be accurately and precisely reproduced in the field. The system and attendant maps facilitate the administration of zoning, land subdivision control, the official map ordinances and the delineation of flood hazard areas. The system and attendant maps also facilitate the preparation of derived maps, such as land use maps, base maps for planning and engineering studies, and utility system maps, and facilitate the graphic display of planning data. The control survey system and attendant maps facilitate the preparation of accurate facility “as-built” records. Importantly, the system and attendant maps provide the foundations for the creation of automated parcel based land information systems and public works managements systems.

If a county or municipality has a properly staffed engineering department, the basic mapping work should be the responsibility of that department—thereby, freeing the city planning and other departments to conduct long-range and current planning operations. Planners, environmental engineers, and other users must, in any case, be familiar with the use and limitations of maps in the conduct of their work.

APPLICATIONS OF MAPPING SYSTEM

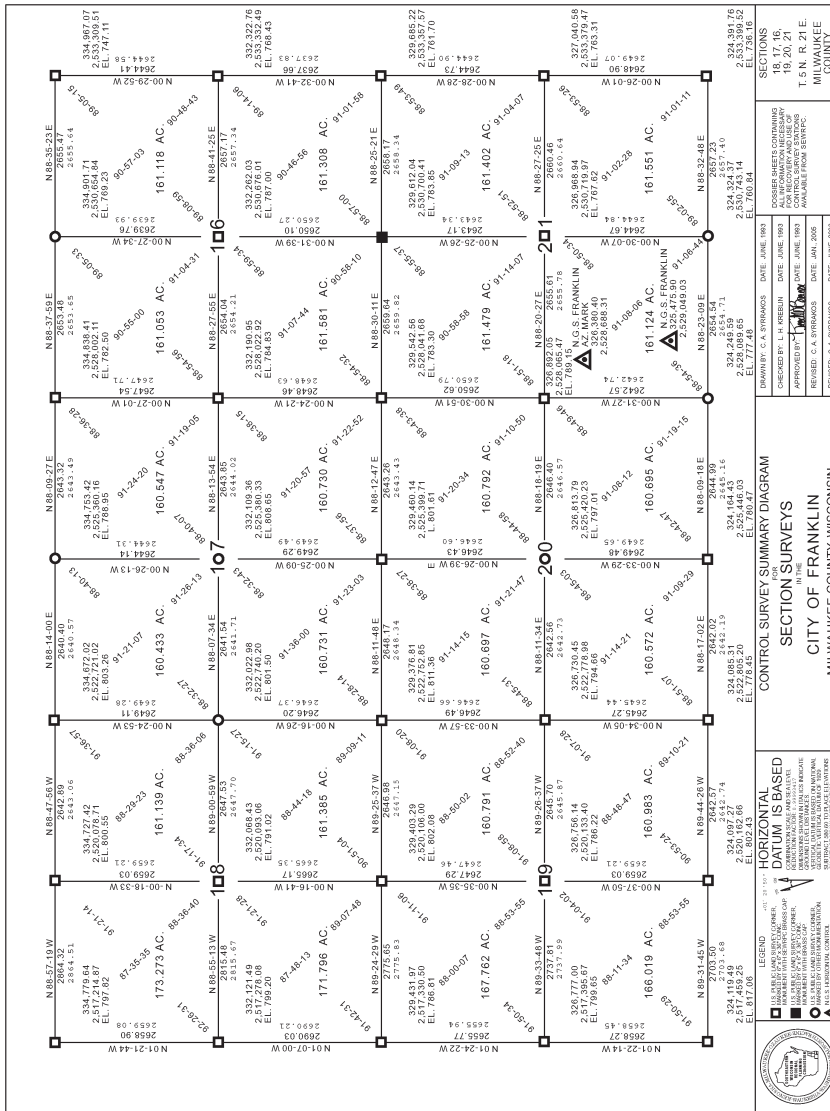
The utility of the described control survey and mapping system in the conduct of environmental engineering studies and assessments may be illustrated by the

presentation of the types of control survey data and maps envisioned, and a few examples of the application of particularly the maps to environmental studies and assessments. The control survey data should be presented in a series of summary diagrams covering the area concerned—typically a county or metropolitan region. The diagrams, as shown in Figure 5.7, should show the State Plane Coordinates of the monumented U.S. Public Land Survey System corners; the ground level lengths, sea level–grid lengths, and grid bearings of the exterior boundaries of each one-quarter section, the number of degrees, minutes, and seconds in the interior angle of each one-quarter section; and the elevations of the control survey station monuments. Any national control survey stations within the area concerned, and used to tie the U.S. Public Land Survey system corners to the National Geodetic Control Survey Network, should be shown, together with the coordinates of those stations. The angle between geodetic and grid north (theta angle) should be given, as should the combination scale and sea-level reduction factor used to convert grid to horizontal ground level distances. In addition, the area in acres of the one-quarter sections, as computed using ground level distances and grid bearings, should be given.

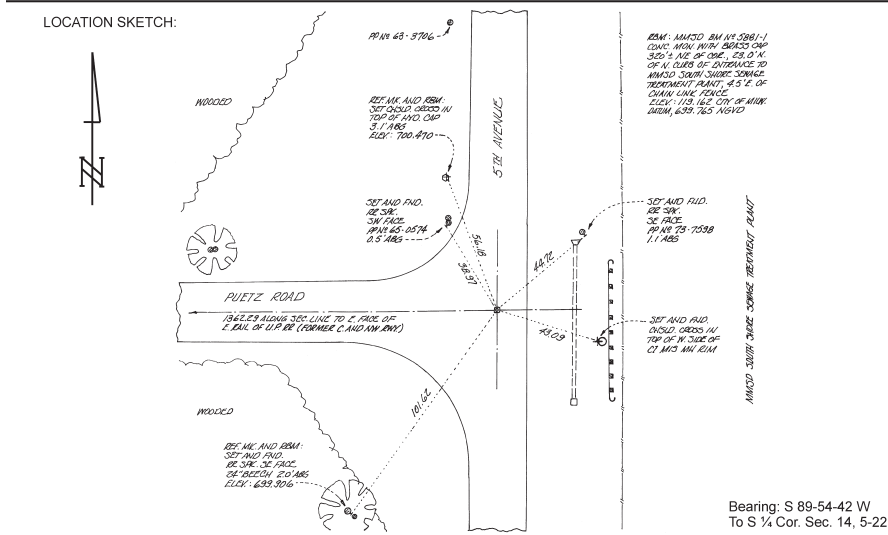
A data sheet similar to the one shown in Figure 5.8 should be prepared for each control survey station to facilitate the ready recovery and use of the station. These sheets should identify the U.S. Public Land Survey corner concerned, the State Plane Coordinates of the corner, and the elevation (orthometric height) of the corner monument and of one or more attendant reference benchmarks. The grid bearing to an azimuth mark visible from the station should be given. The sheets should contain a land surveyor's affidavit certifying to the validity of the corner location, and its use in the conduct of land surveys.

The attendant topographic maps (such as that shown in Figure 5.9) should be constructed upon the State Plane Coordinate System grid and the adopted control survey network. The State Plane Coordinate grid tick marks should be shown at five-inch intervals, and the monumented control survey stations—the U.S. Public Land Survey System corners—and the related one-quarter section lines should be shown, together with the State Plane Coordinates of the monumented corners, and the grid and ground level lengths, and grid bearings of the one-quarter section lines. The maps should be prepared to National Map Accuracy standards and should accurately show the hypsometry and planimetry of the mapped area.

Matching cadastral maps, such as that shown in Figure 5.10, should be compiled on the same coordinate grid as the topographic maps, and should show in their correct location and orientation, the U.S. Public Land Survey System corners and the State Plane Coordinates of those corners, together with the one-quarter section lines and the ground-level lengths and grid bearings of those lines as established by the control surveys. State Plane Coordinate System grid ticks should be shown at five-inch intervals. In addition to showing the real property boundary and street and railway rights-of-way lines, the maps should contain an identification number for each ownership parcel. These parcel identification numbers can be used to link the map parcels to a computerized database containing attribute data for each parcel, thus providing the foundation for the creation of a parcel-based land



U. S. PUBLIC LAND SURVEY CORNER 14113 T 5 N, R 22 E, MILWAUKEE COUNTY, WISCONSIN
23124
 HORIZONTAL CONTROL SURVEY BY: AERO-METRIC, INC. YEAR: 1994
 VERTICAL CONTROL SURVEY BY: AERO-METRIC, INC./SEWRPC YEAR: 1994/2003
 STATE PLANE COORDINATES OF: SECTION CORNER
 NORTH 330,295.96
 EAST 2,575,419.06
 ELEVATION OF STATION: 698.921
 HORIZONTAL DATUM: WISCONSIN STATE PLANE COORDINATE SYSTEM, SOUTH ZONE
 NORTH AMERICAN DATUM OF 1927
 VERTICAL DATUM: NATIONAL GEODETIC VERTICAL DATUM OF 1929 THETA ANGLE: +1-28-31
 CONTROL ACCURACY:
 HORIZONTAL: THIRD ORDER, CLASS I VERTICAL: SECOND ORDER, CLASS II



SURVEYOR'S AFFIDAVIT:
STATE OF WISCONSIN) SS
MILWAUKEE COUNTY)

SURVEYOR'S AFFIDAVIT: As Milwaukee County Surveyor, I hereby certify that I set a concrete monument with SEWRPC brass cap to mark this corner; replacing a broken concrete monument, said monument with SEWRPC brass cap having been set to mark this corner in October 1987 by me; replacing a broken concrete monument, said monument with City of Oak Creek brass cap having been set to mark this corner in May 1961 by William T. Wambach, Jr., S-371; replacing an old, subsurface, cast limestone monument set to mark this corner in 1876 by Eugene H. Engerster, Milwaukee County Surveyor, and the original U.S. Public Land Survey system in the Town of Oak Creek; replacing in turn a wood post set to mark this corner in March 1836 by Elisha Dewide, Deputy United States Surveyor, in the conduct of the original United States Public Land Survey; that I referenced the same as shown hereon; and that this record is correct and complete to the best of my knowledge and belief.



DATE OF SURVEY: 3 September 2003

Kurt H. Bauer
REGISTERED LAND SURVEYOR

S - 157

FORM PREPARED BY SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

81

FIGURE 5.8 Example: control survey station recovery sheet.

information system. Such data may include—among a virtually infinite variety of physical, social and economic data—street address, parcel area, ownership, valuation, existing land use, zoning, and presence of such conditions as flood hazard, and environmental contamination. The topographic maps, cadastral maps, and related attribute data should be prepared and maintained in digital format for ready computer manipulation and automated display.

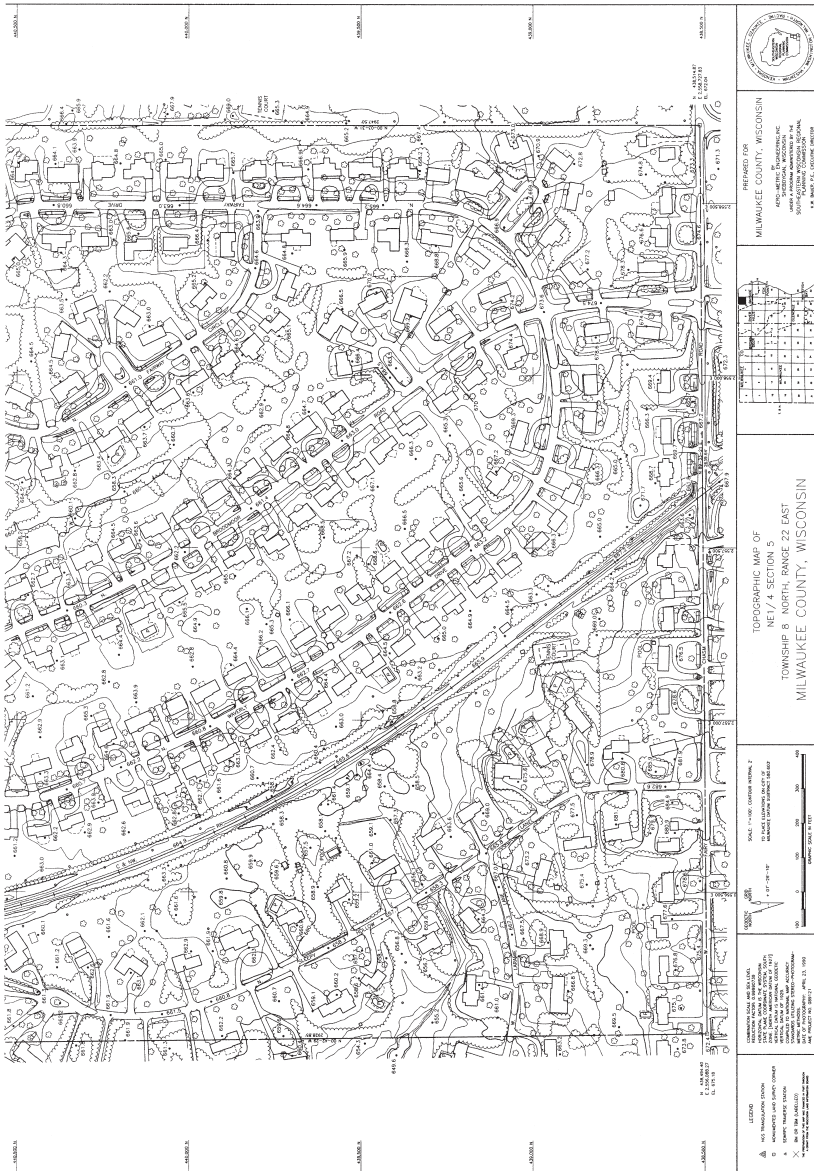


FIGURE 5.9 Typical topographic map.



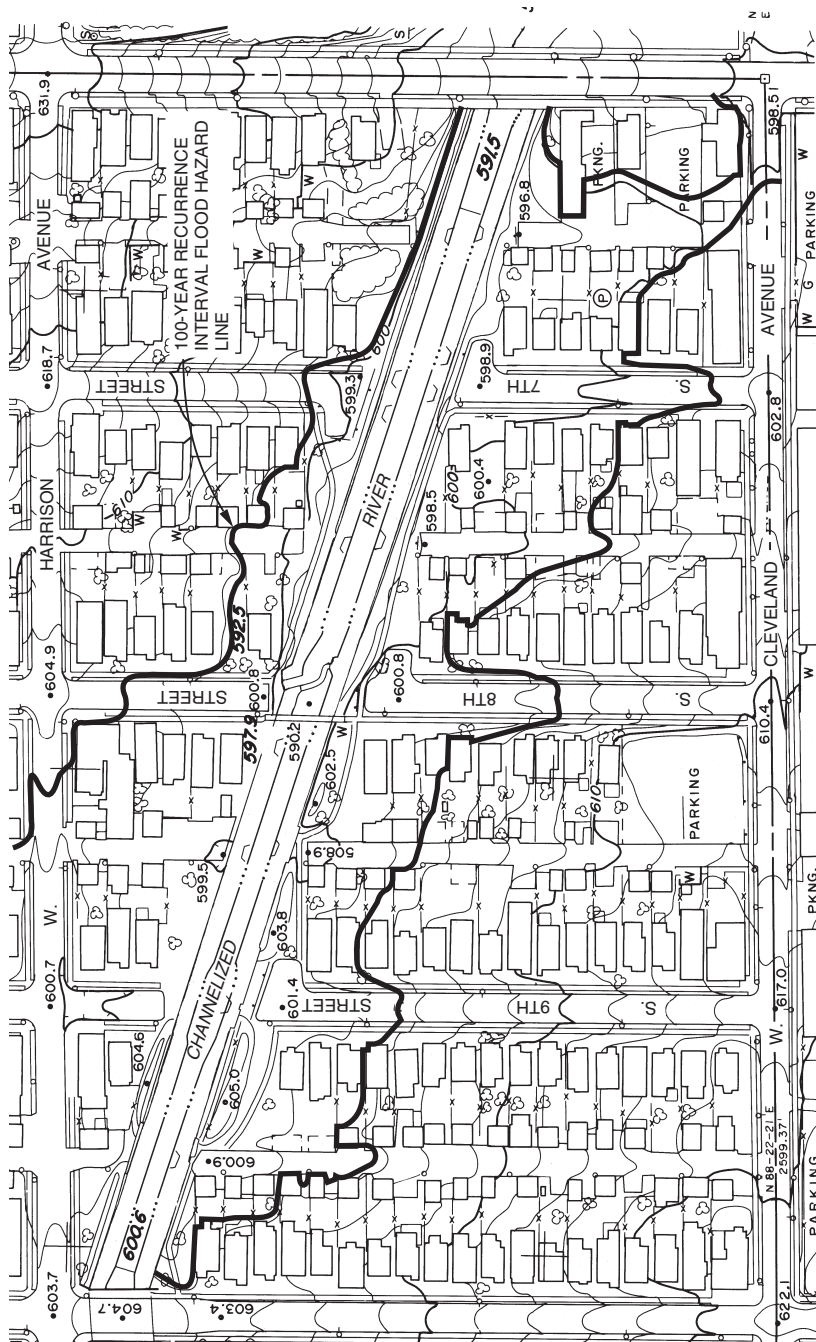
Flood Hazard Area Mapping

Figure 5.11 illustrates the use of the control survey and mapping system in the delineation of flood hazard areas. The figure illustrates the accuracy and precision with which flood hazard lines can be delineated. It should be noted, however, that the maps also greatly facilitate the conduct of the engineering studies required to delineate the flood hazard areas, particularly the hydrologic and hydraulic studies that provide the flood stage elevations that are projected on the map hypsometry to produce the flood hazard lines. The control survey and mapping system facilitates the delineation of the channel profiles and cross-sections and the conduct of the field surveys necessary to determine bridge and culvert waterway openings and related hydraulic characteristics. The maps permit the accurate delineation of both natural and artificial watershed and drainage boundaries essential to determining drainage areas for use in the hydrologic analyses. It should also be noted that since the map planimetry accurately displays rooftops, driveways, paved parking areas, and street and alley pavements, it permits the accurate determination of the impervious surface areas within a water shed, data useful in determining the *C* values used in the rational method, and the runoff factors in the SCS-TR55 method used in calculating runoff. The control survey network also facilitates the conduct of any field surveys that might be necessary to validate the flood hazard delineation and to relate such delineation to historic flood events and attendant flood damages.

Wetland Area Mapping

Figure 5.12 illustrates the use of the control survey and mapping system for the delineation of wetland areas. In wetland delineation, an experienced biologist, soil scientist, or specially trained environmental engineer visits the site concerned and marks (stakes) the boundaries of the wetland and associated plant communities and animal habitats in the field. This visit and survey is facilitated by having a copy of the large-scale topographic map of the area concerned in hand. A registered land surveyor then surveys the boundaries as marked, utilizing plane surveying techniques; and then delineates the surveyed boundaries on a plat of survey tied to the control survey network. This permits integration of the resulting wetland maps into the existing base maps and into a parcel-based land information system for the area concerned.

For some environmental reconnaissance surveys and inventories, somewhat cruder survey techniques may be utilized. These could involve the use of commercially available handheld global positioning system instruments that—with an attendant proper software program—can provide State Plane Coordinate locations with an accuracy of about three to five meters. In this manner, the biologist or soil scientist involved can obtain crude coordinates for the wetland boundaries as they are marked in the field. These boundaries can then be plotted on the topographic maps, cadastral maps, or on a combination of the topographic and cadastral maps for use in the environmental engineering effort.



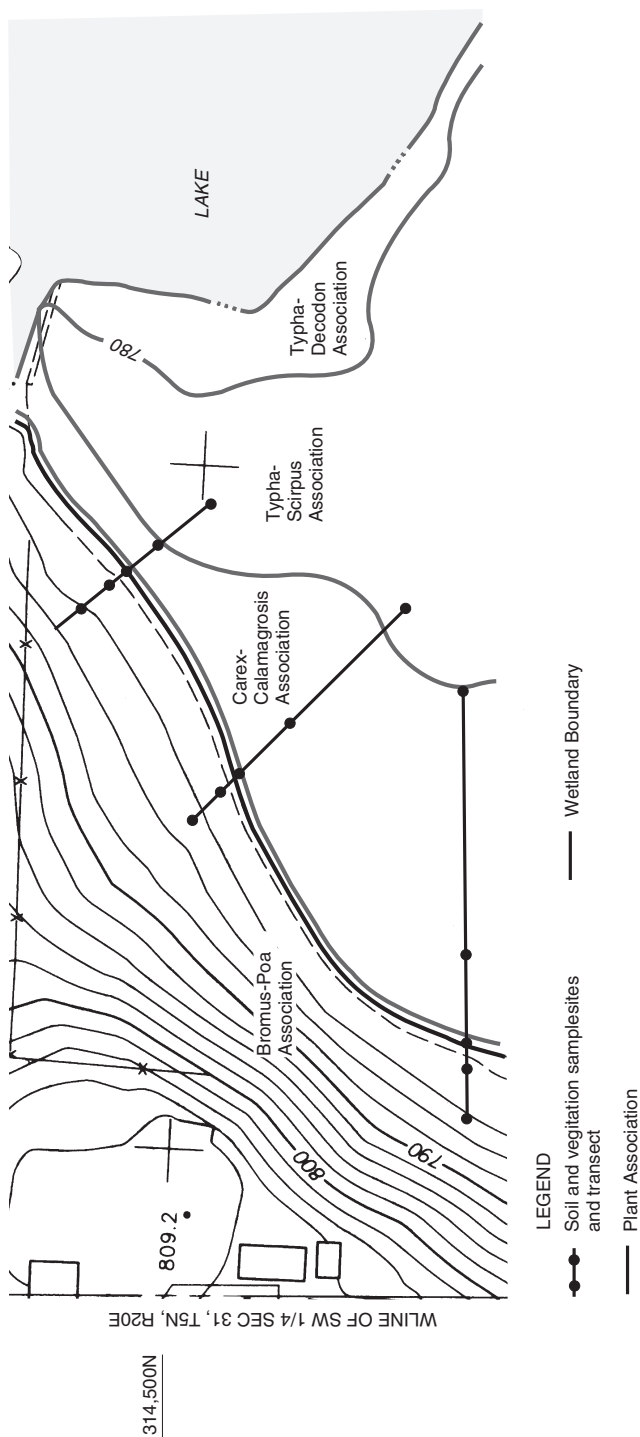


FIGURE 5.12 Example: wetland delineation.

Public Works Management Information System

Public works facilities—water mains, sanitary sewer lines, storm drains, and street improvements—provide the infrastructure essential for urban life. The efficient management of public works requires detailed knowledge about the configuration, condition, and performance of each of the various systems of public works serving the urban area. Such knowledge requires not only the collection of data about the system to be managed, but also the conversion of that data through analyses into pertinent information, and then, by the exercise of professional judgment, into intelligence on the basis of which sound management decisions can be made.

Historically, data about public works were kept on paper records, such as file index cards, construction plans, as-built construction records, special-purpose maps and plats, and written reports. Sometimes, the data resided only in the living memory of staff. The records were often duplicative, poorly maintained, difficult and time-consuming to access and use, and not well coordinated between different functional areas such as tax assessment, planning, and engineering. When meticulously kept and well indexed, such manual systems have worked tolerably well, particularly in smaller communities. As the size and complexity of a community increases, however, the use of manually kept records becomes increasingly difficult and unsatisfactory. The means now exist for the modernization of these records and, therefore, of their conversion into an efficient and effective computer-based public works management information system. The existence of such systems greatly facilitates the conduct of environmental engineering studies and assessments, as well as the preparation of facility system plans.

Two developments make such computer-based public works management information systems possible: the development of powerful, yet relatively low-cost and user-friendly, microcomputer systems; and the development of high-quality, automated base maps. Together, these two developments provide the basis for the creation of parcel-based, automated, land information systems, and in turn, automated public works management information systems. The control survey and mapping system described herein provide a sound foundation for the creation of these land information and public works management information systems.

Figure 5.13 illustrates use of the control survey and mapping system in the development of a public works management information system for a sanitary sewerage system. The addition of sanitary sewerage facilities to an automated base map is valuable in and of itself. Such addition permits sewerage system maps to be readily produced at various scales for analytical and display purposes. If a common control survey and mapping system is used, the sewerage system mapping can be readily correlated with other public and private utility system maps. Importantly, service areas can be delineated for analytical and design purposes, and these service areas can be correlated with real property boundary maps. The sanitary sewerage facilities should be delineated on a base map consisting of a combination of selected features drawn from the available

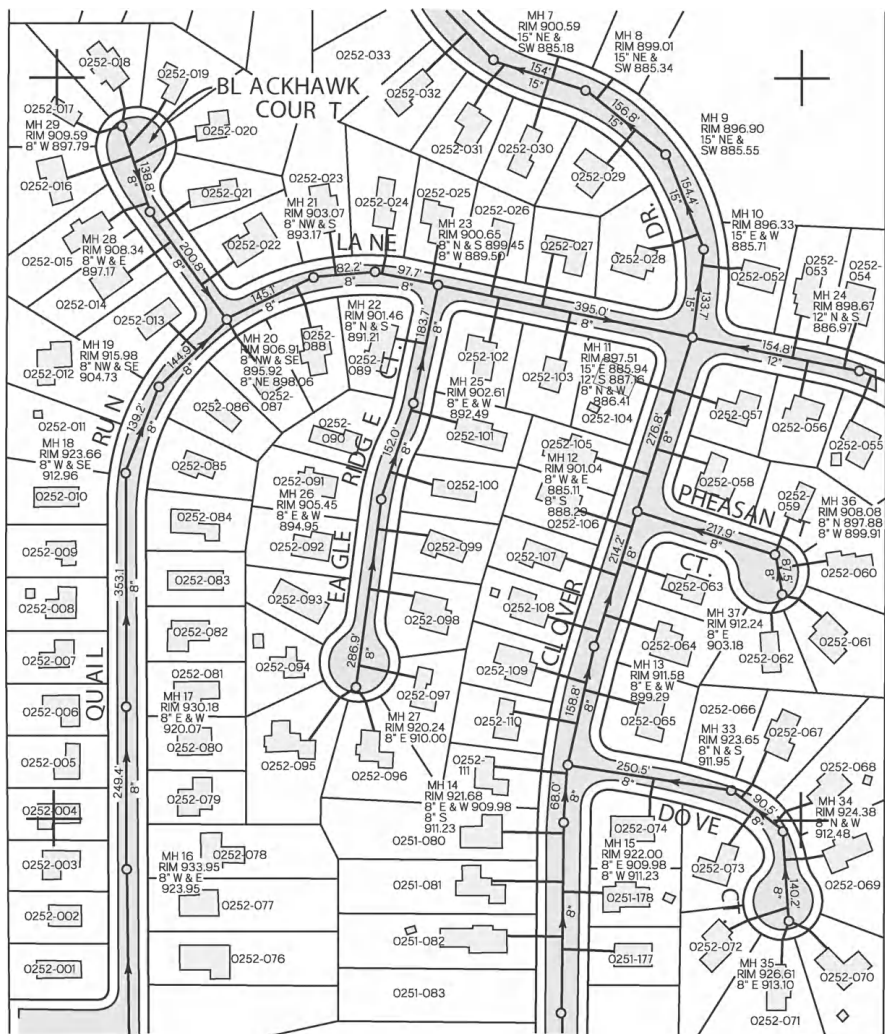


FIGURE 5.13 Portion of a public works information system base map with sanitary sewerage system overlay.

topographic and cadastral maps to provide the necessary foundational element for the facility mapping. The topographic map provides information on building locations and pavement lines; the cadastral map on property boundary and street rights-of-way lines. Since the two maps are constructed on a common projection—the State Plane Coordinate System—the existing sewerage system can be readily inventoried by field surveys using global positioning system techniques for both horizontal and vertical positioning determination. New facilities can then be readily added through the preparation of proper as-built records tied to

the State Plane Coordinate System and common vertical datum. Spatial location identification numbers are provided for manholes, and attendant data on manhole rim and sewer invert elevations, and on segment sizes, lengths, and grades added together with service area delineations.

Although the accurate mapping of the facilities is valuable in and of itself, the creation of a public works management information system requires the systematic development of a set of facility attribute data that can be linked by computer to the geographic location data provided by the automated base map. The attribute data files provide information on the structural type, condition, and performance of the facilities concerned. Creation of the attribute data file for each facility system should be accomplished in accordance with detailed memoranda that clearly specify the form and content of the computerized attribute data file. Attribute data for the sanitary sewerage system should be structured to facilitate efficient planning, design, construction, operation, and maintenance of the system. The scope and conduct of the data file should be structured in close cooperation with the director of public works, the city engineer, and system operating and maintenance personnel. A typical list of attribute data is provided in the following.

Sanitary Sewerage System Attribute Data

I. General

- A. System name
- B. System number
- C. Primary contact

II. Gravity flow sanitary sewers—data by segment between manholes

- A. Identification number
- B. Date of construction
- C. Material
- D. Pipe size in inches
- E. Pipe length in feet
- F. Grade in feet per foot
- G. Manholes
 - 1. Type
 - 2. Cover
 - 3. Location—State Plane Coordinates, NAD-27
 - 4. Rim elevation in feet, NGVD-29
 - 5. Invert elevations in feet, NGVD-29
- H. Capacity flowing full in cubic feet per second
 - I. Flow in cubic feet per second
 - 1. Average daily
 - 2. Instantaneous peak

- J. Surcharge elevation in feet, NGVD-29
- K. Overflow
 - 1. Gravity flow
 - a. Size in inches
 - b. Length in feet
 - c. Location in State Plane Coordinates, NAD-27
 - d. Invert elevation in feet, NGVD-29
 - e. Materials of construction
 - f. Capacity in cubic feet per second
 - g. Frequency
 - h. Duration
 - i. Rate in gallons per day
 - j. Receiving watercourse
 - 2. Pumped
 - a. Type
 - b. Location in State Plan Coordinates, NAD-27
 - c. Rated capacity
 - d. Idling capacity
 - e. Frequency
 - f. Duration
 - g. Receiving watercourse
- L. Condition
- M. Service connections
 - 1. Identification number
 - 2. Date installed
 - 3. Location in cumulative feet from downstream manhole
 - 4. Lateral size in inches
 - 5. Material
 - 6. Service street address
- N. Service area in acres
- O. Construction plans
- P. Construction as-built drawings
- Q. Plan proposals
- R. Instrumentation
 - 1. Flow meter
 - a. Manufacturer
 - b. Model and serial number
 - c. Date installed
 - d. Calibration

- e. Supervisory control and data acquisition system
 - f. identification link to historical database
 - g. Correction factors
- 2. Flume
 - a. Manufacturer
 - b. Model and serial number
 - c. Date installed
 - d. Calibration
- 3. High-level/surcharge monitor
 - a. Manufacturer
 - b. Model and serial number
 - c. Date installed
 - d. Calibration
 - e. Supervisory control and data acquisition system
 - f. identification link to historical database
- S. Pumping and lift stations data by station
 - 1. Identification number
 - 2. Date of construction
 - 3. Location in State Plane Coordinates, NAD-27
 - 4. Floor elevation, NGVD-29
 - 5. Type
 - 6. Capacity
 - a. Pump
 - (1) Manufacturer
 - (2) Model and serial number
 - (3) Date installed
 - (4) Life in feet
 - (5) Capacity at operating head in cubic feet per second
 - (6) Motor
 - (a) Manufacturer
 - (b) Model and serial number
 - (c) Date installed
 - (d) Starter type
 - (e) Horsepower
 - (f) Voltage
 - b. Wet well storage—gallons
 - c. Power
 - d. Auxiliary
 - (1) Generator

- (a) Manufacturer
 - (b) Model and serial number
 - (c) Horsepower
- (2) Engine
 - (a) Manufacturer
 - (b) Model and serial number
 - (c) Horsepower
 - (d) Fuel
 - (e) Cooling
- T. Influent pipes
 - 1. Sizes in inches
 - 2. Invert elevations in feet, NGVD-29
 - 3. Capacities flowing full in cubic feet per second
- U. Effluent force main
 - 1. Size in inches
 - 2. Length in feet
 - 3. Receiving facility
 - 4. Materials of construction
 - 5. Capacity in cubic feet per second
- V. Emergency bypass
 - 1. Outfall
 - a. Location—State Plane Coordinates, NAD-27
 - b. Size in inches
 - c. Length in feet
 - d. Invert elevation in feet, NGVD-29
 - e. Materials of construction
 - f. Capacity in cubic feet per second
 - g. Receiving watercourse
 - 2. Bypassing
 - a. Frequency
 - b. Duration
 - c. Rate in gallons per day
- W. Construction plans
- X. Construction as-build drawings
- Y. Service area
 - 1. Size in acres
 - 2. Resident population
 - 3. Commercial area in acres
 - 4. Industrial area in acres

- Z. Plan proposals
- AA. Instrumentation and controls
 - 1. Controller
 - a. Manufacturer
 - b. Model and serial number
 - c. Date installed
 - d. Date serviced by
 - e. As-built drawings
 - 2. Instrumentation
 - a. Manufacturer/model and serial number
 - b. Date installed
 - c. Date calibrated
 - d. Date last serviced
- III. **Treatment plant: data by plant**
 - A. Plant identification number
 - B. Type of plant
 - C. Date of construction by major treatment units
 - D. Site, location—State Plane Coordinates, NAD-27—of site boundary, site area, in acres
 - E. Hydraulic capacity by major treatment units
 - F. Hydraulic loading by major treatment units
 - G. Biological capacity by major treatment units
 - H. Biological loading by major treatment units
 - I. Plant capacity in population equivalent
 - J. Plant loading in population equivalent
 - K. Permit effluent quality
 - L. Operating effluent quality
 - 1. Dry weather flows
 - 2. Wet weather flows
 - M. Outfall
 - 1. Size in inches
 - 2. Length in feet
 - 3. Invert elevation in feet, NGVD-29
 - 4. Materials of construction
 - 5. Capacity in cubic feet per second
 - 6. Receiving watercourse
 - N. Bypassing
 - 1. Frequency
 - 2. Duration

- 3. Rate in gallons per day
- O. Construction plans
- P. Construction as-built drawing
- Q. Replacement cost by major treatment unit and total service area
 - 1. Size in square miles
 - 2. Resident population
- R. Plan proposals

Similar tables listing attribute data for public water supply, stormwater management and street systems can be developed to provide a comprehensive public works management information system. The existence of the resulting public works management information system can greatly facilitate the conduct of environmental planning and engineering studies and assessments; the assessment of the condition and performance of existing systems; the existence of environmental problems relating to the existing systems; and the preparation of system, preliminary engineering, and construction plans.

SURVEY METHODS

Many environmental engineering studies and assessments can be facilitated by direct use of the mapping system herein described; that is, by direct use of the topographic maps, cadastral maps, or maps that combine selected elements of these two types of maps. The maps can be used directly in the field during the conduct of reconnaissance studies and of certain types of inventories, the findings of which can be directly sketched on copies of the maps. The maps, together with the attribute data residing in attendant land information and public works management information systems, can be used in the preparation of maps displaying such information as ownership, valuation, historic and existing land use, soils and soil capabilities, flood hazard areas, wetlands, utility facilities, and utility service areas, among others. In the presence of attendant land information and public works management information systems, many of the display and analytical maps required can be provided by computer plots.

The conduct of some environmental engineering studies and assessment will, however, require the conduct of field surveys. Such surveys may be required for the accurate location of site boundaries and of features such as buildings and other structures; existing and abandoned wells, waste outfalls, and old mine shafts; above and underground active and abandoned storage tanks; areas of contaminated soils; plant and animal habitat areas; and active and abandoned waste treatment, storage and disposal areas, among others. The field surveys may require the determination of vertical, as well as horizontal, locations and alignments, and information on, for example, the crown and invert elevations of buried conduits and tanks.

If the control survey network such as herein described is available, the surveys can usually be efficiently and effectively conducted utilizing plane

surveying techniques. Modern instrumentation, including total stations equipped with electronic distance measuring capabilities, automated spirit levels, and computerized data collectors, facilitate the connection of the needed surveys to monumented control survey stations of known position on both the State Plane Coordinate and U.S. Public Land Survey Systems, and to the National Vertical Datum. This will permit the survey results to be accurately plotted on the available maps, and correlated with data residing in attendant parcel-based land information and public works management systems. With respect to required elevations (orthometric heights), spirit level surveys initiated at control survey bench marks will directly provide such elevations.

The control survey network herein described, will also facilitate obtaining needed data through traditional photogrammetric means, or through the conduct of newer light detection and ranging (LiDAR) surveys. Properly controlled, such remote sensing technology can be used to quickly obtain information on such features as the location and volume of stock and waste piles that, due to their ephemeral nature, may not be shown on the available topographic maps. Indeed, use of LiDAR technology is being promoted by the Federal Emergency Management Administration for flood plain mapping.

Global positioning system (GPS) equipment can, in many situations, be used in place of the more conventional plane surveying instrumentation. In areas where base stations are available, GPS instrumentation can be used in the real-time kinematic mode to provide horizontal positions to control survey accuracy levels. The surveys can, moreover, be conducted by one person, greatly reducing costs. In the use of GPS instrumentation, care must be exercised to ensure that the instrumentation and attendant software programs are providing coordinate and elevation data referred to the proper datums that are used for the control survey and mapping systems concerned.

The GPS instrumentation can also be used to provide vertical survey control data in the form of ellipsoid heights, as indicated in Figure 5.2. The conversion of such heights to the needed orthometric heights requires knowledge of the geoid heights. Geoid heights are available from the National Geodetic Survey, but the accuracy of the known values (2.5 to 3.0 centimeters) is generally insufficient to provide survey accuracies adequate for many engineering purposes. The availability of the control survey network herein described, however, permits GPS instrumentation to provide orthometric heights to within an accuracy of a few one-hundredths of a foot. This can be done by occupying the monumented control survey stations (e.g., the four corners of a one-quarter section for which orthometric heights are available) and determining the geoid heights at these four locations by comparison of the known orthometric heights to the GPS measured ellipsoid heights. These four values can then be averaged to provide a value for the one-quarter section, and the GPS instrumentation can then be used to obtain both horizontal and vertical positions of utilities and other features located within the one-quarter section. The relationship utilized in the previously described procedure ($H = h - N$) is an approximation, but can be used with excellent results for municipal engineering purposes. Theoretically, as is apparent from

an examination of Figure 5.2, the ellipsoid height, H , and the geoid height, N , are measured along the normal to the ellipsoid, while the orthometric height, h , is measured along the plumb line. Because the ellipsoid and geoid heights are not parallel with the orthometric height, the measurements involved must theoretically be added as vectors, not as scalars. The nonparallelism of the normal to the ellipsoid and the plumb line is known as the deflection of the vertical, and in most cases is small enough to be neglected in surveys conducted for public works and similar engineering purposes.

BIBLIOGRAPHY

- Davis, R. F., Foot, J. Anderson, and E. Mikhael, "Surveying Theory and Practice," McGraw-Hill, New York, 1981.
- National Research Council, "Procedures and Standards for a Multipurpose Cadastre," National Academy Press, 1983.

CHAPTER 6

PLANNING AND ENVIRONMENTAL ASSESSMENT

KURT W. BAUER, PE, RLS, AICP

Executive Director Emeritus, Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin

INTRODUCTION

The practice of environmental engineering requires an understanding of urban planning objectives, principles, and practices. Accordingly, this chapter is intended to serve as an introduction to what was, for a time, a highly specialized branch of civil engineering, namely, city and regional planning. Historically, university courses in city and regional planning were often taught in the civil engineering departments, and textbooks in city and regional planning were often authored by practicing civil engineers. The American Society of Civil Engineers, to this day, maintains a division of urban planning and development, and annually awards the Harland Bartholomew Prize for notable achievement in planning. City and regional planning has, however, increasingly become a discipline separate from civil and environmental engineering—a discipline practiced by the now-separate planning profession. A close association and mutual understandings between these two professions is needed.

This chapter considers city and regional planning as a rational process that seeks the orderly and economic development of urban and urbanizing areas—a process that is oriented to the formulation and attainment of sound urban development objectives, and the formulation and application of standards that specify desirable physical arrangements of cities and urban regions. This view of city planning assumes that the orderly physical development of urban areas is in the public interest, and that public planning should be oriented to furthering the public health, safety, and general welfare. Other views of city and regional

planning exist, such as user-oriented, participatory planning; advocacy planning; and incremental or market-oriented planning. These other views are not, in this chapter, regarded as sound models. Emphasis in this chapter is placed on the central concept of the comprehensive plan, and on plan implementation devices such as zoning, land subdivision control, official mapping, and capital improvement programming. Emphasis is also given to the concept of environmental assessment, which should be an integral part of the planning process, or closely related to that process.

DEFINITION OF TERMINOLOGY

The term *planning* is defined and used in different ways by different professions. Planning is often defined as one of the five functions of management: planning, organizing, directing, coordinating, and controlling. Used in this way, planning is an analytical and creative process that involves the establishment of goals or objectives for organizations, and the establishment of a systematic means for the attainment of these goals or objectives over time. Used in this way, planning, then, is concerned with identifying needs and problems; gathering and analyzing relevant data concerning these needs and problems; developing and testing alternative means for meeting the identified needs and alternative solutions to the identified problems; and adopting and implementing the solution that is judged best. Used in this way, planning is an activity of people who decide matters within an organization, and it encompasses three core tasks, or functions: inventory, goal formulation, and plan design. Techniques aside, planning in this general sense is essentially the same process in whatever milieu it may be applied.

Planning may be classified in a number of ways:

- According to the realm within which the planning decisions lie—as public- or private-sector planning
- According to the disciplines involved in the planning—as economic, social, or physical planning
- According to the jurisdiction concerned as—regional, state, or national planning
- According to the facility or service being planned—as school, hospital, highway, sewerage, water supply, or park planning

Often, several types of resources may be affected by the planning effort, so that planning for the development of any one of these resources may affect one or more others. When this occurs, then one of the resources concerned will be of primary concern, and the others will be of secondary concern in the planning process. Thus, planning for a cultural activity may be defined as social planning, while planning a building for the conduct of this activity may be defined as physical planning. In this case, the physical planning is secondary to the primary

social planning. Planning for the development of physical resources is almost always intended to serve primary social and economic development objectives.

Planners operating within municipal government have appropriated the term *planning*, as heretofore considered in its broadest and most general sense, for their own use, giving it a more narrow and restricted meaning. This is the meaning that will be used in the rest of this chapter.

Under this narrower definition, city—and, by extension, regional—planning is a process concerned with guiding the amount, rate, character, and quality of urban change; and is concerned primarily with the arrangement of land uses and with the provision of the necessary supporting transportation, utility, and community facilities and services. Under this definition, planning is directly concerned with the physical development of cities and metropolitan areas. It does not attempt to establish the broader policies to be pursued with respect to the social and economic development of these areas, but is concerned with providing the physical infrastructure required for such development. It thereby greatly influences the quality of life within cities and urban regions. Under this narrower definition, the core function of city planning includes the preparation of plans for land use, and for the supporting transportation, utility, and community facilities; and the preparation and administration of plan implementation devices such as zoning, land subdivision control, official mapping, and capital improvement programming.

City planning takes effect largely through the operation of government, and requires the application of specialized survey, analysis, forecast, and design techniques. City planning may, therefore, be viewed as a social movement, as a local governmental function, or as a technical profession. Each viewpoint has, to a certain extent, its own concepts, history, and principles of practice. Together, they fuse into the effort of modern societies to shape and improve the environment within which increasing proportions of humanity live and work: cities and their urban regions.

CRITERIA FOR GOOD PLANNING

Good urban planning should meet at least three criteria:

1. Good planning should be comprehensive, considering all aspects of the physical development of an area, and relating these to common unifying objectives. A comprehensive approach is essential to the making of intelligent decisions concerning relative needs and the effective allocation of resources to areas of greatest need.
2. Good planning should be relatively long-range, looking well beyond obvious needs of the moment and attendant expedient solutions.
3. Good planning should encompass a geographic area that permits a sound technical approach to the issues and problems concerned. Thus, for example, drainage and flood control planning must consider natural watersheds as rational planning areas; and transportation system planning must consider entire commuter sheds as rational planning areas.

Consideration of these criteria leads to the conclusion that some important aspects of local urban planning can only be properly conducted within the framework of broader regional planning. Moreover, regional planning can best be conducted within a framework provided by formally adopted state development objectives, and should serve to make these objectives operational at the multicounty regional or metropolitan area. Thus, an adopted state policy might be to maintain floodlands in essentially naturally open uses. The hydrologic and hydraulic studies required to establish flood flows and stages, and to map the attendant flood hazard areas, can best be accomplished at the regional level based on areawide land-use inventories and plans. The adopted regional plans are then made operational through preparation of local plans that are consistent with the regional plans. In the example used, the local land use and community facility plans would identify the mapped floodlands and recommend their preservation in park and open space uses. Local zoning, land subdivision control, and official mapping can then be used to implement the local plans in a manner consistent with regional plans and the state development objectives.

INSTITUTIONAL STRUCTURE FOR URBAN PLANNING

In the United States, municipalities are creatures of the states and have only such powers, duties, and functions as the state legislatures grant to them. Accordingly, states must enact city and regional planning enabling legislation to permit municipalities—cities, villages, and civil towns—counties and multicounty regions to engage in planning. Many state enabling acts follow the approach recommended in the federal model city planning enabling act of 1927, which delegates the urban planning function to advisory bodies known as plan commissions. In theory, this delegation entrusts this important municipal function to a continuing body of public officials and citizens qualified for the task, free from the distractions of routine matters of administration, and somewhat detached and insulated from partisan politics. The state enabling legislation provides for the creation of such commissions and specifies their composition, functions, duties, and powers. The enabling legislation will normally provide that the plan commission may retain a staff and, as necessary, consultants, in accordance with an annual budget provided by the governing body of the municipality. The staff that serves the commission will normally be a department of a municipal government. Some planners argue that the planning function should be under the direction of the chief executive officer of the municipality, rather than under the direction of the plan commission.

The state enabling legislation usually provides that the plan commissions are entirely advisory to the executive and legislative branches of municipal government. The commissions may make reports and recommendations relating to the development of the municipality, not only to municipal officials and agencies, but also to public utility companies, other organizations and citizens. Importantly, the commissions are usually responsible for recommending long-term capital

improvement programs to the executive and legislative branches, for example, to the mayor and common council. In addition, certain matters usually must be referred to the plan commission before the municipal governing body, or other public officer having final authority, thereon acts. These matters usually include, among others, the location and architectural design of public buildings; and the location, extension, alteration, vacation, or acquisition of land for streets and other public ways, and for parks, playgrounds, and other open spaces; and the location, extension, abandonment, or authorization for any public utility; and all land subdivision plats. The enabling legislature usually also provides for the municipal government to adopt, upon recommendation by the plan commission, certain plan implementation devices such as zoning, land subdivision control, and official map ordinances.

THE COMPREHENSIVE PLAN

The most important function and duty of a municipal or regional plan commission is to make and adopt a comprehensive plan for the physical development of the city or region. The plan should show the commission's recommendations for the physical development of the area concerned. The plan is intended to be made with the general purpose of guiding and accomplishing a coordinated, adjusted, and harmonious development of the municipality that will best promote the public health, safety, and general welfare, as well as efficiency and economy in the process of development. In some states, the enabling legislation may specify the permissible content of the comprehensive plan only very generally—in other states, in specific detail.

A comprehensive plan report may be expected to have the following composition:

Chapter 1 Introduction

This chapter should include background information on the geographic limits of the planning area and on its regional setting; the need for and purpose of the plan; the planning process; the planning organization and staff structure; and the scheme of presentation.

Chapter II Demographics and Economic Base

This chapter should provide for the planning area information on the population size, distribution, characteristics, and on historic growth trends in these factors. It should also provide information on the labor force, economic base and structure, trade area, personal income, and property tax base; and on historic trends in these factors.

Chapter III The Natural Resource Base

This chapter should provide for the planning area information on such factors as climate; air quality; geology and physiography, topography and drainage patterns and areas; soils, ground and surface water resources; wetlands, woodlands, wildlife habitat and environmental corridors.

Chapter IV Land Use

This chapter should provide information on historic urban growth patterns in the planning area; and on the existing land use patterns, including the amount and areal distribution of the residential, commercial, industrial, and institutional land uses.

Chapter V Transportation

This chapter should provide information on the location, configuration, capacity and utilization of the transportation facilities of the planning area, including the arterial streets and highways and public transit facilities and, as applicable, railway and airport facilities.

Chapter VI Public Utilities

This chapter should provide information on the location, configuration, capacities, and use of the utilities in the planning area, including the sanitary sewerage, water supply, stormwater management and flood control, and solid waste management facilities.

Chapter VII Community Facilities

This chapter should provide information on the existing parks, public buildings, such as fire and police stations, administrative offices, libraries, and, in some cases, hospitals and public housing facilities of the planning area.

Chapter VIII Housing

This chapter should provide information on the existing housing stock by number of units; distribution, occupancy, and vacancy statistics; structure types, and costs in terms of valuations and rents. The chapter may also include descriptions of existing governmental and private activities in providing decent, safe and sanitary low-income housing within the planning area together with data on housing costs and affordability.

Chapter IX Adopted Plans and Land Use Regulations

This chapter should provide information on areawide plans affecting the local planning area; on past comprehensive plans; on existing land use regulations, including zoning, subdivision control, and official mapping; and on any special purpose districts such as metropolitan sewerage districts, and the relationship of these districts to the local planning area.

Chapter X Anticipated Growth and Change

This chapter should present projections and forecasts of future population, household, and employment levels; and on the demand for the various types of land uses within the planning area.

Chapter XI Objectives, Principles, and Standards

This chapter should set forth agreed-upon land use, transportation, utility, and community facility development objectives, together with a set of supporting standards that can be used to quantitatively link the objectives to alternative and recommended plan elements.

Chapter XII Plan Elements

A. Land Use

This plan element should consist of a recommended future land use pattern for the planning area, including recommendations on the amount and distribution of land proposed to be used for residential, commercial, industrial, and institutional uses. The plan should identify existing land uses to be retained and areas to be devoted in the future to each of the various types of land uses. The plan should identify environmentally sensitive lands that should be maintained in essentially open use, such as in parks, parkways, and open space reservations. The plan should include recommendations concerning the desirable densities and intensities of the various recommended uses. In some cases, provisions may have to be made for lands to be devoted to mineral extraction, sanitary landfills, cemeteries, and other special use areas. At the regional level, the plan should contain recommendations for the preservation of prime agricultural lands.

B. Transportation

This element should include recommendations for the future configurations and capacities of the arterial streets and highway system and of the transit system, and in some cases may address vehicular parking, railway, airport, and seaport facilities. The plan should identify the location, configuration, and proposed capacities of facilities to be retained; those to be improved or otherwise altered, and of new facilities proposed to be constructed.

C. Utilities

This plan element should include recommendations for the future configuration and capacities of the sanitary sewerage, water supply, stormwater management and flood control, and solid waste management facilities, including the location and capacity of needed conveyance, storage and treatment facilities; and for the control of both point and non-point sources of water pollution. The plan should identify the locations and proposed capacities and levels of treatment to be provided by sewage and water treatment plants and of trunk sewer and water transmission lines.

D. Community Facilities

This element should include recommendations for park and parkway development; and for the location, size, and design of public buildings, such as administrative centers, fire and police stations, libraries, and hospitals. The plan should identify facilities to be retained, remodeled and expanded.

E. Special

Depending on the characteristic of the community concerned, the comprehensive plan may include special plan elements relating to the provision of low- and moderate-income housing, including

public housing; for urban revitalization and redevelopment; for historic preservation; and for railway facility realignment and airport facility development.

Chapter XIII Plan Implementation

The comprehensive plan report should also contain recommendations for plan implementation. The chapter should contain recommendations for the adoption of a new, or for the amendment of the existing, zoning ordinance to help carry out the land-use plan by regulating the use of land, the height and bulk of buildings, and the density of population. The chapter should contain recommendations for the adoption of a new, or for the amendment of the existing, land subdivision control ordinance, regulating the development and redevelopment of land. The chapter may contain recommendations for the adoption of an official map to help implement and reserve land for the arterial street, park, and parkway elements of the plan, the official map being final and conclusive as to the location and extent of all existing and proposed streets, parks, and parkways. The chapter may also contain recommendations for the preparation and maintenance of a five-year capital improvement program identifying improvements needed to implement the various recommended plan elements. Finally, the chapter may address the adoption of new or the amendment of the existing, housing and building codes.

Chapter XIV Summary

Each individual plan element is intended to deal with identified developmental or environmental problems. The individual plan elements are coordinated by being related to the land-use plan. Thus, the land-use plan comprises the most basic element of a comprehensive plan, an element upon which all of the other elements are based.

A comprehensive plan for the physical development of the community is essential if land-use development is to be properly coordinated with the development of supporting transportation, utility, and community facility systems; if the development of each of these individual systems is to be coordinated with the development of the others; if serious and costly environmental and developmental problems are to be minimized; and if a more healthful, attractive and efficient settlement pattern is to be evolved.

The preparation, adoption, and use of the comprehensive plan are considered to be the primary objectives of the planning process. All planning and plan implementation techniques are based on, or otherwise related to, the comprehensive plan.

In the late 1960s and early 1970s, the validity of the concept of the comprehensive plan was questioned and its application was opposed by some academicians and even some practicing planners. The critics, however, suggested no constructive replacement that would prevent public planning from becoming an arbitrary and capricious process—more destructive than constructive. The comprehensive

plan has, therefore, remained a viable and valid concept, a concept essential to coping with the environmental and developmental problems generated by urban development and redevelopment in a rational manner.

The comprehensive plan not only provides the necessary framework for coordinating and guiding development, but also provides the best conceptual basis available for the application of system engineering techniques to the growing problems of urban areas. This is because systems engineering focuses on the design of physical systems. It seeks to achieve good design by setting good objectives; assessing the ability of alternative plans to meet those objectives through quantitative analyses; cultivating interdisciplinary team activity; and considering all of the relationships involved, both within the system being defined and between that system and its environment.

THE PLANNING PROCESS

As shown in Figure 6.1, the comprehensive planning process consists of seven major steps: the definition of the planning area; inventory and analysis; formulation of development objectives, principles, and standards; identification of

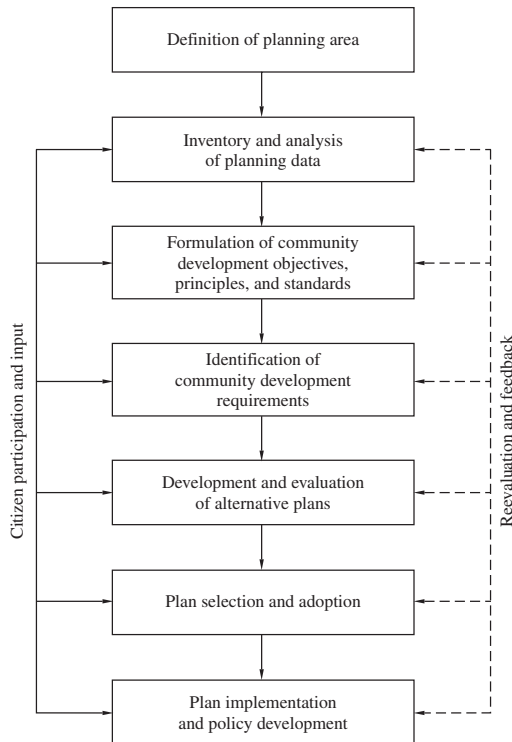


FIGURE 6.1 Comprehensive plan preparation process. (Source: SEWRPC.)

development requirements; development and evaluation of alternative plans; plan selection and adoption; and plan implementation policy development.

Definition of Planning Area

The proper definition—or delineation—of the planning area to be considered requires careful study. For comprehensive urban planning, the planning area should include the existing corporate boundaries and current urbanized areas plus such adjacent open areas as general growth prospects and likely directions of expansion may indicate. Considerations should include, among others, natural drainage basins; existing and proposed transportation facilities; salient topographic features such as large wetlands, woodlands, and open space reservations; and prime agricultural lands. Considerations should also include adopted state, regional, county, and preexisting local plans, and importantly, statutory extraterritorial planning, zoning, and plat approval jurisdictions. Planning areas may be defined by state law and federal administrative regulations—such as the federal regulations governing water quality management and transportation system planning. Some types of planning efforts may require the delineation of planning areas such as water sheds and a commuter shed.

Inventory and Analysis

Reliable planning data are absolutely essential to the formulation of workable development plans. Consequently, inventory becomes the first operational step in the planning process. The crucial nature of factual information in the planning process should be evident, since no intelligent forecast can be made, or alternative courses of action formulated and evaluated, without definitive knowledge of the current state of the area or system being planned.

The necessary inventory and analysis step not only provides data definitively describing the existing conditions, but also provides a basis for identifying existing and potential problems, as well as opportunities and potentials for good development. The inventory data are also crucial to the preparation of forecasts and to the formulation and evaluation of alternative plans.

It is important to recognize that, to a considerably extent, urban development and redevelopment can be guided and shaped in the public interest through the task of collecting, analyzing, and disseminating accurate planning and engineering data. Experience has shown that if the inventory function is properly carried out, the resulting information will indeed be used and acted on by federal, state, and local units and agencies of government and by private investors. This will contribute positively to the shaping and guiding of development in the public interest, even in the absence of a comprehensive plan. For example, the development and dissemination of accurate flood hazard maps will influence the location of new flood-prone development and of redevelopment in the planning area. Similarly, the development and dissemination of detailed operational soils data will influence the location, configuration, and design of land subdivision plats

that are to be served by on-site sewer disposal systems. The development and dissemination of accurate data on the location and configuration of wetlands will similarly shape development decisions.

The proper preparation of comprehensive plans requires the collection of a wide range of definitive data, including data in the following list:

I. Maps

- A. Large-scale topographic maps
- B. Large-scale cadastral maps
- C. Aerial photographs
- D. Base maps that can serve as a basis for the collection, analysis, and display of planning data and plans

II. The Demographic and Economic Base

- A. Demographic base
 - 1. Existing and historic population size and distribution
 - 2. Components of population change
 - 3. Population distribution
 - 4. Population characteristics
 - a. Age and sex composition
 - b. Race and Hispanic origin
 - c. Marital status
 - d. Educational attainment
 - 5. Diurnal changes in population distribution
 - 6. Number and characteristics of households
- B. Economic base
 - 1. Labor force
 - a. Labor force size and distribution
 - b. Labor force characteristics
 - 2. Employment
 - a. Number and distribution of jobs
 - b. Occupational characteristics by place of work
- C. Personal income
- D. Property tax base
 - 1. Equalized property values
 - 2. Property tax levies and rates

III. The Natural Resource Base

- A. Climate
- B. Air quality
 - 1. Ozone
 - 2. Particulate matter

- C. Geology and physiography
 - 1. Surface geology and physiography
 - 2. Bedrock geology
- D. Topography and drainage patterns
- E. Soils
 - 1. Detailed operational soils maps
 - 2. Soil suitability interpretations
 - 3. Suitability for urban development served by public sanitary sewers
- F. Suitability for onsite sewage disposal systems
 - 1. Conventional systems
 - 2. Mound systems
 - 3. Aerobic treatment systems
- G. Suitability for agriculture
- H. Suitability for extraction of minerals
- I. Groundwater resources
 - 1. Groundwater systems
 - 2. Aquifer recharge and discharge
 - 3. Groundwater quality
 - 4. Vulnerability to contamination
 - 5. Radium concentrations
- J. Surface water resources
 - 1. Lakes
 - 2. Rivers and streams
 - 3. Floodlands
- K. Wetlands
- L. Woodlands
- M. Wildlife habitat
- N. Natural resource-base-related elements
 - 1. Major park and open space sites
 - 2. Historic sites
 - 3. Natural area and critical species habitat sites
- O. Environmental corridors
 - 1. Primary
 - 2. Secondary
 - 3. Isolated natural areas

IV. Land Use

- A. Historic urban growth patterns
- B. Existing land use
 - 1. Urban land uses
 - 2. Nonurban land uses

- C. Residential land use
 - 1. Residential building permit authorizations
 - 2. Residential platting activity
- D. Commercial land use
- E. Industrial land use
- F. Governmental and institutional land use
- G. Agricultural land use
- H. Extractive land use
- I. Inefficient and conflicting land uses and blighted areas
- J. Housing
 - 1. Housing stock
 - 2. Housing occupation and vacancy rates
 - 3. Housing building activity
 - 4. Housing value and costs

V. Transportation and Public Utility Facilities

- A. Transportation facilities—locations and capacities
 - 1. Freeways
 - 2. Surface arterial streets and highways
 - 3. Public transit facilities
 - 4. Intracity transit facilities
 - 5. Intercity transit service
 - 6. Specialized transportation services
 - 7. Railway facilities
 - 8. Airports
 - 9. Bikeways
- B. Public utility systems—locations and capacities
 - 1. Sanitary sewerage
 - 2. Water supply
 - 3. Stormwater drainage
 - 4. Quasi-public utilities—electric power, gas, communications
- C. Solid waste management facilities
 - 1. Landfills
 - 2. Recycling
 - 3. Yard waste

VI. Community Facilities

- A. Parks, parkways, and open space
- B. Schools
- C. Libraries
- D. Administrative buildings
- E. Police and fire stations
- F. Medical care facilities

VII. Adopted Plans and Land Use Regulations

- A. Land-use regulations
- B. Local zoning regulations
 - 1. Background
 - 2. General zoning
 - 3. Floodland zoning
 - 4. Shoreland zoning
 - 5. Land-use pattern proposed under existing zoning
- C. Land subdivision regulations
- D. Official mapping
- E. Special-purpose districts
 - 1. Tax incremental financing districts
 - 2. Town sanitary districts
 - 3. Public inland lake protection and rehabilitation districts
 - 4. Business improvement districts
 - 5. Redevelopment areas

The focus, scope, and depth of the inventory and analysis step will differ at the regional, as opposed to the local, level of planning. This difference has important implications for the use of the inventory data in environmental engineering. At the regional level, the inventory efforts will focus on such matters as the accurate delineation of watershed boundaries and the collection of the hydrologic and hydraulic data needed to assess stream flows and attendant stages and the location and extent of floodways and floodplains; surface and groundwater quality, and related point and nonpoint sources of pollution; location, extent, and quality of woodlands, wetlands, and wildlife habitat areas; the location of sites having historic cultural and recreational value; existing land uses determined on a uniform, areawide basis; preparation of detailed soil maps and attendant interpretations for various rural and urban uses; commuter sheds and attendant travel habits and patterns; and transportation system capacity and use. At the regional level, the inventories may involve costly travel inventories, stream gaging and water-quality monitoring efforts, and the formulation, calibration, and validation of simulation models of travel and traffic; stream flows and stages; water quality, and air pollution. Horizontal and vertical control surveys may be conducted, and the large-scale topographic and cadastral maps may also be prepared at the regional level. Automated, parcel-based land information systems may also be developed at the regional level. These systems have uses in many areas, including planning, engineering, assessing, and general public administration. The local inventories will focus on the more detailed factors affecting the preparation of plans, including the configuration, capacity, and use of the total street system; on the sanitary sewerage, water supply and storm water management facilities;

and such community facilities, as parks and parkways, libraries, police and fire stations, administrative centers, and housing.

The inventory efforts should be carried out in accordance with a predesigned structure for the creation of an automated planning information system and of a companion automated public works management system.

Formulation of Objectives and Standards

Planning is a rational process for formulating and attaining objectives. The objectives are intended to guide the preparation and evaluation of alternative plans, and the selection of recommended plans from among the alternatives considered. The comprehensive plan and its various elements should be clearly related to the defined objectives through a set of quantitative standards. The formulation of objectives should involve the active participation of public officials, business and industrial leaders, and citizens and citizen groups.

Some planners make a distinction between the terms *goals* and *objectives*. Under this distinction, the goals are defined as ideal ends toward which the planning process is directed. Objectives are defined as the realistically obtainable ends toward the attainment of which plans and policies are directed. In any case, it should be understood that goals and objectives may change over time as new information is developed, as objectives are achieved through plan implementation, or as objectives fail to be achieved owing to changing public attitudes and values. The objectives should recognize the economic, social, and physical development and redevelopment aspirations of the community, and should include environmental quality objectives. These latter may include a safe and sustainable water supply adequate to meet domestic, industrial, recreational, and firefighting needs; adequate sewage and other wastewater collection, treatment, and disposal facilities; adequate drainage and flood-control facilities; water and air pollution abatement; proper solid waste collection, reduction, treatment, and disposal; adequate parks and outdoor recreational facilities; noise abatement and control; a safe, convenient, and efficient transportation system; decent, safe and sanitary housing; elimination of sources and causes of diseases such as mosquitoes, ticks, black flies, rats, and other vectors; adequate schools; adequate hospitals and other medical care facilities; and adequate power and communication facilities.

Identification of Development Requirements

Any development plan must, to the extent possible, anticipate future requirements as a basis for the formulation of alternative plans and the selection of a recommended plan. Therefore, in the comprehensive planning effort, forecasts are required of future events and conditions that lie outside the scope of the system to be planned. The future demand for land and facilities will depend, to a considerable extent, on the size of the future population and the number of households, and on the nature of future economic activity. Therefore, future

levels of population, households, and economic activity must be forecast. These forecast levels can then be used to determine the probable future demand for the various land uses and for the supporting infrastructure facilities. This is not to say that public policies at the local level cannot influence the course of economic development and, consequently, of population and economic activity growth rates.

Development and Evaluation of Alternative Plans

Having forecast the probable future demand for the various land uses and supporting facilities, alternative plans that meet those demands can be developed. The alternative plans should be evaluated based on their relative ability to obtain the agreed upon development objectives. This is done through the application of quantitative standards that relate the objectives to physical development. The plan that is judged best to meet those objectives should be selected for adoption.

Plan Selection and Adoption

The plan that is judged best to meet the agreed-upon development objective, together with the alternative plans considered, should then be subjected to intensive public review. The public should be involved in the review of the preferred plan and of the alternatives considered through such techniques as the creation and use of advisory committees, public educational programs; and presentation at a series of well-organized public informational meetings supported by the dissemination of information about the plans and the planning process. Special briefings on the plan should be held with cognizant elected and appointed public officials and interested and concerned business and community organizations. In this respect it should be noted that one of the most meaningful ways of providing public participation in the planning process is through the plan commission itself, which directs the work and which should contain citizen members.

The public participation process should culminate in a formal public hearing, or hearings. Based upon the testimony presented at the hearing, or hearings, the preliminarily preferred plan may be revised prior to presentation to the plan commission and governing body concerned for consideration and adoption. This may result in further changes to the plan. Following its adoption the plan should be certified to the appointed public officials responsible for implementation, and as may be necessary to concerned state and federal agencies.

Following plan adoption, the plan commission should guide plan implementation, and monitor changing conditions in the planning area that might affect the structure of the adopted plan. Observed changes in conditions that would require changes in the forecasts upon which the plan is based should initiate a plan review and revision process, as should failure to implement key recommendations in the plan. In any case, the adopted plan should be reevaluated and revisions considered at a minimum of ten-year intervals.

Plan Implementation and Policy Development

Implementation of adopted public plans usually involves the application of several planning tools of a legal and administrative nature. Land subdivision regulations are used to assure that any proposed land subdivision plats conform to the adopted plans with respect to both the proposed land uses to be accommodated, and to such details as street, block, and lot layout, and required infrastructure improvements. The zoning ordinance and attendant zoning district map are used to legally assure that private development and redevelopment occur in conformance with the adopted plans. The zoning regulation should govern the types of the various land uses permitted in the various parts of the planning area; the height and arrangement of buildings on the land; the intensity of use of the land; and the supporting facilities required; all as necessary to carry out the intent of the adopted plans. An official map is used to assure that the land required for proposed streets, parks, and parkways included in the adopted plan is reserved for public use.

A building code sets forth detailed standards and regulations for the construction and alteration of buildings, including materials of construction; structural and fire safety; light and ventilation; and electrical, heating and air conditioning and plumbing facilities. The building code provides authorization for construction plan and specification review, approval of construction and alterations, and the issuance of occupancy permits.

A sanitary code sets forth standards and regulations for the following:

- Disease control
- Qualification of personnel responsible for the operation of food services
- Safe water supply, wastewater disposal, air-pollution prevention
- Solid waste management
- Food, including milk, sanitation
- Radiation
- Noise
- Disease vectors
- Hospitals, nursing homes, and other institutions
- Schools, camps, and resorts
- Bathing beaches and swimming pools
- Occupational health and other preventative measures required to ensure the protection of public health

A housing code sets forth standards and regulations for the provision of decent safe and sanitary dwellings; for necessary utilities and services; occupancy; and maintenance. All of these codes authorize inspection to determine compliance, and are intended to promote the public health, safety, and welfare.

A capital improvement program is used to guide the investment of public funds in improvements that carry out the adopted plan. Project priorities are

established. Approximate costs are estimated, and sources of revenue and means for financing are determined. The estimated costs should include operation and maintenance costs, as well as capital costs. The program is usually prepared for a five-year period into the future. When the governing body of the municipality concerned considers the annual budget for the next calendar or fiscal year, the first year of the capital improvement program is considered for incorporation into the adopted budget, either as proposed or as may be modified by the budget deliberations. At that time, the remaining four years of the capital improvement program are reviewed and an additional year added, so that the program always looks at least five years ahead.

The program should consider all public works construction contemplated by the municipality concerned, and should coordinate such construction within the municipality concerned, and with county, state, and private utility construction. Moreover, the proposed public works construction projects should be coordinated with committed and contemplated public and private land use development projects. Programs should incorporate (as may be appropriate) probable state and federal funding assistance, special assessment and impact fee revenues, and the local tax burden. The program should treat the public works infrastructure as an asset, and should provide for the timely maintenance of existing facilities, as well as the construction of needed new facilities.

The preparation of a capital improvement program requires a working knowledge of engineering economics and of the financing of municipal improvements. Such financing may involve the use of revenue, general obligation and special assessment bonds, and taxes and other revenues. If bonding is used, the effects of debt service on the program must be considered. State laws will usually impose specific limitations on the amount of debt that a municipality may incur. Such debt limits are often set at a percentage of the average full value real property assessment of the municipality concerned. Sometimes, indebtedness for an essential revenue-producing service, such as water supply, may be excluded from such state limitations.

General obligation bonds are issued by a governmental agency such as a municipality. Repayment is guaranteed through the municipal power of taxation. Revenue bonds are repaid from a special source of revenue, such as water service, sewer service, or toll bridge and toll road charges. The cost of the service made possible by the bond issue is, thereby, directly related to the monthly, quarterly, or annual billing for a specific service. Revenue bonds are not backed by the full credit of the municipality. Therefore, interest rates may be somewhat higher than for general obligation bonds.

Although these legal and administrative plan implementation actions are primarily the prerogative of county and municipal governments, federal and state regulations may also be involved. The protection of floodways and floodplains; the delineation of areas to be served, by public sanitary sewer and water supply facilities; the location, capacity, and level of treatment to be provided by wastewater and water treatment plans; and the protection of woodlands and wildlife habitat areas, are often specified by federal and state legislation and attendant

regulations. Federal grants for the improvement of highway and transit facilities in metropolitan areas require the preparation and adoption of transportation system plans and of capital improvement programs that serve to implement such plans.

PUBLIC WORKS DEVELOPMENT PROCESS

The foregoing description of capital improvement programming clearly implies that plan implementation will involve the development of the public works infrastructure required to support planned land-use development, as well as the application of legal and administrative devices. The public works development process should take place in three successive stages:

1. System planning
2. Preliminary engineering
3. Final engineering and construction

Most public works facilities are composed of integrated systems, and each existing and each new facility must function as an integral part of the system concerned—transportation, sanitary sewerage, stormwater management, flood control, parks, and open space. The systems planning stage will often involve the application of mathematical models that can be used to simulate the performance of the system concerned, and the systems planning process should be accomplished as an integral part of the comprehensive planning process. System plans for sanitary sewerage water supply and stormwater management are often termed *facility plans*. If such plans are developed outside of the comprehensive planning process, the effort may require heroic assumptions to be made concerning future population, household, and employment levels, and future land-use patterns within the service areas concerned; as well as about such matters as surface and groundwater quality objectives and the sustainability of water supply sources. Outlines for typical sewerage, stormwater management, and water-supply facilities planning reports follow.

Outline for a Sewerage Facilities Planning Report

I. Introduction

- A. Purpose of planning effort and plan report
- B. Brief description of planning area
- C. Impetus and authority for planning effort
- D. Description of sewerage system planning and development process
 1. Areawide framework plan
 2. Facilities plan
 3. Preliminary engineering plans
 4. Final engineering and construction
 5. Required approvals

II. Historic Studies and Plans

- A. Pertinent areawide framework plan recommendations
 - 1. Service area
 - 2. Treatment
- B. Pertinent local plans
 - 1. Land use and zoning
 - 2. Utility service
 - 3. Stormwater management

III. Description of Existing Conditions

- A. Available mapping
 - 1. Survey control and datums
 - 2. Topographic maps
 - 3. Cadastral maps
 - 4. Parcel-based land information systems
- B. Demographic
 - 1. Population—historic and existing
 - a. Levels
 - b. Distribution and densities
 - c. Seasonal
 - 2. Households—historic and existing
 - a. Size and numbers
 - b. Distribution
 - c. Type, including group quarters
 - d. Seasonal
- C. Employment
 - 1. Type
 - 2. Distribution
 - 3. Special industrial and institutional
- D. Land use—historic, existing, planned
- E. Topography and drainage patterns
- F. Geology and depth to bedrock
- G. Soils
 - 1. Suitability for development with convention septic tanks
 - 2. Suitability for development with mound systems
 - 3. Suitability for development with sewer systems
- H. Climate and weather
 - 1. Rainfall and snowfall
 - 2. Temperature
 - 3. Wind
 - 4. Frost depth

- I. Physical, chemical, biological, and hydrological characteristics of receiving water
- J. Characteristics of municipal and industrial wastewater volumes, strengths, flow rates
- K. Existing sanitary and combined sewer facilities
 - 1. Location, configuration, service areas, and capacities of conveyance and storage facilities
 - a. Trunk sewers
 - b. Collection sewers
 - c. Manholes
 - d. Junction chambers
 - e. Pumping stations
 - f. Storage facilities
 - (1) Near surface
 - (2) Deep tunnel
 - g. Pumping stations
 - 2. Location, type, capacities, and performance of treatment facilities
 - 3. Existing flows and related problems such as surcharging and basement backups
 - 4. Surface and groundwater quality impacts
- L. On-site sewage disposal facilities—septic tank systems and holding tanks
 - 1. Number and age
 - 2. Distribution and densities
 - 3. Soil suitability
 - 4. Sanitary records
 - 5. On-site inspections results
 - 6. Well water testing
 - 7. Leachate detector surveys
 - 8. Household questionnaire surveys
- M. Water supply facilities and service area
- N. Stormwater management facilities and drainage areas
- O. Natural resource base
 - 1. Surface water
 - a. Use objectives
 - b. Quality conditions
 - (1) In stream quality
 - (2) Fishery resources
 - (3) Benthic organisms
 - (4) Aquatic habitat

- c. Sources of pollution
 - (1) Point
 - (2) Nonpoint
- 2. Groundwater
 - a. Depth to water table
 - b. Quality
- 3. Floodlands
- 4. Wetlands
- 5. Woodlands
- 6. Wildlife habitat
- 7. Environmental corridors
- P. Archaeologic and historic sites
- Q. Problems and needs with geographic differentiation
 - 1. Surcharging
 - 2. Basement backups
 - 3. Sanitary sewer overflows
- R. Water pollution control requirements; federal, state and interstate receiving water classifications and efficient standards

IV. Forecast of Future Conditions to Design Year

- A. Demographic
 - 1. Population
 - a. Levels
 - b. Distribution and densities
 - c. Seasonal
 - 2. Households
 - a. Size and number
 - b. Distribution
 - c. Type, including group quarters
 - d. Seasonal
- B. Employment
 - 1. Type
 - 2. Distribution
 - 3. Special industrial

- C. Land use

- D. Problems and needs with geographic differentiation

V. Sanitary Sewerage Objectives, Standards, and Design Criteria

- A. Objectives and supporting standards
 - 1. Quantity management
 - 2. Quality management
 - 3. Land-use relationship

B. Design criteria**1. Flows**

- a. Per capita sewage contribution by size of contributing area
 - (1) Average daily
 - (2) Peak daily
 - (3) Instantaneous peak
- b. Clear water infiltration by size of contributing area
 - (1) Average daily
 - (2) Peak daily
 - (3) Instantaneous peak
- c. Clear water inflow by size of contributing area
 - (1) Average daily
 - (2) Peak daily
 - (3) Instantaneous peak
- d. Waste water reduction, reclamation and reuse
- e. Total flows by size of contributing area
 - (1) Average daily
 - (2) Peak daily
 - (3) Instantaneous peak

2. Hydraulics of gravity and pressure flow sewers

- a. Computational methodologies
- b. Flow to depth relationships
- c. Minimum size
- d. Minimum grade and velocity
- e. Minimum depth

C. Pumping and lift stations**VI. Alternative Plans****A. General description of alternatives**

- 1. On-site sewage disposal
- 2. Conventional gravity flow sewerage systems
- 3. Pressure flow sewerage systems

B. On-site treatment and disposal**1. Description**

- a. Replace existing systems
- b. Mound system
- c. Holding tanks
- d. Aerobic systems

2. Performance and environmental impacts**3. Costs**

- C. Centralized treatment and disposal—may have multiple alternatives and may include pressure flow as well as gravity flow systems
 - 1. Description
 - a. Collection
 - b. Conveyance
 - c. Storage
 - d. Treatment
 - (1) Pollution loads
 - (2) Degree of treatment required
 - (3) Land requirements and buffer zones
 - (4) Outfall sewer
 - (5) Sludge disposal
 - e. Flows
 - 2. Performance evaluation—simulation modeling
 - 3. Environmental assessment
 - 4. Costs
 - a. Capital
 - b. Operating and maintenance
 - D. Comparative evaluations of alternatives considered
 - 1. Costs
 - a. Capital
 - b. Operation and maintenance
 - c. Present worth
 - d. Cost effectiveness
 - 2. Attainment of objectives and standards
 - 3. Environmental impacts
- VII. Recommended Plan**
- A. Description
 - B. Performance and environmental assessment
 - C. Costs
 - 1. Capital
 - 2. Operation and maintenance
 - D. Implementation
 - 1. Institutional structure
 - 2. Procedure
 - a. Plan adoption
 - b. Capital improvement programming, financing, and cost allocation
 - c. Preliminary engineering
 - d. Final engineering and construction

- e. As-built documentation
- f. Operation and maintenance

VIII. Public Participation

- A. Cognizant authority structure
- B. Advisory committee
- C. Public information meetings and hearing
- D. Reflection in recommended plan

Outline for a Stormwater Management Facilities Planning Report

I. Introduction

- A. Purpose of planning effort and plan report
- B. Brief description of planning area
- C. Impetus and authority for planning effort
- D. Description of stormwater management planning and development process
 - 1. Areawide framework plans
 - 2. Local system plans
 - 3. Preliminary engineering
 - 4. Final engineering and construction
 - 5. Required approvals
- E. Basic concepts involved in storm water management planning
 - 1. Difference between stormwater management and flood control planning
 - 2. Areawide flood control plans
 - 3. Major and minor storm water drainage systems
 - 4. Performance simulation
 - 5. Relation of sanitary sewerage and stormwater management system planning and performance
- F. Planning approach
 - 1. Cognizant public body oversight and guidance
 - 2. Public participation
 - 3. Adoption

II. Historic Studies and Plans

- A. Introduction
- B. Pertinent areawide framework plans
 - 1. Land use
 - 2. Flood control
- C. Pertinent local plans

1. Land use and zoning
2. Utility service
3. Drainage

III. Stormwater Management System Components

- A. Introduction
- B. Drainage components
 1. Overland flow
 2. Collection
 - a. Drainage swales
 - b. Roadside ditches
 - c. Roadway curbs and gutters
 - d. Stormwater inlets
 - e. Stormwater catch basins
 3. Conveyance
 - a. Open channels
 - b. Culverts
 - c. Sewers
 - d. Manholes
 - e. Junction chambers
 - f. Outfalls
 - g. Pumping stations
 4. Storage facilities
- C. Water quality management components
 1. Infiltration devices
 2. Sedimentation—floatation basins
 3. Outfall treatment
 4. Construction erosion control
 5. Street sweeping and litter control
 6. Leaf collection
 7. Wetlands
 - a. Natural
 - b. Constructed

IV. Description of Existing Conditions

- A. Introduction
- B. Available mapping
 1. Survey control and datums
 2. Topographic maps
 3. Cadastral maps
 4. Parcel-based land information systems

- C. Land use—historic, existing, planned
- D. Geology and depth to bedrock
- E. Soils
 - 1. Suitability for development
 - 2. Hydrologic classification
- F. Climate and weather
 - 1. Rainfall and snowfall
 - 2. Temperature and seasonal considerations
 - 3. Snow cover and frost depth
- G. Sanitary sewerage
 - 1. Service areas
 - 2. Facility configuration
 - 3. Areas of surcharging and basement flooding
- H. Existing flood control and storm water management systems
 - 1. Topography and drainage patterns
 - 2. Flood stages and inundation areas along receiving streams
 - 3. Overland flow paths
 - 4. Street cross-sections
 - a. Rural—ditches and swales
 - b. Urban—curbs and gutters
 - 5. Storm sewers
 - a. Sewers, manholes, and junction chambers
 - b. Inlets
 - c. Catch basins
 - d. Pumping stations
 - e. Outfalls
 - 6. Roadside ditches and culverts
 - 7. Drainage channels
 - 8. Storage
 - 9. Off-street culverts
 - 10. Catchment areas and subbasins
 - 11. Pollution control facilities
- I. Natural resource base
 - 1. Surface water
 - a. Use objectives
 - b. Quality conditions
 - (1) In-stream quality
 - (2) Fishery resources
 - (3) Benthic organism
 - (4) Aquatic habitat

- c. Sources of pollution
 - (1) Point
 - (2) Nonpoint
 - (a) Agricultural runoff
 - (b) Urban runoff
 - (c) Leaks and spills
 - (d) On-site sewage disposal
 - 2. Groundwater
 - a. Depth to water table
 - b. Quality
 - 3. Floodlands
 - 4. Wetlands
 - 5. Woodlands
 - 6. Wildlife habitat
 - 7. Environmental corridors
 - J. Archaeologic and historic sites
 - K. Existing storm water drainage problems
 - 1. History of significant rainfall events
 - 2. Areas of ponding and inadequate drainage
 - a. Location and extent
 - b. Relation to sanitary sewerage system surcharging and backup
 - c. Monetary damages
 - L. Summary and conclusions
- V. Stormwater Management Objectives, Standards, and Design Criteria**
- A. Objectives and supporting standards
 - 1. Quantity management
 - a. Minor system, 10-year recurrence interval level of protection
 - b. Major system, 100-year recurrence interval level of protection
 - 2. Quality management
 - 3. Land-use relationship
 - B. Analytical procedures and design criteria
 - 1. Rainfall intensity—duration—frequency data
 - 2. Time distribution of design rainfall
 - 3. Hydraulic design criteria
 - a. Open channel flow
 - b. Inlet capacity
 - c. Piped flow
 - d. Culvert flow

C. System performance simulation

1. Flow delivery
2. Pollutant delivery
3. Flow control
4. Pollutant control

D. Assumptions

1. Site grading
2. Street cross sections
3. Open drainage channels
4. Outlet conditions

E. Summary

VI. Performance Evaluation of Existing System

A. Introduction

B. Comparative evaluation of existing hydraulic capacities and anticipated stormwater flows

1. Minor system
2. Major system

C. Identification of problem areas

1. Structure flooding
2. Yard flooding
3. Street flooding
4. Relationships to sanitary sewer system surcharging

D. Evaluation of nonpoint source pollutant abatement characteristics of existing system and required pollutant reductions

E. Summary and conclusions

VII. Design of Alternative Stormwater Management System Plans

A. Introduction

B. Alternative measures

1. Structural measures for drainage and pollution abatement
 - a. Storm sewer conveyance
 - b. Roadside ditch and swale conveyance
 - c. Centralized detention
 - d. Decentralized, on-site detention
 - e. Centralized retention
 - f. Decentralized, on-site retention
 - g. Wetland storage
 - h. Outfall treatment
2. Nonstructural measures for pollution abatement

C. Alternative stormwater drainage system plans considered

1. Maximum conveyance alternative
 - a. Configuration
 - b. Capacity
 - c. Performance
2. Maximum storage alternative
 - a. Configuration
 - b. Capacity
 - c. Performance
3. Composite alternative
 - a. Configuration
 - b. Capacity
 - c. Performance
4. Comparative evaluation of alternatives considered
 - a. Costs
 - (1) Capital
 - (2) Operating and maintenance
 - (3) Cost effectiveness
 - b. Attainment of objectives and standards
5. Selection of preliminary recommended system plan
 - a. Configuration
 - b. Performance

VIII. Recommended Stormwater Management System Plan

- A. Integration of preliminary recommended storm water drainage, sanitary sewerage, and water quality management plans
- B. Description of recommended drainage component
 1. Configuration
 - a. Minor drainage system
 - (1) Overland flow
 - (2) Curb and gutter street cross sections and locations
 - (a) Inlets and catch basins
 - (b) Sewers
 - (c) Storage
 - (d) Outfalls
 - (e) Open channels
 - (3) Rural street cross-sections and locations
 - (a) Roadside ditches
 - (b) Parallel culverts
 - (c) Cross culverts

- (d) Storage
 - (e) Open channels
 - b. Major drainage system
 - (1) Flow paths
 - (2) Storage and areas of inundation
 - (3) Storage
 - 2. Capacity
 - 3. Performance
 - 4. Cost
 - a. Capital
 - b. Operating and maintenance
- C. Description of recommended water pollution abatement component
 - 1. Configuration
 - a. Structural measures
 - (1) Infiltration
 - (2) Sedimentation—flotation basins
 - (3) Outfall treatment
 - b. Nonstructural measures
 - (1) Constructions erosion control
 - (2) Street sweeping and litter control
 - (3) Leaf collection
 - (4) Wetlands
 - 2. Capacity
 - 3. Performance
 - 4. Cost
 - a. Capital
 - b. Operating and maintenance
- D. Performance and environmental impacts
 - 1. Ability to meet objectives and standards
 - a. Land use
 - b. Hydrologic and hydraulic performance
 - c. Water quality management performance
 - d. Cost effectiveness
 - e. Environmental impacts
 - 2. Relationship to adopted areawide flood control plans
- E. Summary

IX. Plan Implementation

- A. Introduction
- B. Institutional structure

1. General-purpose municipal government
 2. Stormwater utility district
 - C. Procedure
 1. Plan adoption
 2. Capital improvement programming, financing and cost allocation
 3. Preliminary engineering
 4. Final engineering and construction
 5. As-built documentation
 6. Operation and maintenance
 - D. Capital improvement program
 1. Prioritization of required capital improvements and sequencing of projects
 2. Financing and cost allocations
 - E. Regulatory consideration
 1. Stormwater management ordinance
 2. Administrative code and ordinance requirements
- X. Summary

Outline for a Water Supply Facilities Planning Report

- I. **Introduction and Background**
 - A. Background
 - B. Study area
 - C. The water supply planning program
 1. Previous planning efforts
 2. Initiation of water supply planning program
 3. Plan purpose
 4. Relationship to other planning program
 5. Staff, cooperating agencies, consultants, and committee structure
 6. Plan presentation and organization
- II. **Description of the Planning Area**
 - A. Manmade features
 1. Regional setting of watershed and political boundaries
 - a. Civil divisions
 - b. Special-purpose units of government with water supply management responsibilities
 2. Demographic
 - a. Demographic base
 - b. Population and housing unit size and distribution
 3. Economic base

4. Land use
 - a. Historical development
 - b. Existing land use
5. Public and private utility base
 - a. Sanitary sewer service
 - b. Water supply service
- B. Natural resource base
 1. Topographic and physiographic features
 - a. Topographic maps
 - b. Cadastral maps
 - c. Survey control and datums
 - d. Geology
 2. Soils
 3. Vegetation
 - a. Wetlands
 - b. Woodlands
 - c. Grasslands
 - d. Natural and critical plant species areas
 4. Surface-water resources
 - a. Streams
 - b. Lakes
 - c. Floodlands
 5. Groundwater resources
 6. Fish and wildlife resources
 - a. Fish and aquatic life
 - b. Wildlife habitat
 7. Park and open space sites
 8. Environmental corridors

III. Existing Water Supply Conditions in the Region

- A. Water Supply Sources
 1. Groundwater
 - a. Shallow Aquifer
 - (1) Water uses
 - (2) Aquifer-quantity characteristics
 - (3) Water-quality characteristics
 - b. Deep aquifer
 - (1) Water uses
 - (2) Aquifer-quantity characteristics
 - (3) Water-quality characteristics

- 2. Surface water
 - a. Availability
 - b. Quality
- B. Existing Water Supply Facilities
 - 1. Public utility
 - 2. Private utility
 - a. Industrial
 - b. Commercial
 - c. Agricultural
 - d. Domestic (residential)

IV. Legal Structures Affecting Water-Supply Planning

- A. Water law
 - 1. Surface water
 - 2. Groundwater
 - 3. State water-supply regulations
 - 4. Source water assessment requirements
 - 5. Water-supply facility requirements
 - 6. Other related state water-quality management regulations
- B. Local water-supply management regulations and policies

V. Water-Supply Management Objectives and Standards

- A. Basic concepts and definitions
- B. Water-supply planning objectives
- C. Design and planning standards for water supply facilities
 - 1. Water demand standards
 - a. Residential demand
 - b. Commercial demand
 - c. Industrial demand
 - d. Public demand
 - e. Firefighting demand
 - f. Unaccounted for water
 - g. Water used in treatment
 - 2. Water quality standards
 - a. Raw water
 - b. Finished water
 - 3. Water system design standards
 - a. Design objective
 - b. Water demand standards
 - (1) Peak day to average day pumpage ratio
 - (2) Peak hour to peak day pumpage ratio

- (3) Distribution system pressures
 - (4) Fire flow considerations
 - c. Pumping and storage standards
 - (1) Source capacity
 - (2) Peak hour storage
 - (3) Fire flow
 - (4) Emergency supply
 - d. Main looping and sizing
- 4. Cost-effectiveness analysis
- D. Other related land and water-resource management planning objectives and standards

VI. Analysis and Forecasts

- A. Population
- B. Households
- C. Employment
- D. Land-use demand
- E. Water supply service areas
- F. Forecast water uses and evaluation of existing systems
 - 1. Public utility
 - 2. Private utility
 - a. Industrial
 - b. Commercial
 - c. Agricultural
 - d. Domestic (residential)
- G. Groundwater systems
 - 1. Shallow aquifer
 - 2. Deep aquifer
 - 3. Groundwater contamination potential analysis
 - 4. Important groundwater recharge areas
 - 5. Groundwater quantity and sustainability analysis
- H. Surface water systems

VII. Problem Identification and Issues to Be Addressed

- A. Problem identification
 - 1. Groundwater quantity and quality
 - a. Shallow aquifer
 - b. Deep aquifer
 - 2. Surface water quantity and quality
 - 3. Groundwater–surface water interrelationships

B. Issues to be addressed

1. Groundwater sustainability and relationships to areas of groundwater recharge and use
2. Groundwater quality
3. Surface water quantity sustainability
4. Surface water quality
5. Relationship of water supply to land use
6. Groundwater–surface water issues
7. Relationship of water-supply systems to sanitary sewerage systems

VIII. Future Scenarios and Alternative Plan Descriptions and Evaluation

A. Applicable water-supply management measures

1. Water conservation
2. Preservation of groundwater recharge areas
3. Groundwater supply options
4. Surface water–supply options
5. Water-supply system optimization
6. Water-supply system interconnection
7. Water-supply treatment
8. Options for areas outside water-supply service areas

B. Alternative plan 1—expansion of existing systems with current groundwater use and probable loss of recharge areas

C. Alternative plan 2—expansion of existing systems with high level of water conservation and recharge area protection

D. Alternate plan 3—expansion of existing systems using existing sources

E. Alternate plan 4—expansion of existing systems using groundwater sources

F. Alternate plan 5—expansion of existing systems using surface water sources

G. Alternate plan 6—combination alternatives

H. Evaluation of alternative water supply plans

1. Evaluation criteria
2. Cost analysis
3. Nonmonetary factors analysis
4. Ranking of alternatives

I. Description of preferred alternative combination plan

IX. Recommended Water Supply Plan

A. Public reaction to the preliminary recommended regional water supply plan

B. Final recommended regional water supply plan

C. Relationship of recommended plan to identified water supply issues

X. Plan Implementation

- A. Basic concepts and principles
- B. Plan implementation organizations
 - 1. Local agencies
 - 2. Areawide-level agencies
 - 3. State agencies
 - 4. Federal agencies
 - 5. Private concerns
- C. Plan adoption and integration
- D. Financial and technical assistance
- E. Subsequent adjustment of the plan and continuing planning process
- F. Summary

XI. Summary and Conclusions

- A. Study organization and purpose
- B. Recommended water supply plan
- C. Plan implementation
- D. Resolution of major issues
- E. Conclusions

PUBLIC PARTICIPATION

For comprehensive plans to be effective, it is necessary that the planning process provides for public participation during important stages in the process. Increasingly, citizens of more economically prosperous and technically advanced nations are demanding, as a fundamental right, not only clean air and pure water and food, but also decent, safe, and sanitary housing; unpolluted land; freedom from excessive noise and glare; adequate outdoor recreational facilities; and communities that provide convenient access to work, shopping, medical services, and educational opportunities. The historic, single purpose type of planning for highway, sanitary sewerage, water supply and drainage and flood control facilities, and for development projects should be set within a comprehensive approach, and thereby broadened to consider a full range of the potential economic, social, and environmental effects produced by the proposed development projects. The planning efforts must ensure that potential problems are avoided in the planning stages; that the solution of one pollution problem is not transferred from one medium to another, such as from water to land; and that projects are designed so as to enhance the overall quality of life.

Public participation is particularly important in the initial formulation of the scope and content of a proposed planning effort; in the formulation and development objectives and standards; in the formulation and evaluation of alternatives, and in the selection of recommended plan elements. Public participation can result in plan improvement, and in implementation programs that achieve agreed upon

development objectives. Public participation is not only a critical function in comprehensive planning, but must also be a part of subsequent plan implementation efforts through the preliminary and final engineering phases.

Public participation can be achieved through various means. One of the most meaningful means is through the composition of official planning bodies such as city plan commissions. The composition of such planning bodies should include the chief executive of the municipality concerned, who should serve as chairman of the planning body, a member of the legislative body of the municipality concerned, and a number of qualified citizens. The director of the planning staff should not be a member of the planning body, but together with the municipal engineer, should constitute the necessary technical advisors to the planning body. Other forms of public participation may include informational meetings and public hearings. Behavioral observational and attitudinal surveys can constitute particularly objective and meaningful means for public participation in the planning process.

Informational meetings should be held with concerned interest groups, as well as with the general public. Such meetings should be carefully planned in order to provide the citizens concerned with the essential information necessary for intelligent participation in the planning work. The process should be supported by newsletters and Internet web sites, as well as through plan commissioners and staff presentations to business, civic, and environmental organizations. Special efforts should be made to bring community leaders into the public participation process. Although state law may specify the means by which public hearings must be advertised, efforts should be made to contact community leaders directly in order to encourage attendance at the hearings.

Good minutes should be kept of the public hearings, and the public reaction to alternative and recommended plans summarized in the planning reports. Sincere efforts should be made to address the issues raised and comments made at the hearings.

CONTINUING NATURE OF COMPREHENSIVE PLANNING PROCESS

The comprehensive planning process should be viewed as a continuing, cyclical process, alternating between comprehensive planning and project planning. With respect, for example, to transportation facility development and management, plan proposals are initially advanced at the areawide, systems level of planning. Attempts are then made to implement the plans through local project planning. If, for whatever reasons, a particular facility construction or management proposal advanced at the areawide systems level of planning cannot be implemented at the local project level, that situation must be taken into account in the next round of systems level planning. Similar situations may exist in land use, park and open space, flood control, and water-pollution-abatement planning, among others. In addition to monitoring the success in plan implementation—or lack thereof—the continued validity of the basic data, analyses, and forecasts and of

the objectives and standards upon which the plans are based should be continually monitored, and the plans revised as may be found necessary by the findings of the monitoring efforts. In any case, plans should be reviewed and revised at approximately 10-year intervals.

Community development objectives and goals may be expected to change with time. New land-use concepts; means of transportation; housing needs and designs; economic, technological, and sociological developments; and changing public aspirations require periodic reevaluation of the comprehensive plan, and revisions of the plan as may be indicated. Keep in mind that human wants are insatiable; as soon as an objective is approached, or reached, another will be sought. This tendency should be kept within realistic bounds, however, and continuing planning should help to accomplish this.

Not be forgotten, is the continuing need for the extension by the planning agency of information, and of descriptions of plans and plan proposals to federal, state, and county agencies; to school districts; to other municipalities; to other sister departments such as public works and engineering, police and fire protection, and tax assessment; to businesses and industries, realtors, appraisers, developers, utilities, and to the general public. Properly carried out, this extension function can be of major assistance in achieving plan adoption and implementation.

The entire process of comprehensive planning can at best be only of limited value unless provision is made for competent direction, staffing and administration, particularly during plan implementation following plan preparation and adoption. Plan implementing ordinances, improvement programs, codes and rules and regulations have little meaning unless administered by competent personnel who are adequately compensated.

PROJECT PLANNING

Following completion and adoption of the comprehensive plan and the attendant capital improvement program, selected improvement projects can move to more definitive planning and engineering phases. The comprehensive planning function is the responsibility of municipal, county, and regional planning agencies, utilizing staff and, as may be necessary, consultants. Responsibility for the execution of the preliminary and final engineering phases of plan implementation projects will normally shift to a municipal, county, or state engineering agency, utilizing staff and consultants. If federal or state grants are involved in the funding of the projects, state agencies, such as state departments of transportation, and federal agencies, such as the Federal Highway Administration may become involved in oversight roles.

As the projects move from preliminary engineering into final engineering and construction, the agencies involved in administration of the projects will become involved in such matters as engineering design, right-of-way acquisition; and funding, including establishment of service districts, levying of special

assessments, approval of bond issues, rate setting and debt retirement. Detailed construction plans and specifications must be completed, advertisements for bids issued, and contracts awarded to construction firms. Construction should be under the supervision of a resident engineer employed by the implementing agency. Importantly, upon completion of construction, the owner of the facility concerned should be provided with adequate *as-built* documents. In some cases, the final engineering may require the provision of operating manuals, and consultants may be responsible for placing a facility into operation and training staff for the continued operation and maintenance of the facilities concerned.

In the systems planning stage, general consideration is given to site and right-of-way requirements, and the location and alignment of proposed facilities will be approximate and subject to refinement and detailing in latter stages of development. Accordingly, the types of environmental impacts normally considered are areawide, including the probable impacts of the proposed systems on existing and planned land-use patterns, on travel habits and patterns, on the provision of sewerage and water supply sources, on air and on surface and groundwater quality, and on the natural resource base, including on woodlands, wetlands, floodlands, and prime agricultural areas. Public hearings should be held to solicit public reaction to each of the alternatives considered and to the recommended plan.

For certain types of major public infrastructure development projects, a corridor planning stage may be inserted between the systems planning and preliminary engineering stages. Corridor planning may be required by federal regulations for major transportation system improvement proposals supported by federal grants. In corridor planning, the transportation improvements recommended in the comprehensive plan for certain major travel corridors are reviewed and detailed. If, for example, the comprehensive plan calls for the development of a fixed guideway transit facility in a given major travel corridor of the planning area, corridor planning will consider alternative applicable fixed guideway modes such as busway, light rail, heavy rail, or commuter rail. The alternatives will include a no-build alternative, and will be evaluated in terms of cost-effectiveness and potential environmental impacts. Such corridor planning may also be conducted for major arterial highway, electric power transmission line, and high-pressure gas transmission line development proposals.

As projects move from system planning through preliminary engineering to final engineering and construction, the proposals become increasingly more definitive and detailed. In the preliminary engineering phase, greater consideration will be given to alternative site and right-of-way requirements, and to the horizontal location and vertical alignment of facilities. In transportation improvement projects, consideration will be given to alternative alignments, facility cross-sections and intersection treatments. In sanitary sewerage, drainage and flood control, and water supply development, consideration will be given to alternative locations for storage, transmission, and treatment facilities, and to alternative types of treatment. Environmental factors considered will become more detailed and include consideration of such factors as specific impacts on

existing land uses; wetlands, floodlands, woodlands, and wildlife habitats, as well as of costs attendant to alternative facility alignments, and treatment options. At the preliminary engineering stage, no detailed engineering or architectural construction plans are prepared. However, the probable engineering, legal, economic, social, and environmental impacts of each alternative considered are presented together with cost estimates and methods of financing for each alternative. Public meetings and hearings should be held to solicit public reaction to each of the alternatives considered, and to the recommended plan.

Final engineering involves the completion of engineering design, and the preparation of construction plans, specifications, and bid documents. The assessment of environmental impacts and incorporation of environmental protection measures becomes even more detailed in the final engineering stage of a project. For example, the design of a major highway improvement must take into consideration the need for service and rest areas with picnic spaces, adequate sanitary facilities, safe drinking water, insect and weed control, and adequate wastewater and solid waste storage and disposal. It must also consider the effects of impervious surfaces on the quantity and quality of stormwater runoff; potential spills of toxic and hazardous chemicals; accident hazards; landscaping, and buffer zones; and the effects of entrance and exit routes on adjoining urban and rural communities. The long-term control of noise vibration and air pollution; the need for dust and weed suppression; and the control of chemical pesticides and herbicides and other pollutants must be carefully considered, particularly to avoid adverse effects on water supply wells, reservoirs, watersheds and recreational areas, as well as on wildlife and vegetation. Beyond these direct environmental concerns, the potential impacts of the project on community cohesion; population and employment levels, infrastructure costs; urban design and quality of life must be considered. Environmental effects during, as well as after, construction must also be considered, including erosion control, control of noise, vibration, and dust; potential pollution effects on lakes and streams, and on fish and wildlife; and the safe disposal of demolition materials without causing air, water, or land pollution.

SITE PLANNING

Introduction

Comprehensive public planning is generally focused on large planning areas such as entire cities, counties, and metropolitan areas. Urban development and redevelopment normally proceed through the conversion of existing land uses to proposed land uses on discrete sites. Such development must then be preceded by a process known as site planning. Site planning is usually undertaken in response to a perceived market demand for the type of proposed development concerned and is generally conducted in the private, as opposed to public, sector. It should, however, take place within the framework provided by adopted

publically prepared comprehensive city, county or metropolitan plans. Site planning is concerned with site selection and the design of land developments that are economically and environmentally sound.

Site Selection

Site selection for major developments such as large manufacturing plants, major shopping and office centers, recreational and entertainment complexes, research and medical centers, prisons and other detention centers, major electric power generation stations, and military installations usually involves a two-stage process. The first stage will usually be conducted by a multidisciplinary location team retained by the developer—usually a private corporation, but in some instances a public utility or a federal or state agency. In the first stage, relatively large alternative areas may be considered such as—for some types of proposed developments—alternative metropolitan areas; for other types of proposed developments, alternative prime agricultural regions; and for yet others, prime recreational resource areas. Considerations in this initial stage will be primarily economic. The location selection criteria will be primarily cost oriented, involving the following factors:

- Market study findings, labor availability, and costs
- Availability of business and industrial service support, including legal, accounting, and marketing services
- Availability and adequacy of transportation facilities and services, including airport, freeway, and, for some developments, railway and waterway facilities
- In some cases, availability of raw or semimanufactured material sources
- Tax structure and burden

Increasingly, the quality of the infrastructure of the alternative areas being considered will be an important factor, considered together with the available amenities that contribute to a high quality of life. In some cases, the criteria will be primarily functional, such as in the case of electric power-generation facilities and military installations. The kinds of information collected for regional and local comprehensive planning will be most useful to the location teams.

In the second stage of site location for major developments, specific sites within the selected metropolitan area, prime agricultural area, or prime recreational resource area are considered. At this stage, more definitive physical site requirements are defined, including the desirable site size, accessibility to freeway interchanges and airport facilities, and in some cases, accessibility to railway and waterway facilities. The need for sanitary sewerage, water supply, telecommunication electric power and gas service, the need for police and fire protection, and the need for emergency medical service will be specified, together with any special liquid or solid waste disposal requirements, foundation conditions, buffer area needs, and zoning requirements.

Sites for the development of such public facilities as parks and parkways, schools, sewage and water storage facilities and treatment plants, stormwater detention or retention facilities, libraries, police and fire stations, and administrative buildings should be identified on the comprehensive plan. The comprehensive plan should also contain standards for the size of the sites required for the proposed facilities of the type concerned, together with, as may be appropriate, service radii or areas. Thus, the comprehensive plan, if technically sound and valid, greatly facilitates and simplifies that process,

Site Assessment

The site selection process should be followed by a site suitability assessment. This assessment is intended to provide the definitive information required for site design, and to identify any physical, environmental, or regulatory constraints on the design, or any obstacles to site development. The assessment should also provide information on the availability and adequacy of required sanitary sewage and water supply facilities; on the availability and adequacy of electric power, gas and telecommunications facilities; and on the adequacy of the arterial street and highway network serving the site. The assessment should identify the presence of flood hazards, contaminated soils, and contaminated groundwater, and should determine if the site was historically used as a hazardous or other solid waste disposal site. The presence of any old burial areas, areas of archeological and cultural significance, and of any old buried tanks, foundation walls, abandoned wells, active or abandoned agricultural drain tiles, or other structures should be determined. Information required for the assessment will include the location and configuration of the boundaries of the site, the existing land uses on the site, the presence of easements and other encumbrances, the topography as depicted by 1 foot or 2 feet vertical interval contours, the soils and soil characteristics, depths to water table and bedrock, and the presence of wetlands, woodlands, and wildlife habitat areas. Information on the frontages along, and attendant access to, public streets. The relationship of the site to existing and proposed freeway interchanges, public transit stations, and aircraft flight patterns should be determined. The existing zoning and recommendations concerning planned future land uses on the site and environs, as set forth in the comprehensive plan, should be obtained.

Much of the required information should be available from the planning database assembled for, and maintained under, the comprehensive planning process. Obtaining this information in a readily usable format will be greatly facilitated if the county or municipality involved has developed an automated, parcel-based, land information system. The comprehensive planning agency should also be able to provide topographic and cadastral maps, and ratioed and rectified aerial photographs, or ortho photographs, of the site and environs. These maps and photographs can be used, together with real property boundary land survey, to prepare a base map that can be used to display the required information in an integrated and useful manner. Soil survey information,

together with interpretations of the characteristics of the mapped soils for various rural and urban uses, should be available from the U.S. Natural Resources Conservation Service, preferably through the local land information system. U.S. Geologic Survey 1-to-24,000 scale quadrangle maps may be useful in providing a general setting for the site. Such maps are, however, at too small a scale and have too large a contour interval to be useful in a site assessment, or in urban planning, for that matter.

The site assessment should include an inspection by a qualified and experienced engineer. A base map, or aerial photograph, displaying the pertinent information, as collated from the existing sources, should be prepared for use in the field inspection. The purpose of the inspection should be to verify the information shown on that map or photograph. The inspection may include personal interviews with former owners or users of the site, and present owners and occupants of surrounding sites,. Based on the field inspection findings, the map or photograph should be annotated to show any conflicts with existing data shown; desirable features such as attractive overviews, and undesirable features such as unattractive land uses or adjacent sites, should be noted; together with locations of the locations of safe ingress and egress along bordering streets and highways.

Generally Desirable Site Features

The desirable features of a site will depend on the specific intended use. Generally desirable site features, however, will include the presence of ten characteristics or features:

1. An adequate groundwater or surface-water source not subject to pollution that can be developed into a satisfactory supply at an accessible and convenient location on the site if an adequate public water supply is not available. The water supply source should meet federal and state standards.
2. Permeable soils that will readily absorb rainwater, and permit the disposal of sanitary sewage and other wastewater by conventional, on-site, anaerobic subsurface means—septic tanks and drain tile fields—where public sewer service is not available. Depths to watertable, impervious subsoil, or bedrock should be at least 5 feet.
3. Land to be used for the location of buildings and other structures should have soils with suitable load-bearing characteristics, and should be well above flood levels. Ground slopes should normally not exceed 10 percent; slopes of more than 10 percent require careful soil analyses for stability and careful site design.
4. Areas of well-drained, dry land, open to sunshine part of the day, on gently sloping, partly wooded hillsides or ridges. The cleared land should have a firm, grass-covered base to prevent erosion and dust. Slopes having a southern or eastern exposure protected from strong north and west winds are generally desirable.

5. The area of the site should be large enough to provide privacy, avoid crowding, accommodate needed buildings and structures in a well-sited manner, and allow for future expansion. The property should be accessible by automobile; and, for some intended uses, by public transit. For some intended uses, the site should have access to railway and waterway services, and be conveniently located for airport service. Careful attention should be given to traffic conditions on arterial streets and highways serving the site area. Inner-city locations should facilitate ready pedestrian and bicycle, as well as public transit access.
6. For sites intended for certain types of major recreational use, area for the provision of bathing, swimming, and other water sport facilities should be available. The facilities may include a clean stream or lake or an artificial swimming pool. A stream should not have a strong current, or remain muddy during its period of use. An artificial swimming pool equipped with filtration, recirculation, and chlorination equipment may be proposed to advantage.
7. Noxious plants, poisonous reptiles, harmful insects, excessive dust, steep cliffs, old dumps, chemical burial grounds, old mine shafts or wells, dangerous rapids, dampness, and fog should be absent.
8. Availability of centralized public sewerage, water supply, solid waste disposal, police and fire protection, and emergency medical services is desirable and may be essential for some intended uses. Electric power, gas, and telecommunication services should be readily available.
9. An adopted land-use plan and implementing zoning ordinance should provide for the development and protection of the intended use. A modern building construction code vigorously enforced by competent people should be ensured.
10. Air pollution, noise, and traffic problems from adjoining areas should not interfere with the proposed use.

Site Inventory

The information required as a basis for good site planning and design will also depend on the specific intended use. A good site inventory, however, will consist of the following general data collation and collection efforts.

Topography and Site Survey A boundary and topographic survey of the property, at a scale of 1 to 1,200 or larger, with the topography depicted by contours with 1 foot or 2 feet vertical intervals and with roadways, watercourses, wetlands, woodlands, existing structures, powerlines, rock outcrops, and other significant physical features indicated, is essential to the proper study and analysis of a site. If such a survey map is not available, a large scale ratioed and rectified aerial photograph, or orthophotograph may be used.

If a natural bathing and swimming area is to be involved in the intended use, the bathing and swimming area should be sounded and the slope of the

bottom determined. The need for cleaning and removal of mud, rocks, and aquatic growths should be noted. The drainage area tributary to the stream or lake to be used for bathing should be determined, and the probable minimum flow, or level, should be determined to ascertain if an adequate quantity of water will be available during the dry months of the year. Long-term hydrological data, such as provided by U.S. Geological Survey stream gaging stations, would be very valuable in this report.

In most cases, the watershed area tributary to a beach on a stream or lake will extend beyond the boundary of the land under consideration. Therefore, it will be important to determine the existing and planned land uses in the watershed. The existing level of water quality of the streams or lakes concerned, existing and probable future sources of pollution, and probable future levels of water quality should be determined. This should permit determination of whether or not chemical, bacterial, or physical pollution may be expected to make the stream or lake concerned unsuitable for bathing and swimming use, or for water supply purposes. It may be necessary to collect water samples at different times of the year for chemical, physical, and microbiological analyses. Municipal, county, environmental, and agricultural agencies may be able to provide assistance. In addition to satisfactory quantity and quality, the water should be relatively clear and slow moving. Study of the stream bottom, and float or weir measurements to determine the velocity and quantity of water at different seasons of the year will provide supplemental information.

The presence of any flood hazard should be determined. This should involve delineation of the 10- and 100-year recurrence interval flood flows, stages, and attendant inundation areas. Evidence of high-water levels, as indicated by stranded tree trunks and debris; discoloration of rocks and trees; the width, depth, and slope of the stream channel; pertinent highway and railway culvert and bridge waterway openings; and the limits of terrestrial and aquatic vegetation, should be observed.

The presence of old orchards may indicate the presence of pesticide-contaminated soil and groundwater. Municipal, county, and state government agencies should be questioned regarding past agricultural, industrial, and commercial land uses on the site; permits issued; known accidental spill occurrences of toxic and hazardous materials; old dumps; and illegal dumping.

Geology, Soil, and Drainage Detailed, operational soil maps prepared by the U.S. Natural Resources Conservation Service (formerly the U.S. Soil Conservation Service), together with attendant soil properties and use suitability interpretations should be obtained. It may be necessary to obtain soil samples at representative locations to supplement the information provided by the soil maps. Borings should be made to a depth of about 15 feet in order to record variations in the strata penetrated, and the elevation of the groundwater level, if encountered, with respect to the ground surface. Borings may also indicate the depth to bedrock and the presence and thickness of clay or hardpan layers that might interfere with proper drainage, or construction of foundations

for buildings and other structures. Old dump sites will require careful investigation with respect to the presence of toxic and hazardous wastes, groundwater pollution by leakage of septage, leakage of methane with attendant fire hazard, and stability of foundations for buildings, other structures, roadways, driveways, service walks and parking areas. Soil percolation tests may be required to determine the suitability of the site for subsurface sewage disposal, if needed.

If a proposed development is to be located on the side of a long hill or slope, the necessity and feasibility of providing stormwater runoff diversion facilities should be noted. The possibility of erosion and earth slides should be given careful study. Slopes with a greater than 10 percent incline require special engineering study and treatment to control and prevent erosion, slides, and runoff. All wetlands, as defined by federal and state laws and regulations, need to be identified and mapped for consideration in the site design. Where appropriate, wetland mitigation and banking may be considered.

Utilities The need for and existence of centralized sanitary sewerage, water supply, solid waste collection and disposal, electric power and gas, and telecommunications services should be determined. This will indicate the type of on-site services that may be needed.

If an adequate, satisfactory, and safe water supply is not obtainable on- or off-site at a reasonable cost—with or without treatment—further consideration of the site should be abandoned. This is of particular importance in large-scale residential, commercial, industrial and institutional developments that are dependent on the availability of large volumes of safe water.

The probable cost of wastewater collection and treatment should be estimated before any commitment to a site is made. The use classification, minimum flow, and effluent standards for recovering streams and lakes, and water pollution abatement requirements will govern the degree of treatment required, and hence the wastewater treatment facility capital operating and maintenance costs. For large developments, elaborate wastewater treatment plants may be required. For small developments, subsurface sewage treatment and disposal system may suffice if the soil conditions are satisfactory.

The ready availability of centralized electric power for lighting, the operation of water and wastewater pumps, kitchen equipment, refrigerator compressors, and other electrical and mechanical equipment is often taken for granted. If the provision of adequate electric power requires the construction of long transmission lines, the purchase of electric-generating units, or gasoline motor-driven equipment, then the capital, operating, maintenance, and replacement cost should be estimated.

Roads to the buildings and structures forming the intended uses, will be needed for access, for the provision of freight and package deliveries, and for the provision of various maintenance services. The distance from the main arterial roads to the property, the length and condition of secondary roads, and the length and width of access roads within the property should be determined, as well as the

need for culverts and bridges. The traffic generation potential of the intended use should be considered, together with the impacts on the existing street and highway system. Options for alternative sites in urban areas served by public transit facilities should be given weight.

If a proposed electric power generation of industrial plant will cause air pollution, prevailing winds, temperatures, and air-pollution requirements will have to be studied, and the cost of treatment devices will have to be determined in evaluating the suitability of a proposed site. If a plant process will result in the production of large quantities of solid wastes, the treatment and disposal of the residue must also be considered. If a brownfield site involving redevelopment of an urban area is involved, the need for and cost of remedial measures required to restore polluted soil and groundwater should be determined.

Meteorology In North America, slopes having an eastern or southern exposure are preferred for building locations in order to obtain the benefit of the morning sun. This possibility can be ascertained by inspection of available topographic maps and by field inspection. The potential for solar space and water heating should be considered; this will require knowledge of the latitude of the site and of existing and proposed buildings and other structures and of tree growth. Information about the direction of prevailing winds under both summer and winter conditions is valuable. Needed information on maximum, minimum, and average monthly temperatures, humidity, snowfall, and rainfall should be available from federal and state agencies and some water and power companies.

Location The relative location of the property can best be appreciated by marking its outline on planning base maps available from the cognizant municipal or county planning agencies. In the absence of such base maps, a recent U.S. Geological Survey quadrangle map may be used. In this way, the distances to freeway interchanges, airports, railway and bus stations, shopping and employment centers, recreational areas, schools, and medical facilities will be apparent. The plan proposals of municipal, county, and state transportation agencies should be obtained and proposed new or widened arterial street and highway should be marked on the site maps to determine the probable effects of the planned facilities.

Natural Resource Base For large tracts, the presence, location, content, and character of significant elements of the natural resource base should be determined. Much useful natural resource base information can be obtained from municipal, county, state, and federal agencies. The location, size, and type of wetlands, woodlands, and prairies and of economically workable sand, gravel and bedrock formations should be determined.

Broad knowledge and extensive investigation are needed to properly evaluate the presence and importance of animal and plant life on the site and environs and the need for protection and conservation measures. The presence of poison ivy, for example, must be accepted as a potential source of serious skin irritations, and

ragweed and other noxious plants as sources of allergic reactions. It is important to mark the location of any infested areas on the site map so that attention is directed to their existence in the construction and planning program. This would also apply to the presence of mosquitoes, flies, ticks, chiggers, rodents, poisonous reptiles, and dangerous animals. Attention should also be given to the presence of wildflowers, useful reptiles and wild animals, and native trees. The location and extent of rare and endangered species habit should be determined.

Environmental Corridors Beginning with its first regional land use plans proposed and adopted in the early 1960s, the Southeastern Wisconsin Regional Planning Commission advanced the concept of the environmental corridor. This concept was not originated by the Commission, but had its roots in the earliest parkway system planning for Milwaukee County early in the turn of the twentieth century. In the late 1950s, this concept was articulated and advanced in an academic sense by Professor Phillip H. Lewis Jr. of the Department of Landscape Architecture of the University of Wisconsin, Madison. The Commission then advanced the concept in its land-use planning efforts, and thereby accomplished the first practical application of the concept on a regional scale.

Environmental corridors were defined by the Commission as linear areas in the landscape that encompass the most important elements of the natural resource base. Constituting about 17 percent of the 2,700 square mile southeastern Wisconsin region, the corridors encompass about all of the best remaining elements of the natural resource base, including the best remaining woodlands, wetlands, and wildlife habitat areas; surface waters and associated shorelands and floodlands; areas covered by organic soils; areas containing rough topography and significant geological formations; sites having scenic, historic, and scientific value; and areas of groundwater recharge and discharge. The delineation of the corridors required the conduct of detailed inventories of the various elements of the natural resource base, and the integration of the inventory data into an, at first, graphic database, later an automated, geographic information system.

Through its land-use planning efforts, the Commission collected the detailed, definitive information necessary to delineate these corridors, accurately delineated the corridors, and promoted their protection and preservation in essentially natural open uses. The Commission has found the corridors to be essential to the protection and wise use of the natural resource base, to the preservation of the cultural heritage and natural beauty of the region, and to the enrichment of the physical, intellectual, and spiritual development of the resident population of the region. The preservation of the corridors not only helps to ensure the maintenance of the overall quality of the environment in the region, but also helps to prevent the creation of serious and costly environmental and developmental problems. These problems include surface and groundwater pollution; poor drainage and flooding; failing on-site sewage disposal systems; excessive infiltration of clear water into sanitary sewerage systems; wet basements and excessive operation of sump pumps; and settlement and structural failure of roadways, parking areas, utilities, and buildings. Importantly, the corridors help to give form and structure to urban development within the region.

Through the Commission planning efforts, the environmental corridor concept has been institutionalized not only in southeastern Wisconsin but throughout the state of Wisconsin, finding its way into county, and local land-use plans, county and local zoning and land subdivision control ordinances, and state water pollution abatement and sanitary sewer extension regulations, state land acquisition programs for park and resource conservation purposes, and into federal and state wetland protection regulations. The concept of the environmental corridor has become well established in contemporary planning practice within the region.

Improvements Needed

Inasmuch as the ideal site for an intended use is rarely, if ever, found, the work that needs to be done to make the site suitable should be determined. An undesirable feature may, for example, be a low, swampy area on and adjacent to the site. It may not be possible to fill this area unless mitigative measures have been arranged with federal and state regulatory agencies. With careful site design, that swamp may be retained as needed for open space, stormwater storage area, and wildlife preserve. Each possibility and constraint should be examined and reviewed with the regulatory agencies having jurisdiction, the cost of the work estimated, and the probable value of the improvement appraised. Needed clearing, seeding, and reforestation should be considered.

The need for new roads and drives within the site connecting with the existing municipal, county, or state roads is an important consideration. The need for the widening of existing public arterial streets and highways and, for intersection improvements and traffic signalization engendered by the proposed development should be determined. The needed road improvements may involve major earth work and culvert and bridge construction, all of which may mean high costs. Other needed physical improvements may include surface-water diversion ditches, brush clearing, boat docks, parking areas, and the preparation of areas for recreational purposes. All such improvements will have environmental impacts that must be assessed.

Site Design

After a site has been selected and its properties have been inventoried and analyzed, site design may be undertaken. If not already available as a part of the site inventory, this will require a preparation of a property boundary and topographic map of the proposed site at a scale of 1 to 1,200 or larger, with 1 foot or 2 feet as vertical interval contour lines, displaying the information collated and collected in the site inventory and assessment. Desirable and undesirable features of the site should be noted on the map. Alternative plans for the development of the site should then be prepared. The location of buildings; access roads, parking and truck loading and unloading areas; sanitary sewage, water supply, refuse disposal facility locations; and other needed facility locations determined. Particular attention should be given to drainage requirements and to the design of stormwater

runoff conveyance and storage facilities. The alternatives should be evaluated on the basis of costs, effectiveness, and environmental impacts, and a final site plan prepared. For major developments, preparation of a scale model may be desirable. Such a model will help others visualize the proposed buildings and structures to each other and to roadways, streams, lakes, hills, and neighboring land uses. Scheduled public information and participation sessions should be an essential component of the site planning process for major developments.

For major projects a design team consisting of an architect, landscape architect, planner, and engineer should be assembled to prepare the site plan and engineering designs. State, county, and municipal planning and engineering agencies should be consulted on applicable regulations and requirements. Environmental protection and conservation agencies should be consulted about required measures for the protection of the flora, fauna, and ecology of the site and environs, and the need for an environmental impact assessment or environmental impact statement. Such consultation is particularly important when a large housing development, industrial plant, office complex, shopping center, landfill, wastewater treatment plant, hospital, or other major development is contemplated. The agency staff may also be in a position to offer valuable information regarding former uses of the site and possible hazards not readily apparent.

The site plan should show, in addition to the improvements already noted, such other details as may be required by the regulatory agencies having jurisdiction in order to permit their staffs to review and approve the plans. After plan approvals are received and permits issued, contract drawings and specification can be prepared, bids solicited, contracts let, a construction schedule established, and the work carried on in accordance with a preconceived, carefully thought-out plan. There should then be no looking back at useless, inefficient, wasteful structures or spaces; but instead, satisfaction with the realization of a good development.

The importance of obtaining competent professional advice in the site selection and planning process cannot be emphasized too strongly. All too often, developers may seek the cheapest, rather than the best, professional services, while charitable institutions may often solicit "free" engineering and architectural services. This represents poor policy. The consultants so engaged may, for economic reasons, have to conclude the site selection, planning, and design process as quickly as possible; and the recipients of the services may proceed with development on the basis of a possibly inadequately studied site and incompetently conceived plans, detailed drawings, specifications, and contract documents. For major site developments, it may be useful to assemble a committee of outside experts to assist in the selection of the design team, contractors, and construction equipment and techniques; to review plans, specifications, and contracts; and to evaluate bids received. The fee for consultant services, in comparison to the cost of a project, is usually relatively small. Moreover, these fees pale in comparison to the costs associated with such errors as the incorrect sizing of building; the use of improper materials; poor planning and design of equipment and facilities; foundation and structural weaknesses; and bad location or exposure of buildings. When savings

in the selection of proper materials and equipment for minimum long-term maintenance and operating costs, and compliance with plans and specifications, are considered, the savings far outweighs the professional fees involved.

LAND SUBDIVISION

The design of land subdivisions may be viewed as a special case of site planning, often involving large tracts of land ranging in area from 80 acres to 1,200 or more acres. The process of land subdivision may be described as the division of land into smaller parcels, usually for the purpose of urban development. Land subdivision, however, is more than a means of describing, marketing, and taxing land; it is, in effect, the first step in the process of building a community. Much of the form and character of a community is determined by the quality of its land subdivisions. Once land has been divided into blocks and lots, streets constructed, schools and park sites dedicated, and utilities installed, the urban development pattern is established and is unlikely to be changed. Residential, commercial, and industrial structures will be built on the sites created by the land subdivision. After many decades of use, some of the structures may be razed to make way for new structures and, thereby, accommodate new uses. Yet the street pattern established by the initial land subdivision will probably remain basically unchanged. For generations the entire community, as well as the individuals who occupy the subdivision, will be influenced by the quality of its design and by the character of its improvements. Many of the environmental problems that affects communities, such as traffic congestion, drainage, flooding, high street and utility operation and maintenance costs, inadequate park and school sites and facilities, high fire and police protection costs, and urban blight may be directly attributable to the manner in which areas of the community were originally subdivided. Just as important, in this respect, in the design of land subdivisions is the issue of whether or not the areas concerned should have been subdivided at all. The scattering land subdivisions—often referred to as *urban sprawl*—located too far from essential community services such as sanitary storage, water supply, fire and police protection, emergency medical services, public transportation and schools, not only create a less desirable place in which live and work, but also tax the resources of the community in attempting to furnish the necessary public facilities and services. The continued availability of agricultural areas may also be destroyed through scattered land subdivision development. Also important in this respect is the issue of whether an excess of building sites is being created at any one time, thereby leaving the community with scattered, partially developed neighborhoods.

The community is required in one way or another to provide the public facilities and services that make urban life possible. Therefore, the community should be able to require that street rights-of-way and roadway pavements be wide enough to accommodate firefighting, emergency service, solid-waste collection and snow removal equipment; that street configuration, grades, and curves are adequate for the safe movement of traffic, good access to building sites, and snow

storage; that building sites are adequately drained and not subject to flooding; and, if public sanitary sewer facilities are not be provided, that lots are of sufficient size and have soil characteristics that can accommodate on-site sewage disposal facilities without creating a public health hazard. Land subdivisions will have impacts extending beyond the site boundaries and the subdivision itself, and the community should be able to require that the developer bear a fair and proportionate share of required off-site improvement costs, considering the impacts of the proposed subdivision development on arterial traffic, on sanitary sewerage conveyance, storage, and treatment facilities; on water supply transmission, storage, and treatment facilities; on stormwater management facilities; and on school, library, and park facilities. Subdivision development will also have important fiscal impacts. These impacts may be positive or negative, depending on whether the revenues obtained from the new development exceed the costs of the facilities and services to be provided or are less than those costs. In the latter case, some development may results in higher incremental costs of services than the taxable value of the development may provide in revenues. The potential fiscal impacts of a proposed subdivision development warrant careful analysis, even though the developer may be required to pay the costs of all on-site improvement, costs that the developer will pass on to the lot purchasers.

Because land subdivision affects a broad spectrum of interests, and the welfare of the community in many respects, the public regulation of land subdivision has become widely accepted as a function of municipal, county, and state government. Land subdivision regulation is an exercise of control by the community over the conversion of land into building sites. It is through such regulation that the public interest in land subdivision is expressed and directed. Land subdivision regulation is intended to accomplish the following seven purposes:

1. Ensure that proposed land subdivision will fit harmoniously into the existing land-use pattern, and will serve to implement the community comprehensive plan for the physical development of the community.
2. Ensure that adequate provision is made for the necessary and planned neighborhood and community facilities, including parks, access ways to navigable waters, schools, and shopping areas, so that a healthy, attractive, and efficient urban environment results.
3. Ensure that sound standards for the development of land are met with particular attention to such factors as street layouts, widths, and grades; vehicular and pedestrian circulation; park and open space requirements; block configurations and lot sizes; and street, utility, stormwater management, and transit improvements.
4. Provide a basis for clear and accurate property boundary line, demarcations and records. This was the sole purpose of many original state subdivision control enabling acts dating back to the early nineteenth century.
5. Ensure the fiscal stability of the community, minimizing the capital, operating and maintenance costs of public facilities and services, and protecting against the development over time of blighted areas.

6. Promote the public health safety and general welfare.
7. Balance private property rights against the need to protect and preserve the public health safety and general welfare.

The community zoning ordinance relates to the type of building development that can be placed on the land, whereas the land subdivision control ordinance relates to the way in which land is divided and made ready for building development. The purpose of a land subdivision control ordinance should be to ensure compliance with at least minimum standards for sound development, and to prevent further occurrence of the abuses in land development that have occurred in the past.

Because of its importance to sound community development, subdivision design and development is highly regulated. State statutes provide the enabling authority for the exercise of subdivision control at the county and municipal levels. State statutes and administrative codes will usually also provide for the review and approval of proposed land subdivision plats by such state agencies as the departments of transportation and natural resources. State administrative codes will often specify in great detail the survey data that must be shown on final subdivision plats, as well as the levels of precision and accuracy required for the surveys and survey computations on which the plats are based. County and municipal ordinances will usually specify in great detail design standards and required improvements such as of streets, sanitary sewers, water mains, stormwater management facilities, and street trees, lighting, and signing. Approved plats must be recorded with the county register of deeds in order to permit reference to plats in the conveyance of title to real properties, to levy real property taxes, and to prevent fraud. State statutes normally require that the plats be prepared by registered land surveyors, and the surveyors are usually made responsible for the compliance with subdivision control regulations.

Subdivision Design

Land subdivision design is an art requiring a high degree of technical skill and full realization of the importance of the design of the various interests involved and affected. Good land subdivision design requires imagination and creativity, as well as adherence to sound principles of land planning and engineering practices and to sound design and development standards. For these reasons, public regulation alone is no guarantee of good land subdivision design. For large subdivisions, a design team consisting of a land planner, a landscape architect, a civil engineer, and a land surveyor should be employed. In undertaking a subdivision design, a designer, or design team, may face one of three situations that will determine the manner in which the design must be approached:

1. The land proposed to be subdivided is located within a community that has not prepared and adopted a comprehensive plan.

2. The land proposed to be subdivided is located within a community that has prepared and adopted a comprehensive plan, but that plan does not include, as a component, detailed neighborhood unit development plans or platting layouts.
3. The land proposed to be subdivided is located within the community that has prepared and adopted a comprehensive plan, and that plan includes detailed neighborhood unit development plans or platting layouts.

In the case where a community has not prepared and adopted a comprehensive plan, the designer or design team will have no overall planning framework within which to work. Accordingly, great skill and experience are required, together with intimate knowledge of the principles and practices governing good subdivision design. Substantially greater effort will be required on the part of the designer, or design team, than would be the case if sound local planning had provided a framework for the design process.

In the case where the land proposed to be subdivided is located within the community that has prepared and adopted a comprehensive plan, but has not prepared and adopted detailed neighborhood unit development plans or platting layouts as an element of that plan, the adopted community plan will provide a broad, invaluable guidance to the designer, or design team. The comprehensive plan should contain specific recommendations relative to such matters important to good subdivision design as the location and width of arterial streets, the generalized location of needed school and park sites; and the generalized location and configuration of needed drainage ways and stormwater retention or detention areas. The plan should also provide much of the information essential to good design, including current aerial photography, large-scale topographic and cadastral maps; detailed soil maps with attendant use interpretations; definitive information on the location and configuration of flood hazard areas; and on the location and configuration of such elements of the natural resources base as wetlands, woodlands, and wildlife habitat areas. Importantly, the comprehensive plan should specify the type and densities of land uses to be accommodated within the proposed subdivision; the densities for residential use usually being expressed as the maximum number of dwelling units permitted per gross acre. In this case, the designer, or design team, can focus on the creation of an efficient and attractive street, block, and lot layout, and on the creation of a unified design for the proposed subdivision.

In the case where the land proposed to be subdivided lies within a community that has adopted a comprehensive plan that includes detailed neighborhood development plans or platting layouts, the local unit of government concerned will have provided not only data concerning the types of and entities of land use to be accommodated on the land concerned, but proposed specific locations for neighborhood schools, parks and drainage ways, together with a specific layout for collector and land access, as well as arterial, streets. In this case, the designer or design team will be responsible for reviewing the design provided in the comprehensive plan, for proposing design improvement to that plan, and for

ensuring the unity of design with the subdivision itself. In this case, the adopted neighborhood unit plans or platting layouts should be viewed as points of departure for the design of the subdivisions of individual tracts of land included within the neighborhood units. The adopted neighborhood unit plan should not unduly constrain the designer, or design team, in seeking more creative or cost-effective approaches to the subdivision design concerned. Changes in the adopted neighborhood unit development plan may be particularly warranted if that plan no longer adequately reflects current market conditions.

Figure 6.2 depicts a neighborhood unit plan that incorporates sound design principles. It provides, for example, a centrally located neighborhood park in conjunction with a neighborhood school site. The collector street layout is designed to carry traffic into and out of the neighborhood, rather than through it; and neighborhood shopping center having access to the collector and arterial street system is provided. The collector and land access streets are carefully designed to fit the topography of the site in order to minimize grading, and the destruction of existing tree growth, ground cover, and top soil; to facilitate good drainage; and to facilitate the design of gravity drainage sanitary sewers. The street layout facilitates good lot layout; and access to arterial streets is limited. The system of natural drainage ways, together with the street rights-of-way, form a viable major stormwater drainage system. The neighborhood shown is an area slightly larger than one square mile and a development density of about 5,200 persons per square mile, or about eight persons per gross acre. The elementary school would have an enrollment of about 450 children.

It should be noted that the principles underlying the design of the particular neighborhood unit shown predate the recent interest in what has been termed *new urbanism design*. The new urbanism design is, however, in essence little more than a return to older subdivision designs used in developing the central cities and first-ring suburbs of American cities. The neighborhood unit shown would meet the new urbanism design principles in many respects, such as the provision of neighborhood shopping, park and playground, and school facilities. A new urbanism design would probably favor a higher density of development—perhaps up to about 10,000 persons per square mile—and the promotion of mixed land uses, particularly in the provision of commercial and residential subareas.

Site Selection and Assessment

As in any site planning effort, the land subdivision design process should be preceded by site selection and assessment. Site selection should be determined by market analyses and land availability and value studies, but should be constrained by the recommendations contained in adopted comprehensive plans and in the implementing zoning ordinances. The comprehensive plan should identify the areas recommended for new residential, commercial, industrial, and institutional development within the municipal planning area, including the extraterritorial areas envisioned as being part of the municipal sphere of interest. The comprehensive plan should recommend the placement of new land-use development in time as well as space, while the zoning ordinance, in accordance with the

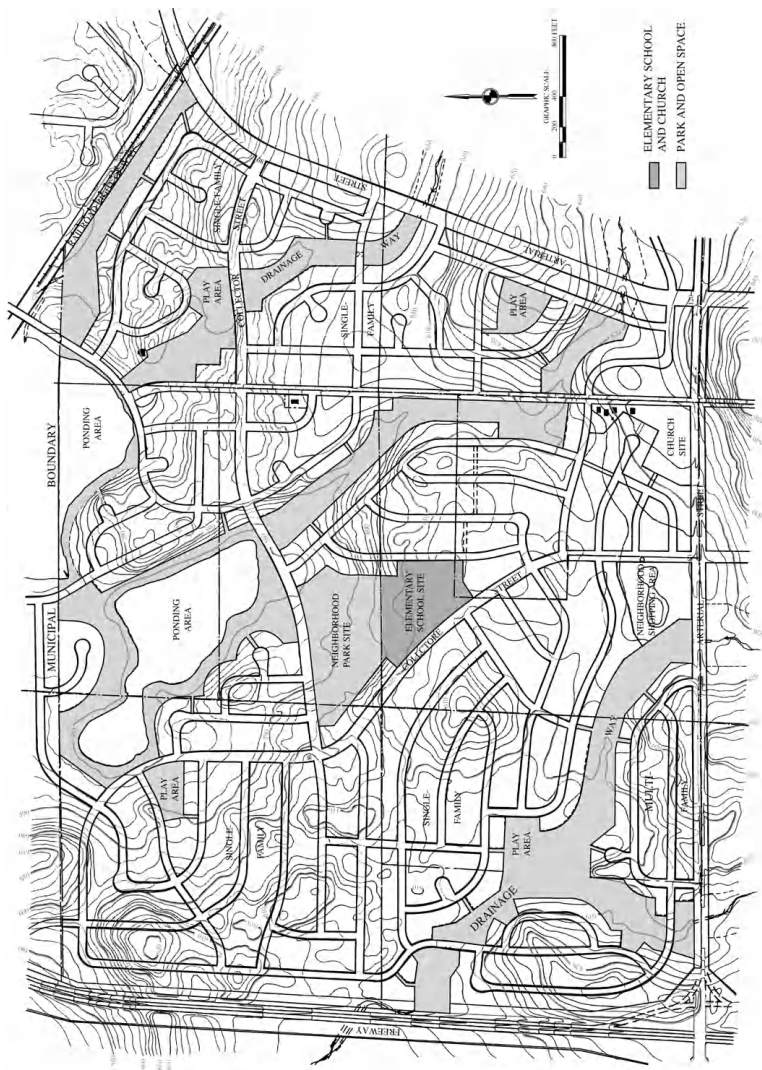


FIGURE 6.2 Depicts a neighborhood unit design that incorporates the five design principles described herein. It provides, for example, a centrally located neighborhood park in conjunction with a neighborhood school site, allowing dual use of the facilities and efficient maintenance. The collector street layout is designed to carry traffic into and out of the neighborhood, rather than through it. A neighborhood shopping center convenient to the collector and arterial street system is provided. The collector and land access streets are carefully adjusted to the topography of the site to minimize grading a destruction of tree growth and ground cover. Access to arterial streets is limited by backing lots against such streets. The street layout facilitates good lot layout. A system of natural drainageways, together with the streets rights-of-way, form a viable major stormwater drainage system.

comprehensive plan, should set aside holding areas for future development. As the market for additional building sites develops, appropriate portions of the holding zones can be redistricted to provide for the needed additional development. The placement of new development in time and space should be such as to facilitate the completion of all partially development neighborhood units before the development of part or all of other such units is contemplated.

Site assessment should be based on field inspection. The assessment should include the following:

- A topographic analysis, identifying areas of steep slopes, the locations of hilltops, ridges, and scenic overviews
- Analysis of drainage patterns
- Delineation of areas of existing vegetation and, particularly, of fine stands of trees
- Identification of water bodies and associated flood hazard areas, and of wetlands
- Identification of the boundaries and characteristics of environmental corridors
- Identification of existing structures having historic or other cultural value

The assessment should also identify the classification of existing streets and highways located adjacent to the development parcel or tract, and the location of desirable and safe points of entrance to and exit from the site. Proposed streets within, or adjacent to, the parcel depicted on the adopted comprehensive plan or official map should be identified. Pertinent existing physical conditions surrounding the parcel, and recommendations in municipal, county, regional, or state plans affecting the parcel, should be identified. The availability of public sanitary sewerage and water-supply services should be determined. Certain areas within a proposed subdivision may be considered for maintenance in permanent open space, including land within any 100-year recurrence interval flood hazard areas, wetlands, and areas of steep slopes. The results of the field assessment should be presented in a site analysis map, similar to the one shown in Figure 6.3.

Alternative Subdivision Design Types

There are three basic subdivision design types in current use at the municipal scale of development: conventional curvilinear, urban cluster, and new urbanism. Selection of the design type that should be used for any given tract of land depends on many factors, including market identification and conditions, surrounding land uses, and site conditions. Site conditions are a particularly important consideration in this respect, as some sites are more suited to a given design type due to the topographic and natural resource features present on the site. The application of these three subdivision design types to the 80-acre tract depicted in the site analysis map given in Figure 6.3 are set forth in Figure 6.4.

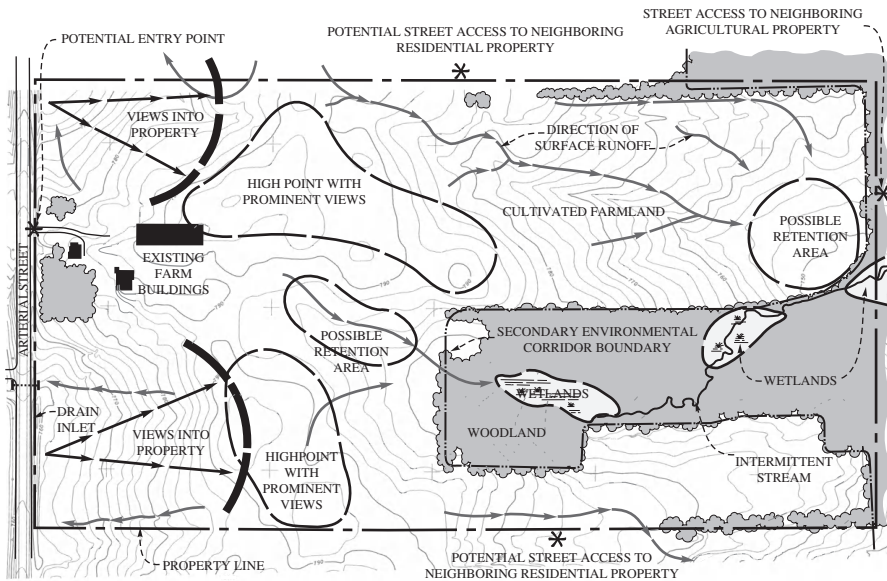
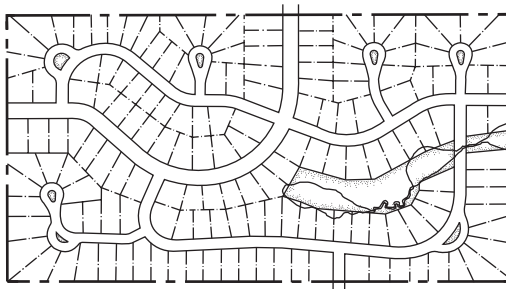


FIGURE 6.3 A site analysis should be conducted before a subdivision design type is selected and any subdivision layout created. In general, the analysis should include a topographic analysis, identifying areas of steep slopes; the locations of hilltops, ridges, and scenic overviews; an analysis drainage patterns; a vegetation analysis; a delineation of soil types and characteristics; an identification of water bodies, wetlands, woodlands, and flood hazard areas; an identification of the boundaries and characteristics of environmental corridors; and identification of structures having historic or other cultural value. The site analysis should also identify the classification of existing streets and highways adjacent to the development parcel, and the location of desirable and undesirable points of entrance to and exit from the site.

It is important to note that the subdivision layouts shown were prepared assuming that a local comprehensive plan was available to specify the type and density of land use to be accommodated, and assuming further that the comprehensive plan concerned did not include a neighborhood unit development plan or platting layout. The comprehensive plan was assumed to set forth a specific overall residential development density for the 80-acre tract concerned; and identified the arterial street pattern and related right-of-way widths. It is particularly important that the comprehensive plan set forth a specific maximum density of development in order to ensure that the public infrastructure and services are adequate and appropriate to serve development within the community.

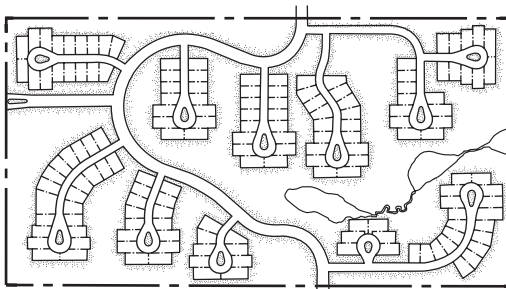
Table 6.1 sets forth a comparative analysis of the three designs shown. To facilitate the comparison, a common development density of approximately two dwelling units per gross acre—or a total of 160 dwelling units for the tract—was assumed. In an actual design setting, the density used might be varied between the three designs, as long as it did not exceed the maximum density specified in the comprehensive plan.



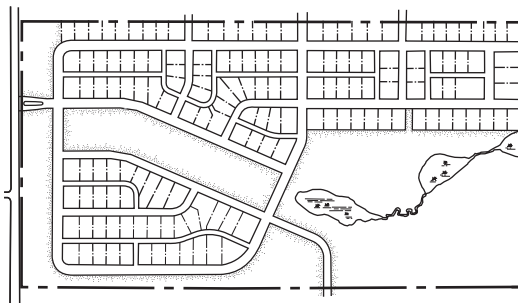
(a)

The curvilinear subdivision design type has been the most common type of subdivision developed in the United States in the post–World War II era. The curvilinear subdivision has generally been designed to provide relatively large lots that permit larger homes with more private open space on each lot. The design of a curvilinear subdivision facilitates adjustment to fit the topography and minimize required grading while providing good drainage and efficient sewerage.

The urban cluster subdivision design type maintains a significant portion of a site in common open space by minimizing individual lot sizes while maintaining the required overall density of development. The cluster subdivision, whether located in an urban or rural area, can effectively protect environmentally sensitive areas by maintaining such areas in open space, while concentrating lot into small groups or “clusters.” Each residential lot in this subdivision layout has direct access to the common open space, and the use of cul-de-sac streets enhances residential quiet, privacy, seclusion, and safety.



(b)



(c)

The new urbanism design type is based on urban development patterns of the past, with consideration given to the open space concerns of the present. New urbanism subdivisions attempt to provide a central public common that is surrounded by residential lots, or, in some larger subdivisions, may provide for a neighborhood business or civic center. Residential lots are often double-fronted, with one face to the street and one to a utility corridor or alley running behind the lots, where garages are located. The new urbanism design is better suited to relatively level sites where the desired density of development is easily achieved without substantial grading. The grid street pattern provides more connections to adjoining tracts, and often results in shorter walking and bicycling distances, but may also result in higher volumes of through traffic using subdivision streets, increasing noise levels and safety concerns.

FIGURE 6.4 (a) Conventional curvilinear subdivision layout, (b) urban cluster subdivision layout, and (c) new urbanism subdivision layout.

The curvilinear subdivision design is intended to maximize the use of developable land for lots, while limiting open space to environmentally sensitive areas that are to be protected based on recommendations contained within the local comprehensive plan, or restrictions contained in the local zoning ordinance. The design process focuses on the street layout, considering desirable block lengths and widths, and desirable lot configuration. The curvilinear street pattern is fitted to the topography of the site to minimize earth work, achieve good drainage, and facilitate the provision of gravity drainage sanitary sewerage. The design provides

TABLE 6.1 Comparative Analysis of Subdivision Designs

	Subdivision Type		
	Conventional Curvilinear	Urban Cluster	New Urbanism
Lot information			
Number of lots	160 lots	160 lots	160 lots
Average lot size	17,002 square feet	6,028 square feet	7,325 square feet
Average lot width	95 feet	60 feet	62 feet
Average lot depth	179 feet	101 feet	118 feet
Total area within lots	62.5 acres	22.1 acres	27.3 acres
Percent of site area within lots	77.0 percent	27.3 percent	33.2 percent
Street information			
Total street length	10,363 lineal feet	10,730 lineal feet	17,154 lineal feet
Total area within street rights-of-way	14.7 acres	12.8 acres	16.6 acres
Percent of site area within street rights-of-way	18.1 percent	15.8 percent	20.7 percent
Open space information			
Total area within open space	4.0 acres	46.4 acres	37.4 acres
Percent of site area in open space	4.9 percent	57.2 percent	46.1 percent
Grading information			
Volume of earth work	51,000 cubic yards	93,000 cubic yards	130,000 cubic yards

relatively large lots that can accommodate larger homes with more private open space on each lot. Grading for a curvilinear subdivision is typically minimum and preserves much of the existing topography and vegetation. Disadvantages of a curvilinear subdivision design may include higher costs of infrastructure per lot due to the relatively large size of the individual lots. Also, such subdivisions usually provide smaller areas of land for public or common open space. The urban cluster design type maximizes the provisions of common open space by minimizing individual lot size while maintaining the required overall density of development.

A cluster subdivision can be used to effectively protect environmentally sensitive areas by maintaining such areas in open space, while concentrating lots into smaller groups or clusters. The urban cluster design provides relatively small lots fronting on a public street, with all lots being adjacent to common open space. This design type usually results in the lowest percentage of combined area devoted to streets and lots, thus providing the greatest amount of common open space. The design is somewhat more conducive to use with more level sites, where terracing of the small lots making up the clusters is not necessary.

The advantages of a cluster subdivision design include protection of natural resource features and the opportunity to maintain a significant portion of the site in common open space. This can provide attractive recreational opportunities for residents of the subdivision; maintain the scenic beauty and biodiversity of the site; and decrease the amount of impervious surface area. If the subdivision is laid out in a way that concentrates lots on a limited portion of the site, the cost of providing infrastructure may be less than that required for a curvilinear type subdivision. Disadvantages of cluster subdivisions may include relatively small lots that require careful design of lot arrangements and building placement in order to provide privacy for the individual residences. The control of architectural design may be needed in urban cluster subdivisions due to the relatively small lots and the proximity of the clustered homes. A homeowners association is required to own and maintain the common open space and related facilities. Provision must be made, however, for public assumption of the maintenance if the homeowners association fails to meet its responsibilities, with the associated costs assessed back to the lots in the subdivision.

Because the subdivision design shown in Figure 6.4 is assumed to be located in an area provided with a full range of urban services, including public sewer and water supply, the design presented is for an urban cluster. Cluster subdivisions may also be located in rural areas, in which case they are often known as conservation subdivisions. Although such rural locations may, in the absence of a comprehensive plan, raise concerns about urban sprawl, the cluster design can be effectively used to maintain agricultural uses in an area, preserve and protect wildlife habitat, and provide outdoor recreational opportunities. A rural cluster—or conservation—design subdivision is shown in Figure 6.5. Such rural conservation subdivisions may also facilitate the provision of sanitary waste disposal and the provision of water supply in rural areas not served by centralized sewerage and water supply systems. This may be illustrated by a simple example. If a rural area is planned and zoned to permit residential use at a gross density not to exceed one dwelling unit per 5 acres, a 100-acre tract might be subdivided into twenty 5-acre lots, using a curvilinear design each with its own on-site sewage treatment and disposal system—usually a septic tank system—and with its own on-site well for water supply. If the development were to use a cluster design with a net lot size of 1 acre, while maintaining the overall density of the tract at 20 dwelling units, approximately 24 acres of the site would be used for residential development, including supporting streets, and 76 acres would be maintained in common open space. This would permit the provision of a sanitary sewage collection and conveyance system tributary to an integrated anaerobic or aerobic treatment unit and an integrated soil drainage tile disposal facility located on a carefully selected part of the open space area. This approach could even be used with a centralized holding tank, the accumulated wastes in the tank being tracked to a recovery wastewater treatment plant. Similarly, water mains properly sized, valved, and equipped with fire hydrants and served by a common well could be provided. In this way occupants of the subdivision would perceive no difference between the sanitation services provided and such services provided in

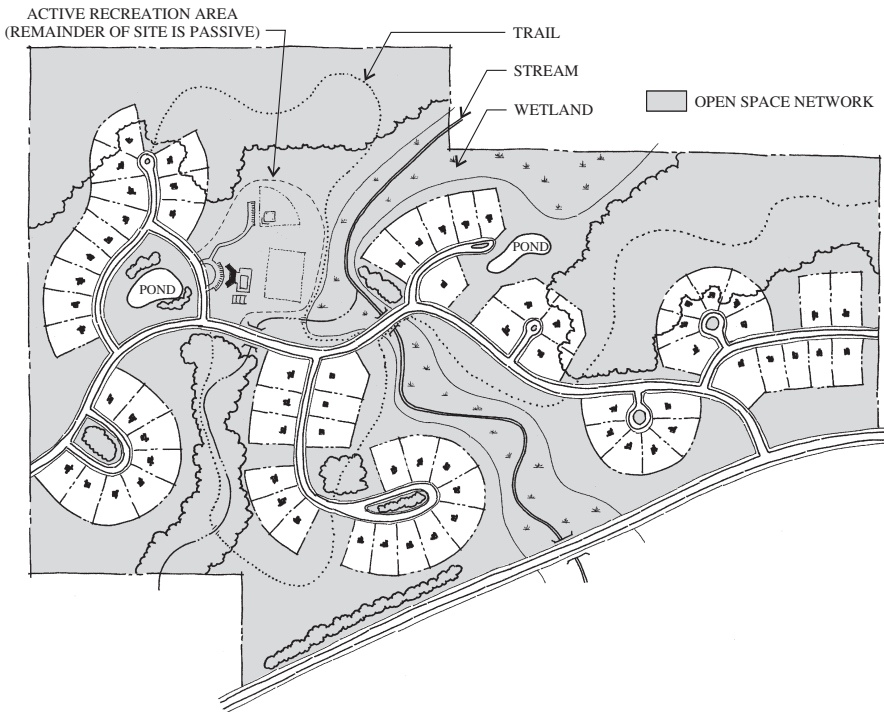


FIGURE 6.5 The open space system should be connected and contiguous; active and passive recreation areas should be designed.

an area served by public centralized sanitary sewer and water supply services. The common sewer and water supply facilities could be owned and operated by a homeowners association. In such an arrangement, however, it is important that public oversight be provided in order to assure proper operation and maintenance of the sanitation facilities. Failure to properly perform these functions should result in the facilities being taken over by a public entity—a civil town or sanitary district—for proper operation and maintenance, with the associated costs being assessed back to the lots in the subdivision. Alternatively, a public sanitary district could be created to oversee the design and construction of the facilities concerned, and to operate and maintain those facilities.

The new urbanism design type subdivision layout is conceptually based on the urban development patterns of the past, with consideration given to the open space concerns of the present. Large-scale new urbanism subdivisions typically attempt to provide a central focal point in the form of a public “common” that is surrounded by mixed-use residential and commercial lots, and which may provide a neighborhood business and community center. Residential lots are often double-fronted, with one frontage on a public street and a second frontage on a utility corridor or alley running behind the lots and on which garages are

located. The lots are smaller than typical in a curvilinear or even cluster design type subdivision, and residences are intended to be located close to the street line. The hierarchy—functional classification—of the streets is typically less distinct in a new urbanism design type subdivision than in a curvilinear or cluster design, and street rights-of-way and street pavement widths are often narrower. A grid, or modified grid street pattern, is typically favored. The closely spaced lots and small front yards are intended to contribute to an increased sense of neighborhood for the subdivision residents, but may demand a uniform architectural treatment of the buildings. The disadvantages associated with the new urbanism design type include smaller on-lot areas for private outdoor use due both to the smaller lot sizes and the location of garages adjacent to alleys. The grid street pattern may encourage the use of residential land access streets by through traffic, reducing desirable residential quiet, privacy, seclusion, and safety. Importantly, the grid street pattern cannot be readily adjusted to the topography of even gently rolling sites and may require excessive grading.

Utility Services

The type and quality of subdivision design will affect the location and cost of the utilities required to serve the development. In each of the three design types presented, sanitary sewers, water mains, and storm sewers would typically be located in the street rights-of-way. In a curvilinear design type subdivision, electric power and telecommunications facilities would typically be located within easements along side and rear lot lines. In a new urbanism design type subdivision, the electric power and telecommunications facilities would typically be located within the alley rights-of-way. The location and configuration of utilities to serve the urban cluster design type subdivision requires particularly careful consideration on site specific bases. Where narrow street rights-of-way and roadway pavements are used, utilities can only be located under the street pavements to the extent that required horizontal separation distances between sanitary sewers, storm sewers, gas mains and water mains can be maintained within the limits of the narrower pavements.

The provision of adequate treatment and disposal of sanitary wastes, and the provision of a safe water supply are particularly important to the sound development of land subdivisions. The preferred method of providing these essential services is through the provision of centralized public sanitary sewer and water supply services. If a subdivision is not located within the boundaries of an existing service district, the needed services may become available through annexation to the central municipality, through the formation of a sanitary district, or through a utility corporation. In some situations, developers may propose to construct their own facilities including treatment plants. Rising federal and state environmental standards, together with the need to operate and maintain the systems over time, makes this approach problematic in the absence of public oversight and regulation. An increase in the number of connections required to sustain a financially viable sanitary sewerage or water supply system means that a growing number

of small systems may no longer be financially viable. Therefore, questions of the future size, ownership, and quality of management need to be addressed as part of the development proposal.

In some situations, on-site well water and septic tank treatment and disposal systems may offer the only practical means of serving scattered low-density residential developments. To be acceptable, the individual sanitary facilities must be carefully designed, constructed, and maintained in accordance with good practices. Where the soils are unsuitable for the proper treatment and disposal of septic tank wastes by conventional subsurface means, every effort should be made to prevent the subdivision and development of the land concerned until public sewer service becomes available.

Where individual on-site wells are proposed for a subdivision, a hydrogeologic study, including test wells, may be indicated to ensure that the aquifer concerned can supply adequate water for the proposed development. It may also be desirable to require that wells drilled on-site be tested for yield and for microbiological, chemical, and physical quality before a permit to build is given. To constitute an adequate water supply for a single-family home, a well should have a sustained yield of 8 to 10 gallons per minute. In some situations, a lesser yield may be acceptable, but a special engineered design, including storage, may be required.

When either individual well or septic tank systems are required, or when both are required, the preparation of a proper set of plans for the subdivision development will make possible the orderly installation of these facilities on individual lots. Details to be included on the development plans should include the site topography; soil maps; location of required soil borings and test pits, and the attendant soil tests and test results; depth to water table; lot layouts showing the proposed location of houses, wells, and sewage disposal systems; together with the provision for good lot, block, and street drainage; diagrams showing, typical well construction, pump connections, and sanitary seals. Similar diagrams showing details of typical septic tank, distribution box, and soil absorption field details should be given. In some situations, mound-type systems may be required. Each lot requires careful study and adaptation of general principles and typical details so that proper development results. For example, the soil percolation tests and soils information should determine the type and size of the required on-site sewage disposal facility. The final lot grade and house, driveway, walks, and patio locations should determine the locations of the on-site well and sewage disposal system. The type of well, required minimum depth of casing, need for grouting of the annular space around the casing, and sealing of the bottom of the casing in solid rock will vary with each location. These are some of the considerations requiring the adequate engineering services.

Counties, cities, villages, and towns should adopt sanitary, building and plumbing codes, and zoning ordinances regulating the use, installation, operation, and maintenance of on-site sewage treatment and disposal and water-supply facilities. These codes and ordinances should be adopted within the context of a comprehensive plan. Individuals proposing to install an on-site sewage treatment and

disposal, or an on-site water-supply facility, should be required to make application to a designated department for a permit to build and to use and install attendant proposed sewage disposal and water supply facilities. The applications should be accompanied by soil maps, percolation tests, and facility-location design details. The cognizant public agency staff should be responsible for inspection during construction of the facilities to ensure compliance with the plans. When the facilities concerned have been properly installed, an occupancy permit may be issued for the residence concerned.

Fiscal Analysis

A proposed land subdivision should be accompanied by a fiscal impact, as well as an environmental assessment. The fiscal impact assessment requires estimates to be made of the total cost of providing the required public infrastructure, including capital investment, operation, maintenance, and replacement costs, together with estimates of the total public revenues to be derived from the proposed development. The types of infrastructure and attendant public services to be considered should include, among others, sanitary waste treatment and disposal; water supply; solid-waste collection and disposal; parks and playgrounds; libraries; street cleaning, snow plowing and pavement maintenance; traffic control; police and fire protection; emergency medical services; street lighting; street trees and other plantings; and schools. The costs of providing these facilities and services should be estimated based on local conditions and experience. Sources of revenue may include real property taxes, impact fees, sales taxes, income taxes, property transfer fees, permit and license fees, user charges, interest earnings and federal and state loans and grants. An analysis of the potential cost of the required facilities and services versus the potential revenues derived from the development will provide important information on the probable fiscal impact of the proposed development on the community. This impact, together with other factors, such as compatibility with the adopted comprehensive plan and findings of an environmental assessment should be considered in granting approval, or conditional approval, for the proposed development, or in rejecting the proposed development. Generally, fiscal impact assessment will show that low- and moderate-value residential development does not yield enough in property taxes to pay for the municipal services required unless supplemented by user charges or other revenues.

PROGRAM PLANNING

A number of laws related to environmental protection have emerged at the federal and state levels. These include, at the federal level:

- National Environmental Policy Act of 1969 (NEPA)
- Chemical Safety Information, Site Security and Fuels Regulatory Relief Act

- The Clean Air Act (CAA)
- The Clean Water Act (CWA)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund)
- The Emergency Planning and Community Right-to-Know Act (EPCRA)
- The Endangered Species Act (ESA)
- Federal Insecticide, Fungicide and Rodenticide Act (FIFRA)
- Federal Food, Drug, and Cosmetic Act (FFDCA)
- Food Quality Protection Act (FQPA)
- The Freedom of Information Act (FOIA)
- The Occupational Safety and Health Act (OSHA)
- The Oil Pollution Act of 1990 (OPA)
- The Pollution Prevention Act (PPA)
- The Resource Conservation and Recovery Act (RCRA)
- The Safe Drinking Water Act (SDWA)
- The Superfund Amendments and Reauthorization Act (SARA)
- The Toxic Substances Control Act (TSCA)

States have adopted similar legislation mirroring the federal legislation in order to maintain some level of state control over the issues concerned. Many of these federal and state laws contain planning requirements. Some of these federal laws have included substantial grant programs intended to encourage the conduct of planning at the state and local levels of government. Other federal laws support the development of infrastructure facilities and include grant programs that promote planning for the physical development of urban areas. Historically, such programs have included the Federal Housing Act of 1954, Section 701, which provided grants to local municipalities, counties, and areawide planning agencies in partial support of the development of comprehensive plans. The Section 701 planning program, which was initially administered by the Federal Housing and Home Finance Agency (HHFA), did indeed result in the preparation of a large number of municipal comprehensive plans. Section 208 of the Federal Demonstration Cities and Metropolitan Development Act of 1966, administered by the U.S. Department of Housing and Urban Development (HUD), the successor agency to the HHFA, required that all applications for federal loans and grants be submitted to cognizant metropolitan planning agencies for review and comment prior to federal consideration. This requirement provided a powerful incentive for areawide planning and plan implementation.

These types of federal laws and grant programs often led to the establishment of federally driven areawide planning programs. Perhaps the most important and far reaching of such federally driven programmatic planning requirements were those initiated by the Federal Aid Highway Act of 1962. This act required the preparation of metropolitan transportation system plans as a prerequisite for the receipt of federal grants in support of highway system improvements. The

engineering staffs of the U.S. Bureau of Public Roads, the predecessor agency to the Federal Highway Administration, understood and were firmly committed to the need for areawide transportation system planning in metropolitan areas and, unlike other federal agencies, such as the U.S. Environmental Protection Agency, remained steadfastly committed to the support of such planning over time. The program was instrumental in developing the current state-of-the-art of transportation system planning, requiring the integration of land use and transportation system planning, and the application of mathematical simulation models in the design of transportation system plans. The program was also instrumental in the development of the present state-of-the-art of environmental assessment of transportation system plans, particularly with respect to the abatement of air pollution emissions and the pursuit of air quality management. Successive amendments broadened the required planning to include transit as well as highway facilities. The inclusion of strong implementation measures, including the required biennial preparation of metropolitan transportation improvement programs, is evidence of the federal transportation engineers' commitment to effective system planning. The latest version in the chain of acts initiated by the 1962 Act is known as the Safe, Accountable, Flexible, Efficient Transportation Equity Act of 2005. Without the Federal Aid Highway Act of 1962, and its successor acts, it is highly unlikely that strong metropolitan and regional planning programs would have developed in the United States as they indeed have.

Similar federal programs, exemplified by the programs administered by the Federal Aviation Administration (FAA) for airport system planning and by the U.S. Environmental Protection Agency (EPA) for water quality management planning have been less successful. This is particularly true of the planning requirements contained in Section 208 of the Federal Water Quality Act of 1972. Although the federal planning requirement and attendant grant program produced some very good areawide water-quality management plans, the lack of a firm commitment to those plans and the planning process over time by the EPA staff has hampered the ability to achieve the national objective of fishable and swimmable surface waters. Other federal and state planning requirements have been established in, among others, the fields of solid-waste management, coastal zone management, and air-quality management. Unfortunately, with the exception of the transportation planning program, most of these federal and state planning initiatives are not well integrated at the federal or state levels, and often ignore the needed foundation in comprehensive metropolitan or regional planning. Ideally, all such federal and state programmatic planning requirements should be coordinated through metropolitan or regional planning agencies so that the plans and plan implementation actions may be effective rather than counterproductive.

OPERATIONAL PLANNING

All of the planning efforts previously considered in this chapter have dealt with planning for the physical development of municipalities, counties, metropolitan

areas, and regions; recognizing, however, that all physical development is intended to serve social and economic needs, and that planning for such development must contain a strong environmental assessment and protection orientation. Such physical planning is appropriate in both developed and developing countries.

A parallel need exists, however, to promote strong public health organizations and services, and, as a basis for such promotion, to develop sound public health agency operational plans, perhaps as operational public health plans. Such plans should be directed at guiding the organization and operation of public agencies responsible for the protection and enhancement of public health. In the United States, this need is recognized at the federal level by the existence of the U.S. Public Health Service. This need was also recognized in the past by the historic development of strong public health departments within the structures of state and large city governments. The city departments were often headed by medical doctors, and employed competent staffs of public health nurses, sanitary engineers, and sanitation officers. A decline in the importance attached to such departments with respect to the containment of contagious diseases and the provision of pure food and water appears to have occurred following the close of World War II and the introduction of antibiotics, new immunization techniques, and advanced medical treatments to control, and in some cases eliminate, infectious diseases such as tuberculosis, poliomyelitis, and some socially transmitted diseases. The development of intercontinental travel based on rapid air transport, together with the emergence of often-fatal diseases, such as human immunodeficiency virus–acquired immunodeficiency syndrome (HIV–AIDS), bovine spongiform encephalopathy (mad cow disease), avian influenza (bird flu), and severe acute respiratory syndrome (SARS), among others, is creating a critical need to strengthen public health agencies and services at all levels of government. Good public administration would dictate that the operation of public health agencies be focused through the preparation of sound operational plans. An outline for a potential public health element of a comprehensive plan follows.

Public Health Element of Comprehensive Plan

I. Introduction

- A. Purpose of planning effort and plan report
- B. Brief description of planning area
- C. Impetus and authority for planning effort
- D. Planning approach
 - 1. Cognizant public body oversight and guidance
 - 2. Adoption

II. Historic Studies and Plans

- A. Pertinent federal and state public health planning efforts, plans and programs
- B. Pertinent local public health planning efforts, plans and programs

III. Description of Existing Conditions

A. Epidemiological and demographic

1. Population—historic and existing
 - a. Levels
 - b. Fertility, mortality and morbidity rates
 - c. Age and sex distribution
 - d. Diseases—types and prevalence, age and sex specific occurrences
 - (1) Infectious
 - (2) Noninfectious
 - (3) Chronic
 - e. Disease vectors
 - (1) Waterborne
 - (2) Rodent and Insect borne
 - (3) Foodborne
 - (4) Domestic and wild animal related
 - (5) Air related
 - (6) Pesticide and other chemical poisonings
 - (7) Congenital malformations, mental disorders
2. Households—historic and existing
 - a. Levels
 - b. Types
 - c. Housing conditions
3. Health Services
 - a. Types
 - b. Availability

B. Cultural and Natural Resource Base

1. Land use—historic, existing, planned
2. Topography and drainage patterns
3. Geology and depths to water and bedrock
4. Soils
5. Climate and weather
6. Surface water resources
7. Groundwater resources
8. Floodlands, wetlands

C. Public water supply

1. Sources, treatment, storage, distribution
 - a. Operator qualifications
 - b. Quality control

- c. Cross-connection control
 - d. Well construction control
 - e. Fire protection
 - f. Costs
- 2. Areas and populations served
- D. Wastewater disposal
 - 1. Domestic and industrial wastewater flows and characteristics
 - 2. Collection, transmission, treatment, disposal
 - a. Centralized sewerage systems
 - (1) Areas and populations served
 - (2) Adequacy of collection, transmission, storage, treatment
 - (3) Operator qualifications
 - (4) Cross-connection
 - (5) Costs
 - b. On-site treatment and disposal systems
 - (1) Areas and populations served
 - (2) Soil and groundwater conditions
 - (3) Performance and failure rates
 - (4) Regulation
 - (5) Costs
 - 3. Water pollution
 - a. Surface waters
 - b. Groundwaters
- E. Solid waste management
 - 1. Sources, amounts, types and characteristics of wastes
 - a. Managed refuse
 - b. Industrial wastes
 - c. Agricultural wastes
 - 2. Storage, collection, transport, processing and disposal
 - 3. Resource recovery, salvage, recycling
 - 4. Hazardous wastes
 - a. Handling
 - b. Prevention of contact
 - 5. Air, water, land pollution
 - 6. Areas and populations served
 - 7. Costs
- F. Air resources
 - 1. Air-quality conditions
 - 2. Pollution sources

3. Emission standards
4. Effects on human, livestock, vegetation
5. Meteorological and topographic factors
- G. Housing
 1. Amount, condition, availability—historic and existing
 2. Building, plumbing, electrical, heating and ventilating, occupancy codes and code enforcement
 3. Overcrowding
- H. Schools—elementary and secondary
 1. Locations
 2. Buildings and attendant recreation facilities
 3. Adequacy of water supply, sewage and solid wastes disposal, food service, sanitary facilities, indoor air quality
- I. Health care institutions
 1. Type, location, capacity, adequacy
 - a. Hospitals
 - b. Clinics
 - c. Nursing homes
 - d. Rehabilitation centers
 - e. Day care centers
 2. Staffing, budgets, workloads
- J. Recreational Facilities
 1. Parks, pools, bathing beaches, marinas
- K. Environmental Factors
 1. Drainage, mosquito breeding
 2. Noise and vibration
 3. Insect, rodent, and other vermin control
 4. Natural and manmade hazards slides, earthquakes, brush and forest fires, storms
 5. Radiological hazard
 6. Laws, codes, and ordinances
 7. Health criteria and standards

IV. Projected Conditions and Problem Identification

- A. Epidemiological and demographic
- B. Water supply
- C. Wastewater collection and disposal
- D. Solid waste collection and disposal
- E. Air-quality conditions
- F. Housing
- G. Schools

- H. Healthcare institutions
- I. Recreational facilities
- J. Environmental factors

V. Needed Public Health Facilities and Programs

- A. Staffing
 - 1. Medical doctors
 - 2. Public health nurses
 - 3. Sanitary engineers
 - 4. Sanitation officers
 - 5. Laboratory technicians
- B. Facilities
 - 1. Office
 - 2. Laboratory
 - 3. Motor vehicle and support equipment
- C. Legal authority
- D. Programs
 - 1. Water supply and food inspection including restaurant and food service inspection
 - 2. Environmental monitoring
 - a. Air quality including indoor
 - b. Water quality including swimming pool and bathing beach
 - c. Insect, rodent and other vermin
 - d. On-site sanitary waste disposal and attendant ground and surface water pollution
 - e. On-site water supply
 - f. Health care institutions
 - 3. Code enforcement
 - a. Housing
 - b. Sanitation
 - c. Health care institutions
 - 4. Health care monitoring
 - a. Infant
 - b. Elementary school pupils
 - c. Secondary school pupils
 - d. Immunization
 - 5. Emergency preparedness
 - a. Water supply
 - b. Waste disposal
 - c. Toxic hazardous and radiological contamination
 - d. Immunization

- e. Quarantine
- f. Medical services
- 6. Educational and training programs
 - a. Personal hygiene
 - b. Sanitation
 - c. Nutrition
 - d. Infant and child care
 - e. Emergency response
- 7. Other

It should be noted that a number of the inventories required for operational public health emergency planning are identical to those required for comprehensive physical planning. Close coordination of and cooperation between the agencies involved in these kinds of planning effort is, therefore, high desirable.

The need for public health services, while clearly important in rich developed countries, is critical in poor, developing countries. Improving public health should be a high priority in such countries that have large populations lacking sufficient supplies of safe, potable water, adequate sanitation systems, and adequate electrical power and road systems. Primary environmental problems include insufficient water supplies and rapid rural to urban migration, which exacerbate waste management problems and constitute threats to human health. Contagious diseases, high infant mortality rates, and unsatisfactory life expectancy rates should make the provision of strong public health services and the promotion of good individual health in such countries a major objective. Many lives could be saved, and a great deal of human misery avoided, through the provision, at a relatively low cost, of simple measures to promote good sanitation, safe potable water, and pure food nutritional guidance and assistance, and immunization programs. Public health agencies should be ready to react promptly, efficiently, and effectively to potential epidemics, and pandemics and to abate, or eliminate, any endemic diseases such as malaria and cholera. The effectiveness of good public health services has been demonstrated historically by examples, such as the control of malaria and yellow fever that permitted the construction of the Panama Canal.

ROLE OF ENGINEERING

There is a need for sound engineering in the conduct of all types of planning for the physical development of an area, and more sensitivity to comprehensive planning in engineering, with emphasis on areawide metropolitan and regional approaches. Certain key elements of a comprehensive plan dealing with sewerage, stormwater management, water supply, and transportation should be prepared by competent engineers. Environmental protection and natural resource conservation must be successfully integrated into essential engineering efforts. Engineering factors that are essential for continued community survival

and growth, and for the social and economic well being of the community residents, need to be carefully considered in the planning and engineering of any proposed development projects. Public awareness demands a quality environment that provides such fundamental needs as pure water, clean air, unpolluted land, the absence of traffic congestion, the availability of convenient public transit services; decent, safe, and sanitary housing; adequate recreational facilities, and the preservation of open space and historic values. These goals and objectives cannot be attained without the involvement in the planning and plan implementation processes of competent engineers.

State and local health and environmental protection agencies have vital planning, plan approval, and regulatory responsibilities to ensure that the public health and welfare are protected. The performance of these responsibilities requires competent engineering staff to deal with such issues as water-quality management and pollution abatement; wastewater treatment and disposal; provision of safe and adequate water supplies; air-pollution control; solid hazardous and nonhazardous waste disposal; radiation protection; land subdivision development; disease vector control; and safe use of herbicides and pesticides. The responsibility of health and environmental protection agencies extends to issuance of permits and continual environmental monitoring to protect the public health and welfare, and to enhance the home, work, and recreational environments. Hence, such agencies have an important stake in all planning programs to ensure that the public does not inherit situations that are dangerous, costly, and difficult or impossible to correct.

Sound, comprehensive, community planning that gives proper attention to environmental health considerations, followed by phase, detailed planning, engineering, and capital budgeting, are among the most important functions a community can engage in for the immediate and long-term benefit of its residents. The potential environmental effects of projects such as new highway or industrial and housing developments should be considered in the planning and engineering design phases, and then during the construction and operational phases. Alternatives should be proposed and comparatively evaluated on the basis of costs, benefits, and environmental impacts. For major projects, the responsible engineers should seek the assistance, as necessary, of other professions, including, among others, landscape architects, soil and water conservationists, and fish and wildlife biologists.

It is also important to understand that environmental criteria and standards that implement laws and regulations and affect engineering will vary significantly with time and place. It is, therefore, essential that current criteria and standards be used in the planning, engineering, and environmental assessment processes. Sometimes, there will be proposed criteria and standards available that may have not yet been adopted, but that deserve careful consideration.

ENVIRONMENTAL ASSESSMENT AND IMPACT STATEMENTS

The preceding text has indicated that comprehensive plans, project plans, site plans—including land subdivision plans—and program plans should be

accompanied by environmental assessments. An environmental assessment may also be related to an existing site or plant. The environmental assessment attempts to identify all existing and past activities that may have a deleterious effect on human health, the environment, or safety. In so doing, compliance with all applicable federal, state, and local laws, rules, and regulations, and required permit conditions are also determined.

An environmental assessment may be conducted for different purposes. It may be used to help validate comprehensive project and site plans. It may emphasize compliance with existing regulations and permit requirements, respond to a toxic or hazardous material spill, or relate to the existing or potential environmental risks and liabilities associated with the acquisition of a property.

An assessment to determine compliance with regulatory requirements may be referred to as an environmental audit. It may be carried out by regulatory personnel, in-plant personnel, or a consultant. The audit may relate to a single-purpose facility, such as an incinerator, wastewater treatment plant, hazardous waste operation, or water system, or to all operations and procedures at a plant or site. An assessment that is concerned with a property or its acquisition may be referred to as an environmental property assessment. It includes investigation for possible above-ground and subsurface contaminants and hazards, violations associated with structures on the property—including health and safety—and real property title searches.

At an existing operating site or facility, pollutant, emission, water, wastewater, solid waste, and soil samples may be collected, if indicated, for physical, chemical, and microbiological examinations and evaluations. Volume or weight measurements may be made. Materials balances of input versus output may be compared where possible. Raw-material and process changes to reduce and eliminate toxic or polluting discharges of product or wastes are considered. Deficiencies are identified, and a correction and prevention program is developed. In making an environmental property assessment, local residents, employees, and retirees may be interviewed regarding present and past products stored or manufactured, operations, practices, wastes produced, waste disposal methods, and previous land uses. Plant records, reports, and other documents may be useful.

A site investigation may include acquisition and analysis of old and recent land deeds, zoning district maps and ordinances, topographic maps and aerial photographs, historical reports, state archive records, regulatory agency and university reports, fire department and insurance files, and library files. Evidence of old mines, dumps, burial grounds, swamps, vegetation-free areas, wells, pipelines, buried tanks, impoundments, orchards, farmlands, laboratories, and factories may be found. Investigations and old reports and industrial directories may reveal types of waste materials generated and discarded at the site. Adjacent properties and uses may impact on the study site and should be explored. Site field surveys should be made at properties to be acquired and include—if indicated—soil, groundwater, waste, and air sampling for physical, chemical, radiological, and microbiological analyses and evaluation.

The value of an environmental assessment is dependent on the types and competencies of the professionals employed, the comprehensiveness of the survey, and the quality of the supporting laboratory results. Professionals who may be involved include engineers, land surveyors, geologists, hydrogeologists, archaeologists, historical geographers, chemists, biologists, health physicists, attorneys, toxicologists, and others who have the proper, specialized training and experience. Professional organizations, governmental agencies, institutions, and others may provide useful environmental assessment information, including guidelines, checklists, manuals, and texts that can be of value.

Purchasers of real estate, including plants and other properties, are advised to have an environmental site and facility assessment completed before purchase. The legal and financial liabilities assumed due to the presence of potentially hazardous contaminants on the site, or to building violations that may exist—structural, fire hazard, asbestos materials, polychlorinated biphenyls (PCBs), leaking underground petroleum and chemical storage tanks—should be understood and evaluated before ownership is finalized. Consultants performing environmental site assessments and audits may become involved in legal actions as a result of their studies and reports. They may be sued for having knowledge of the existence of hazardous conditions and not acting thereon. A consultant should be careful not to guarantee that a property is free of all contamination or what level of cleanliness a regulatory agency may require. Therefore, it is prudent for a consultant to limit liability in an agreement with a client, as the extent of the environmental assessment or audit to be prepared.

ENVIRONMENTAL IMPACT ANALYSIS

Concurrent with site selection and planning is the necessity to consider the effects of all proposed land uses, development activities, and required services and facilities on the environment or geography of the area concerned. It is extremely difficult to identify and evaluate in depth all possible factors that may affect, and be affected by, a particular development project or action. Good comprehensive regional, county, and municipal plans constitute a good source of pertinent data and greatly simplify preparation of an environmental impact assessment, and, if necessary, an environmental impact statement (EIS).

National Environmental Policy Act (NEPA)

Planning, design, and implementation of a project, without regard to its environmental effects, shirk the custodial responsibility and moral obligation of society to protect the environment for future generations and ensure their survival. Public concern over environmental pollution, aided by scientific and professional prodding and support, has led to federal and state legislation mandating consideration and documentation of the beneficial and adverse effects of proposed actions in the project planning stage for official and public scrutiny and indicated potential adjustments. This concept was given national recognition by the National

Environmental Policy Act (NEPA) of 1969, as amended. This act established a national policy that requires consideration of the effects of any significant federal actions on the environment. The act recognizes the impact of human activity on all components of the natural environment and the importance of environmental quality to public welfare. The act is intended to improve federal actions in order to achieve a number of objectives. Included among these are the following:

- To assure all Americans safe, healthful, productive, and aesthetically and culturally pleasing surroundings
- To attain the widest range of beneficial use of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences
- To preserve important historic, cultural, and natural values

The act directs that all agencies of the federal government do the following:

- Utilize a systematic, multidisciplinary approach that will ensure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision making that may impact on the environment.
- Identify and develop methods and procedures that will ensure that unquantified environment amenities and values may be given appropriate consideration in decision making, along with economic and technical considerations.
- Include a detailed environmental statement prepared by a cognizant official in every recommendation for legislation or other major federal actions significantly affecting the quality of the environment.

That statement is to set forth the environment impact of the proposed action, including any adverse environmental effects which cannot be avoided should the proposal be implemented; alternatives to the proposed action; the relationship between local short-term uses and the environment and the maintenance and enhancement of long-term productivity; and any irreversible and ir retrievable commitments of resources involved in the proposed action. The NEPA also permits these statements to be prepared under specific conditions by state agencies or officials. The Act requires that prior to completing the required detailed statement, consultations shall be held with other federal agencies, and the views of appropriate state and local agencies obtained.

A number of states have also adopted legislation and prepared procedures for environmental assessment of proposed actions, and for the preparation of environmental impact statements similar to the federal legislation.

Terminology

The federal regulations for implementing the procedural provisions of the National Environmental Policy Act define certain terms. These definitions warrant inclusion here because of the important concepts contained within them.

The term *categorical exclusion* is defined to mean a category of actions that do not individually, or cumulatively, have a significant effect on the human environment, and for which, therefore, neither an environmental assessment nor an environmental impact statement is required.

The term *cumulative impact* is defined as the impact on the environment that results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency—federal or nonfederal—or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over time.

The term *effects* is defined with two parts:

1. Direct effects are caused by the action and occur at the same time and place.
2. Indirect effects are caused by the action, and are delayed in time or farther removed in distance, but are still reasonably foreseeable. Indirect effects may include growth-inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems.

The term *effects* and *impacts* as used in the federal regulations are synonymous. Effects include ecological—such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems—esthetic, historic, cultural, economic, social, and health, whether direct, indirect, or cumulative. Effects may also include those resulting from actions that may have both beneficial and detrimental effects, even if on balance the agency believes that the effect will be beneficial.

The term *environmental assessment* is defined to mean a concise public document, the preparation of which is the responsibility of a cognizant federal agency—or delegated state agency—and which serves to do three things:

1. Provide sufficient evidence and analysis for determining whether the preparation of an environmental impact statement or a finding of no significant impact is required.
2. Aid in compliance with the Natural Environmental Policy Act when no environmental impact statement is required.
3. Facilitate preparation of an environmental impact statement when one is required.

An environmental assessment is similar to an environmental impact statement but is not necessarily as comprehensive or in the same depth. It can be used to determine if a negative declaration is indicated, or if an environmental impact statement is required. An environmental assessment is not required if it has been determined in any case to prepare an environmental impact

statement. An environmental assessment should include a brief description of the need for the proposed action concerned; of the alternatives thereto; of the potential environmental impacts of the proposed action, and of the alternatives thereto. It should also list the agencies and persons consulted in preparing the assessment.

The term *environmental impact statement* is defined as a detailed written statement required by Section 102(2)C of the NEPA.

The term *federal agency* is defined to include all agencies of the federal government. It does not mean the Congress, the judiciary, or the president. It also includes, for purposes of the federal regulations, states, units of local government, and Indian tribes assuming National Environmental Protection Act responsibilities under Sec. 104(h) of the Housing and Community Development Act of 1974 as amended.

The term *finding of no significant impact* is defined as a document prepared by a federal agency briefly presenting the reasons why an action, not otherwise excluded, is not expected to have a significant effect on the human environment and for which an environmental impact statement therefore need not be prepared. The term is intended to include the environmental assessment concerned with it and any other environmental documents related to it.

The term *human environment* is defined to include the natural and physical environment, and the relationship of people with that environment. This means that actions having purely economic or social effects are not intended by themselves to require preparation of an environmental impact statement. However, when an environmental impact statement is prepared and economic or social and natural or physical environmental effects are interrelated, then the environmental impact statement is to describe all of these effects on the human environment.

Scoping

Scoping is an important element of all planning processes because it defines what will and what will not be included in the process. Scoping must be conducted early in the planning process, preferably at the beginning of the public participation effort. The federal regulations relating to environmental assessments and environmental impact statements address scoping. Under those regulations, scoping is defined as an early and open process for determining the scope of issues to be addressed, particularly the significant issues related to a proposed action. As soon as practicable after a decision is made to prepare an environmental impact statement, and before initiation of the scoping process, the lead agency must publish a notice of intent in the Federal Register. As part of the scoping process the lead agency shall take these steps:

1. Invite the participation of affected other federal, and of state and local agencies, any affected Indian tribe, the proponent of the action, and other interested persons—including those who might not be in accord with the action on environmental grounds.

2. Determine the cope and the significant issues to be analyzed in depth in the environmental impact statement.
3. Identify and eliminate from detailed study the issues that are not considered to be significant, and explain why those issues are not expected to have a significant effect on the human environment.
4. Allocate assignments for preparation of the environmental impact statement among the lead and cooperating agencies, with the lead agency retaining responsibility for the statement.
5. Indicate any public environmental assessments and other environmental impact statements that are being, or are expected to be, prepared, that are related to, but are not a part of, the scope of the impact statement under consideration.
6. Identify other environmental review and consultation requirements so the lead and cooperating agencies may prepare other required analyses and studies concurrently, and in an integrated manner with, the environmental impact statement.
7. Indicate the relationship between the timing of the preparation of environmental analyses and the agency's tentative planning and decision-making schedule.
8. The lead agency may hold an early scoping meeting, or meetings, which may be integrated with any other early planning meetings the agency holds. Such a scoping meeting, or meetings, will often be particularly appropriate when the impacts of a particular action are confined to a specific site or sites.

Recommended Format for Environmental Impact Statement

A format should be used for environmental impact statements that will encourage good analysis and clear presentation of the alternatives, including the proposed action. The following standard format for environmental impact statements may be followed unless the agency determines that there is a compelling reason to do otherwise:

1. Cover sheet
2. Summary
3. Table of contents
4. Purpose of and need for action
5. Alternatives including proposed action
6. Affected environment
7. Environmental consequences
8. List of preparers
9. List of agencies, organizations, and persons to whom copies of the statement are sent
10. Index
11. Appendices

Content of an Environmental Impact Statement

The environmental impact statement (EIS) required under the National Environmental Policy Act is intended to be a detailed written statement prepared by a responsible official on every proposal for legislation, or other major federal action, significantly affecting the quality of the human environment. Guidelines for the preparation of an EIS have been published by the Council on Environmental Quality, and a number of states have adopted similar guidelines. A draft EIS is generally first prepared and circulated for comment. The EIS may be for a proposed legislative act, program, planning study, or construction project. The comments received are then evaluated and considered in the decision-making process.

The EIS should include a description of the proposed action; a statement of the purpose or purposes of the action; and a description of the environment affected, including summary technical data, and maps and diagrams, as may be required. The description should be adequate to permit an assessment of the potential environmental impacts by commenting agencies and the public. Highly technical and specialized analyses and data should be avoided in the body of the draft impact statement. Such materials should be attached as appendices, or footnoted with adequate bibliographic references. Importantly, the statement should succinctly describe the environment of the area affected as it exists prior to the proposed action. The interrelationships and cumulative environmental impacts of the proposed action and other related federal projects should be presented in the statement. The amount of detail provided in such descriptions should be commensurate with the extent and expected impact of the action, and with the amount of information required at the particular level of decision making—planning, design, construction. Agencies should also take care to identify, as appropriate, the following:

- Population and growth characteristics of the affected area
- Any population and growth assumptions used to justify the project or programs
- Growth impacts resulting from the proposed action and its alternatives
- Sources of data used to identify, quantify, or evaluate any and all environmental consequences

The relationship of the proposed action to land-use plans, policies, and regulations for the affected area should be described, including the plans developed in response to the Federal Clean Air Act, Federal Water Pollution Control Act, and Federal Transportation Act. Where a conflict or inconsistency exists, the statement should describe the extent to which the agency has reconciled its proposed action with the plans, policies or regulations concerned, and the reasons why the agency has decided to proceed notwithstanding the absence of full reconciliation.

The statement should contain a clear description of the probable impact of the proposed action on the environment. This requires assessment of the positive and

negative effects of the proposed action on the environment. The attention given to different environmental factors should vary according to the nature, scale, and location of the proposed actions. Among factors to consider should be the potential effect of the action on these aspects of the environment:

- Air quality, water quality, shellfish sanitation
- Stream flows and stages, fish and wildlife, solid waste, noise, radiation, toxic and hazardous substances, contamination of foodstuffs, herbicides and pesticides, transportation and handling of hazardous materials
- Energy supply, renewable resource development, natural resource conservation
- Land use and management
- Protection of environmentally critical areas—floodplains, wetlands, beaches and dunes, unstable soils, steep slopes, aquifer recharge areas
- Land use in coastal areas, redevelopment, and construction in built-up areas
- Density and congestion mitigation
- Neighborhood character and continuity
- Impact on low-income populations
- Historic architectural and archeological preservation
- Soil and plant conservation, hydrology
- Outdoor recreation

Primary attention should be given in the statement to those factors most evidently impacted by the proposed action. Secondary, or indirect, as well as primary or direct, consequences for the environment should be included in the analysis. Many actions, in particular those that involve the construction of infrastructure investments, stimulate or induce secondary effects in the form of changed patterns of social and economic activities and related land-use patterns. Such secondary or indirect effects—through their impacts on existing community facilities and activities, through inducing new facilities and activities, or through changes in natural conditions—may often be more substantial than the primary effects of the proposed action itself. The effects of the proposed action on population growth and land-use development may be among the most significant secondary effects.

Alternatives to the proposed action, including, where relevant, those not within the existing authority of the responsible agency, should be described. A rigorous exploration and objective evaluation of the environmental impacts of all reasonable alternative actions, particularly those that might enhance environmental quality, or that might avoid some or all of the adverse environmental effects, is essential. Examples of such alternatives include the following:

- The alternative of taking no action, or of postponing action pending further study
- Alternatives requiring actions of a significantly different nature that would provide similar benefits with different environmental impacts—as, for

example, nonstructural alternatives to flood control projects, or mass transit alternatives to highway construction

- Alternatives related to different designs or details of the proposed action that would present different environmental impacts—as, for example, cooling ponds, in place of cooling towers for an electric power generation power-plant or alternatives that will significantly conserve energy
- Alternative measures to provide for compensation of fish and wildlife losses, including the acquisition of land, waters, and interests therein

In each case, the analysis should be sufficiently detailed to reveal the comparative evaluation of the environmental benefits, costs, and risks of the proposed action and of each reasonable alternative thereto.

Any probable adverse environmental effects that cannot be avoided—such as water or air pollution, undesirable land-use patterns, damage to life systems, urban congestion, or threats to public health—should be described. Included for purposes of contrast should be a clear statement of how avoidable adverse effects will be mitigated.

The trade-offs between short-term environmental gains at the expense of long-term losses, or vice versa, should be described, together with the extent to which the proposed action forecloses future options. In this context, the terms *short-term* and *long-term* should be viewed in terms of the environmentally significant consequences of the proposed action, without reference to any fixed level period.

Any irreversible and irretrievable commitments of resources that would be involved in the proposed action, should it be implemented, should be described. Construing the term *resources* to mean only the labor and materials devoted to an action should be avoided. Resources should also be defined as the natural and cultural resources committed to loss or destruction by the action.

An indication of other considerations that are thought to offset the adverse environmental effects of the proposed action should be described. The statement should also indicate the extent to which these countervailing benefits could be realized by following reasonable alternatives to the proposed action that would avoid some or all of the adverse environmental effects. In this connection, agencies that prepare cost–benefit analyses of proposed actions should attach such analysis, or summaries thereof, to the environmental impact statement, and should indicate the extent to which environmental costs have not been reflected in such analyses.

Every effort should be made to convey the required information succinctly in a form easily understood, both by members of the public and by public decision makers, giving emphasis to the substance of the information conveyed rather than to the particular form, length, or detail of the statement. Each of the points of attention need not always occupy a distinct section of the statement if an action is otherwise adequately covered in the descriptions of the impact of the proposed action and of the alternatives thereto. The statements should indicate at appropriate points in the text any underlying studies, reports, and other

information obtained and considered in preparing the statement, including any available cost–benefit analyses. A suggested outline for the content of an EIS follows:

- I. Project Description**
 - A. Purpose of action
 - B. Description of action
 1. Name
 2. Summary of activities
 - C. Environmental setting
 1. Environment prior to proposed action
 2. Other related federal activities
- II. Land-Use Relationships**
 - A. Conformity or conflict with other land-use plans, policies, and controls
 1. Federal, state, and local
 2. Clean Air Act and Federal Water Pollution Control Act Amendment of 1972
 - B. Conflicts and/or inconsistent land-use plans
 1. Extent of reconciliation
 2. Reasons for proceeding with action
- III. Probable Impact of the Proposed Action on the Environment**
 - A. Positive and negative effects
 1. National and international environment
 2. Environmental factors
 3. Impact of proposed action
 - B. Direct and indirect consequences
 1. Primary effects
 2. Secondary effects
- IV. Alternatives to the Proposed Action**
 - A. Reasonable alternative actions
 1. Those that might enhance environmental quality
 2. Those that might avoid some or all adverse effects
 - B. Analysis of alternatives
 1. Benefits
 2. Costs
 3. Risks
- V. Probable Adverse Environmental Effects that Cannot Be Avoided**
 - A. Adverse and unavoidable impacts
 - B. How avoidable adverse impacts will be mitigated

- VI. **Relationship Between Local Short-Term Uses of Man's Environment and the Maintenance and Enhancement of Long-Term Productivity**
 - A. Trade-off between short-term environmental gains at expense of long-term losses
 - B. Trade-off between long-term environmental gains at expense of short-term losses
 - C. Extent to which proposed action forecloses future options
- VII. **Irreversible and Irretrievable Commitments of Resources**
 - A. Unavoidable impacts irreversibly curtailing the range of potential uses of the environment
 - 1. Labor
 - 2. Materials
 - 3. Natural
 - 4. Cultural
- VIII. **Other Interests and Considerations of Federal Policy that Offset the Adverse Environmental Effects of the Proposed Plan**
 - A. Countervailing benefits of proposed action
 - B. Countervailing benefits of alternatives

Selection and Analysis of Alternatives

The selection and analysis of alternatives is an important element of all planning processes and of the impact analysis process. It is important to make sure that the alternatives that are studied are reasonable. This means that the group of alternatives that will be considered is not selected so as to make a favored alternative "look good." This is important and suggests that the "preferred" alternative not be identified as proposed in the regulation. It is also important that alternatives are discrete, which means that each alternative can on its own fulfill the objectives of the plan or project concerned. The analysis of the *null*, or no-action, alternative is also important from a policy point of view to show the value of the project or plan. Finally, it is important to identify the specific criteria, such as cost, environmental impact, and feasibility, by which each alternative is to be analyzed. The proposed alternatives and the criteria for their analysis are important elements of the early public participation process.

The analysis concerned should present the environmental impacts of the proposal and the alternatives thereto in a comparative form, thus sharply defining the issues and providing a clear basis for choice among the options available by the decision makers concerned and the public. The analysis should rigorously and objectively evaluate all reasonable alternatives including, importantly, the alternative of no action. For alternatives that were eliminated from the detailed study, the analysis should set forth the reasons for elimination. The analysis should also include appropriate potential mitigation measures not already included in the proposed action or alternatives thereto.

Comprehensive Assessment

To be comprehensive, the environmental assessment should include, to the extent possible, a description of all of the environmental impacts of the alternatives considered, including the proposed action; any adverse environmental effects which cannot be avoided should the proposal be implemented; the relationship between short-term uses of the environment and the maintenance and enhancement of long-term productivity; and any irreversible or irretrievable commitments of resources that would be involved in the proposed action. The assessment should include eight factors:

1. Direct effects and their significance
2. Indirect effects and their significance
3. Possible conflicts between the proposed action and the objectives of federal, regional, state, and local—and in the case of a reservation, Indian tribe—land use plans, policies and regulations for the area concerned
4. The environmental effects of alternatives including the proposed action
5. Energy requirements and conservation potential of various alternatives and mitigation measures
6. Natural or depletable resource requirements and conservation potential of various alternatives and mitigation measures
7. Urban quality, historic and cultural resources, and the design of the built environment, including the reuse and conservation potential of various alternative and mitigation measures
8. Means to mitigate adverse environmental impacts

Various methods and techniques have been devised to assist in making a comprehensive impact analysis. Each method needs to be adapted to the particular plan, project, or action under consideration to properly reflect the action and assess its impact. It is unlikely that any analysis, no matter how carefully made, will satisfy everyone, but it is important to describe the method or criteria used in the analysis early in the public participation process in order to attain consensus.

The methods used for analysis have certain steps in common. The first involves identification and grouping of the environmental categories or factors involved. One possible grouping is by social and physical factors as illustrated in Table 6.2.

Another category grouping used might be physical/chemical, ecological, aesthetic, social, with appropriate subcategories under each as illustrated in Table 6.3.

The second step in the method used for analysis includes selection of criteria, or standards within each subcategory that will measure the quality of the category. The third step involves measurement and interpretation of the significance of the criteria or standards and effect on each of the categories. These may include value judgments—that is, evaluation of scientific knowledge by an expert—and assessment of the value that society places on a factor.

TABLE 6.2 Social and Physical Factors Grouping

Social Services	Safety	Sense of Community
Education facilities	Structures	Structural organization
Employment	Materials	Homogeneity and diversity
Commercial facilities	Site Hazards	Physical stock and facilities
Health care/social services	Circulation conflicts	
Liquid waste disposal	Road safety and design	Psychological well being
Solid waste disposal		Physical threat
Water supply	Physiological well-being	Crowding
Stormwater drainage	Noise	Nuisance
Police	Vibration	
Fire	Odor	Historic value
Recreation	Light	Historic structures
Transportation	Temperature	Historic sites and districts
Cultural facilities	Disease	
		Visual quality
		Visual content
		Formal coherence
		Apparent access
Physical Geology	Special Features	Biota
Unique features	Sanitary landfill	Plant and animal special lists
Resource value	Wetlands	Vegetative community types
Slope stability/rockfall	Coastal zones/shorelines	Diversity
Foundation stability	Mine dumps/spoil areas	Productivity
Depth of impermeable layers		Nutrient cycling
Subsidence	Water	
Weathering/chemical release	Hydrologic balance	Climate and air
Tectonic activity/volcanism	Aquifer yield	Macroclimate hazards
	Groundwater recharge	Forest and range fires
	Groundwater flow direction	Heat balance
Soils		
Slope stability	Depth to water table	Wind alteration
Foundation support	Drainage/channel form	Humidity and precipitation
Shrink-swell	Sedimentation	Generation and dispersion of contaminants
Frost susceptibility	Impoundment leakage and slope failure	
Liquefaction	Flooding	Shadow effects
Erodibility	Water quality	
Permeability		Energy
		Energy requirements
		Conservation measures
		Environmental significance

TABLE 6.3 Physical/Chemical, Ecological, Aesthetic, and Social Factors Grouping**Physical/Chemical****Water**

Biochemical oxygen demand
 Groundwater flow
 Dissolved oxygen
 Fecal coliforms
 Inorganic carbon
 Inorganic nitrogen
 Inorganic phosphate
 Heavy metals
 Pesticides
 Petrochemicals
 pH
 Stream flow
 Temperature
 Total dissolved solids
 Toxic substances
 Turbidity

Noise

Intensity
 Duration
 Frequency

Ecological

Species and populations
 Game and non-game animals
 Natural vegetation
 Managed vegetation
 Resident and migratory birds
 Sports and commercial fisheries
 Pest species

Aesthetic**Land**

Geologic surface material
 Relief and topography

Air

Odor
 Visual
 Sounds

Land

Soil erosion
 Floodplain usage
 Buffer zones
 Soil suitability for use
 Compatibility of land uses
 Solid waste disposal

Air

Carbon monoxide
 Hydrocarbons
 Nitrogen oxides
 Particulate matter
 Photochemical oxidants
 Sulfur oxides
 Methane
 Hydrogen and organic sulfides
 Other

Habitats and Communities

Species diversity
 Rare and endangered species
 Food chain index

Ecosystems

Productivity
 Biogeochemical cycling
 Energy flow

Biota

Animals—wild and domestic
 Vegetation type
 Vegetation diversity

Manmade Objects

Consonance with environment

(continues)

TABLE 6.3 *(continued)*

Water	Composition
Flows and stages	Composite effect
Clarity	Unique composition
Interface of land and water	Mood atmosphere
Floating materials	
Social	
Individual Interests	Individual well being
Educational/scientific	Physiological health
Cultural	Psychological health
Historical	Safety
Leisure/recreation	Hygienic
	Community well being
	Social Interactions
	Political
	Socialization
	Religious
	Family
	Economic

To ensure proper consideration of potential impacts requires an interdisciplinary approach. Among the disciplines required may be the following:

- Land related: geography, geology, soils, geomorphology, land resources economics
- Air related: meteorology, bioclimatology
- Water related: hydrology, limnology
- Plant related: botany, forestry, microbiology
- Animal related: zoology, wildlife
- Human related: anthropology, sociology, medicine, economics, geography

The more significant or critical parameters or variables affected by the proposed actions or activities are identified for further study. This should include measurement of the effects—primary and secondary, or indirect—of the activities of humans on themselves and on the environment, and of the environment on humans. The effects of the actions or activities are evaluated as positive or negative and summarized as in Figure 6.6. The results are weighed and the total effects noted as none, moderate, or significant. Tables 6.4 and 6.5 can be helpful in this regard. Evaluation and interpretation of the data assembled, including methods to mitigate adverse effects, can then assist in making the environmental impact assessment and in preparing the environmental impact statement, if found necessary.

TABLE 6.4 Air Quality Parameters

Pollutant	High	Moderate	Poor	Federal Air Quality Standards	Notes
Particulates ($\mu\text{g}/\text{m}^3$) ^a PM _{2.5} PM ₁₀	0 to 80	80 to 230	230 to 500+	15 ^b 35 ^c 150 ^d	Visibility affected as low as 25 $\mu\text{g}/\text{m}^3$; human health effects begin at about 200 $\mu\text{g}/\text{m}^3$; condensation nuclei less desirable in concentrations less than 25 $\mu\text{g}/\text{m}^3$. The minimum SO ₂ concentration for vegetation damage is 0.03 ppm; less than 0.03 ppm can denote a safe environment; increased mortality observed at 0.2 ppm SO ₂ .
Sulfur oxides (ppm) ^e	0 to 0.10	0.10 to 0.17	0.17 to 0.25+	0.03 0.24 ^f	
Hydrocarbons (ppm) ^g	0 to 0.19	0.19 to 0.27	0.27 to 0.40+	—	Conditions for smog development approached at 0.15 to 0.25 ppm.
Nitrogen oxides (ppm) ^h	0 to 0.025	0.025 to 0.075	0.075 to 0.20+	0.05	Nitrogen dioxide is about four times more toxic than nitric oxide. Nitrogen dioxide below 0.05 ppm does not pose a health problem, but above that level begins to act as a toxic agent.
Carbon monoxide (ppm) —	—	—	—	9 ⁱ 35 ^j	Concentrations of 10 to 15 ppm for 8 hours or more can cause adverse health effects; 30 ppm can cause physiologic stress in patients with heart disease; 8 to 14 ppm correlated with increased fatality in hospitalized heart patients.
Photochemical oxidants (ppm) ozone —	—	—	—	0.08 ^k	Ozone can irritate lung airways and cause inflammation. Even at very low levels, ground-level ozone triggers a variety of health problems including aggravated asthma, reduced lung capacity, and increased susceptibility to respiratory

Asbestos	0.0	None visible	Visible	—	illnesses like pneumonia and bronchitis. Leaf injury in sensitive species after 4-hour exposure to 0.005 ppm. Polymers and rubber adversely affected. Smog develops at concentrations of 0.15 to 0.25 ppm. Long-term exposure to high concentrations of asbestos dust can cause asbestosis.
Beryllium (mg/m ³)	0.01	0.10	>0.10	—	Above 0.01 $\mu\text{g}/\text{m}^3$ produces disease; at 0.10 or above larger number develop disease; should not exceed 0.01 $\mu\text{g}/\text{m}^3$ over 30-day period.
Mercury (mg/m ³)	0.0	0.1	>1.0	—	Mercury should not exceed 1.0 $\mu\text{g}/\text{m}^3$ over 30-day averaging period.
Odor	No odor to odor threshold	Odor threshold to slight odor	Slight odor to strong odor	—	Odor threshold can be detected by 5 to 10 percent of panelists. Moderate odor can be detected by about 40 percent; strong odor by 100 percent.

^aBased on 24-hour annual geometric mean.

^bBased on a 3-year average of the weighted annual mean $\text{PM}_{2.5}$ concentrations.

^cBased on a 3-year average of the 98th percentile of 24-hour $\text{PM}_{2.5}$ concentrations.

^dBased on a maximum PM_{10} concentration not to be exceeded more than once a year

^eBased on 24-hour annual arithmetic mean.

^fBased on maximum 24-hour concentration not to be exceeded more than once a year.

^gBased on 3-hour average annual concentration.

^hBased on average annual concentration.

ⁱBased on maximum 8-hour concentration not to be exceeded more than once a year.

^jBased on maximum 1-hour concentration not to be exceed more than once a year.

^kBased on 3-year average of the 4th highest daily maximum 8-hour average.

Source: Information abstracted from *Environmental Quality handbook for Environmental Impact Analysis*, Department of the Army, April 1975, pp. A-1 to A-1. Superintendent of Documents, GPO, Washington, D.C., 2402 and United States Environmental Protection Agency.

TABLE 6.5 Selected Attributes (Variables) and Environmental Impact Categories—Water Quality

Selected Attributes	Observed Condition	1 ^a	2 ^a	3 ^a	4 ^a	5 ^a
Physical aquifer safe yield ^b	Changes occurring in physical attributes of aquifer (porosity, permeability, transmissibility, storage coefficient, etc.)	No change	No change	Slight change	Significant change	Extensive change
Flow variations ^c	Flow variation attributed to activities: Q_{max}/Q_{min}	None	None	Slight	Significant	Extensive
Oil ^d	Visible silvery sheen on surface, oily taste and odor to water and/or to fish and edible invertebrates, coating of banks and bottom or tainting of attached associated biota	None	None	Slight	Significant	Extensive
Radioactivity ^{d,e}	Measured radiation limit 10^{-7} $\mu\text{Ci/ml}$ 5pCi/l	Equal to or less	Equal to or less	Exceed limit	Exceed limit	Exceed limit
Suspended solids ^c	Sample observed in a glass bottle	Clear	Clear	Fairly clear	Slightly turbid	Turbid
	Turbidity in Jackson Turbidity Units	3 or less	10	40	60	140
	Suspended solids mg/l	4 or less	10	15	20	35
Thermal discharge ^c	Magnitude of departure from natural condition	0	1	2	4	6
Chemical	Departure from natural condition	0	1	2	3	4
	pH units					10
Acid and alkali	mg/l	1	2	3	5	Low
BOD ^d	Percent saturation	100	85	75	60	High
DO ^c	mg/l	300 or less	400	500	1,000	Large

Dissolved solids ^d	Total phosphorus, mg/l	0.02 or less	0.05	0.10	0.20	Large
Nutrients ^c						
Toxic compounds ^e	Concentration, mg/l	Not detected				
Pharmaceuticals and personal care products	Concentration, mg/l	Not detected	Traces	Traces	Small	Large
Synthetic organic compounds (pesticides and herbicides) ^d	Concentration, mg/l	Not detected	Traces	Traces	Small	Large
Biological fecal coliforms and E-coli ^d	Number per 100 ml	50 or below	200	1,000	20,000	Large
Aquatic life ^c	Green algae	Scarce	Moderate quantities in shallows	Plentiful in shallows	Abundant	Abundant
	Gray algae	Scarce	Scarce	Scarce	Present	Plentiful
	Delicate fish; trout, grayling	May be plentiful	Plentiful	Probably absent	Scarce	Absent
	Coarse fish; chub, dace, carp, roach	May be present	Plentiful	Plentiful	Scarce	Absent
	Mayfly naiad, stonefly nymph	May be plentiful	Plentiful	Scarce	Absent	Absent
	Bloodworm, sludge worm, midge larvae, rat-tailed maggot, swage fly larva and pupa	May be absent	Scarce	May be present	Plentiful	Abundant

^aEnvironmental Impact Category. Category 1 indicates most desirable condition; Category 5 indicates an extensive adverse condition. Because all attributes are related to environmental quality between 0 and 1, it is possible to compare attributes and five categories on a common base. Each category is equivalent to approximately 10 percent of the overall environmental quality. In the physical sense, water quality for five categories will be very clean, clean, fairly clean, doubtful and bad. Environmental impact may be adverse or favorable. Adverse impact will deteriorate the environmental quality while favorable impact will improve the quality. Proper signs and weights must be used to achieve overall effects.

^bApplies to groundwater systems only.

^cApplies to surface water systems only.

^dApplies to both the groundwater and surface water.

^eSurface combined radium—226 and radium—228.

Source: Adapted from *Environmental Quality Handbook for Environmental Impact Analysis*, Headquarters, Department of the Army, April 1975, Supt. Of Documents, GPO, Washington, D.C.

Since the goal is to measure the impact of the project being considered on the environmental attributes, a great deal of expert professional judgment is needed to identify, evaluate, and weigh the significance of the information assembled. Engineering is one of the important areas of expertise required.

BIBLIOGRAPHY

- Kent, T. J., “ *The Urban General Plan*, ” APA Planners Press, 1990.
- Dion, Thomas R., “ *Land Development for Civil Engineers*, ” John Wiley and Sons, New York, 1993.
- Dewberry, Sidney O., “ *Land Development Handbook*, ” McGraw Hill, New York, 2003.
- Anderson, L. T., “ *Planning the Built Environment*, ” Planners Press, 2000.
- Bruegman, Robert, “ *Sprawl—A Compact History*, ” University of Chicago Press, Chicago, 2005.
- Environmental Audits—Internal Due Diligence*, MOP FD-18, Water Pollution Control Federation, Alexandria, VA, 1989.
- Environmental Impact Assessment Methods: An Overview*, NTIS, PB-226 276, U.S. Department of Commerce, Washington, DC, 1973.
- Handbook for Environmental Impact Analysis*, Department of the Army, U.S. Government Printing Office, Washington, DC, 1975.
- National Environmental Policy Act of 1962 as amended 42 USC 4321-4347 .

INDEX

A

- Aalborg Portland, 69
- Absolute auditory threshold, 370f
- Absorption ratios, slag type comparison, 64f
- Acid rain (acidic precipitation), 319–320
 - control measures, 320
 - impact, 320
- Activated carbon, usage, 358
- Activated-carbon adsorption bed, life (reduction), 358
- Adhesive materials, expense, 17
- Adjacent barriers, usage, 381
- Administrative hearing letter, 116f
- Administrative plan implementation
 - actions, prerogative, 446–447
- Adsorbers, 358
- Adsorption, process, 358
- Advanced direct waste recycling industry, inclusion, 66
- Aerated static pile, composting, 232
 - process, 234–235
- Aeration. *See* Forced aeration
 - composting factor, 26
- Aerobic composting process, design considerations, 237t
- Aerobic fermentation process, 25–26. *See also* Anaerobic fermentation process
- Aerosol collection equipment, operating principles, 351
- Aerosols, inertial entrapment, 351
- Aesthetic factors grouping, 517t–518t
- African countries, industry classifications, 2
- Agglomerate marble, 51
- Agglomeration machine, 15f
- Aggregates, elasticity (modulus), 49
- Air change, measurement, 149
- Air circulation
 - levels, 334–335
 - organized circulations, 335
- Air composition, 310t
- Air contaminants, 141
 - production, 361
- Air cooling rate. *See* Warm dry air
- Air flow, turbulence (impact), 336
- Air infiltration, reduction, 148
- Air layer, instability, 337
- Air monitoring
 - data, usage, 327
 - updates, 360
- Air motion, 334
 - order of importance, 334
- Air opacity, 326
- Air parcels, vertical motion/displacement, 336–337
- Air pollutants. *See* Hazardous air pollutants; Indoor air
 - behavior, 333
 - concentration, 334–335
 - model, accuracy, 362–363
 - plume diffusion, meteorological conditions (impact), 358–359
 - types, 325
 - wind speed, impact, 336f
- Air pollution, 309–310
 - aesthetic/climatic impact, 315–320
 - analyses, 341–342
 - carbon monoxide, contribution, 322t
 - concentration data, 362–363
 - control equipment

- Air pollution (*Continued*)
- design, 351
 - requirement. *See* Incinerators
 - controls, 347–363
 - achievement, 350
 - dilution, stack height (impact), 358–360
 - direct impact, observation, 333
 - economic impact, 311–320
 - effects (minimization), steps (WHO Expect Committee recommendations), 360–361
 - emission inventory, data, 341
 - environmental factors, 333–340
 - episodes, 311
 - list, 312t–313t
 - health impact, 310–311
 - impact. *See* Animals; Plants
 - interference, absence, 473
 - inventory, 340
 - lead, contribution, 324t
 - manmade sources, 321
 - mathematical models, 341
 - measurement, 326–333
 - meteorological data, 362
 - model, accuracy, 362–363
 - natural sources, 321, 324–325
 - nitrogen oxides, contribution, 322t
 - organization/staffing, 365
 - particulates, range, 321
 - planning/zoning, 360–361
 - PM_{2.5}, contribution, 324t
 - PM₁₀, contribution, 323t
 - program/enforcement, 363–367
 - information, 363–364
 - regulation/administration, 365, 367
 - sampling, 326–333, 341
 - short-term/long-term objectives/priorities, 341–342
 - source control, 347–351
 - source emission data, 362
 - sources/types, 320–325
 - standards, 275
 - studies, 341–342
 - implementation, proposal, 363–364
 - sulfur dioxide, contribution, 323t
 - surveys, 340–342
 - U.S. source/type, 322t–324t
 - VOCs, contribution, 322t–323t
- Air quality. *See* Indoor air
- maintenance, 360
 - modeling, 361–363
 - models, categorization, 361
 - monitoring system, 327
 - parameters, 520t–521t
 - measurement methods. *See* Ambient air
 - public/private agencies, working relationships/memoranda of agreements (development), 367
 - real-time data, 327
 - standards. *See* Hospitals; Nursing homes
- Air Quality Act of 1967, 342
- Air resources management functional organization chart, 366t
- Air sampling
- devices, usage, 326
 - sites, 341
- Air zoning, air quality standards, 360
- Airborne exposure limit, OSHA limit, 145
- Air-cooled slag, cutting, 69
- Alexandria National Iron and Steel Company, slag study, 61–62
- Alkyds, 9
- Ambient air
- federal standards, 342–345
 - particulate sampling, 327–328
 - quality
 - improvement, CAA (impact), 345
 - parameters, measurement methods, 326t
 - standards, 342–347
 - sedimentation/settling devices, usage, 328
 - TSP measurement, 328
- Ambient noise, 369
- American Conference of Governmental Hygienists, sound pressure recommendations, 384
- American National Standards Institute (ANSI) specifications, 377
- American Public Health Association (APHA)
- appraisal items, 92t
 - appraisal method. *See* Quality of living
 - application, 95
 - development, 91
 - basic deficiencies of dwellings, 93t

Committee on the Hygiene of Housing,
health criteria, 99–103
environmental survey, standard penalty
scores, 94t–95t
housing quality scores, 95t
maximum standard penalty scores, 92t
American Society of Civil Engineers
surveying/mapping division, 395
urban planning development division,
429
American Society of Heating, Refrigerating
and Air Conditioning Engineers
(ASHRAE), comfort zone description,
147
American University in Cairo (AUC),
cradle-to-cradle approach, 7
Anaerobic fermentation process, 29
Animals
air pollution, impact, 315
wastes, collection, 195
ANSI. *See* American National Standards
Institute
Apartments, dirt, 126
APHA. *See* American Public Health
Association
Area landfill, 249f
Area method. *See* Sanitary landfill
Area-type landfill, geomembrane liner
(placement), 255f
Ash monofill waste landfill liner
configuration, 256f
Ash residue, 178
ASHRAE Guide and Data Book, Systems
(1970), 384
Asian countries, industry classifications, 2
Asnaes Power Station, fish farm, 69
Asphalt concrete containing slag, Marshall
Test, 62t
Asphalt mixtures, 39
Assembly/examination phase, sand molding
process, 53
Atmosphere, stability/instability, 336–337
Atmospheric vacuum breaker, 136f
Atomic Energy Act, 293, 296
Atomic spectrometry, usage, 330
Attic, refuse (presence), 125
AUC. *See* American University in Cairo
Automatic (tape) smoke sampler, usage,
328

Automobile catalytic converters, impact,
325
Average transmission coefficient. *See* Sound

B

Backflow prevention, 134–137
Background noise, 378
correction, 379
Baghouse filters, 352–353
diagram, 354f
Ball mill machine, 15f
usage, 16
Bangalore composting, 236
Base road pavement layer, usage, 39
Basic oxygen furnace (BOF)
dust/sludge, generation, 57
fume formation, reduction, 63
slag
management, 59
production, 57
stockpiles, 58
study, 61
usage, 56
Basic Principles of Healthful Housing
(APHA), 99
Bell, Alexander Graham, 370
Bench marks, 403
BF. *See* Blast furnace
Biodegradable material, 178
Biogas
applications, 31
energy source uses, 30t
Biological contaminants
health effects, 140–141
sources, 141
Bioreactor type landfill, leachate
recirculation, 257f
Blast furnace (BF)
dust/sludge, generation, 57
usage, 56
BOF. *See* Basic oxygen furnace
Bonded marble, example, 52f
Bottle law. *See* Returnable bottle deposit
law
Bottom ash, disposal, 287, 289
Bricks
development, 17, 19
photo, 19f
tiles, compositions, 46t

Buffalo (New York), population trends, 84f

Buildings

- acid rain, impact, 320
- code, 445
- department letters, landlord seizures, 113
- hot water demands/use, 134f
- location, 478
 - land use, 472
- roads, access, 475–476

Bulldozer. *See* Tracked bulldozer

blade, usage. *See* Crawler tractor

C

CAA. *See* Clean Air Act

Cadastral maps. *See* Large-scale cadastral maps

usage, 471

Candida spp., impact, 156

Canyon landfill, 249f

Capacity ranges. *See* Materials recovery facility

Capital improvement program

- completion/adoption, 467
- preparation, 446
- usage, 445–446

Carbon dioxide

- impact. *See* Global warming
- release, 319

Carbon monoxide

- infrared (IR) analyzer, usage, 331
- NAAQS, 343

Carbon tetrachloride, phaseout, 346

Carbon to nitrogen ratio, composting factor, 26

Cascade impactor, usage, 329

Cast marble, 51

Casting resin, 51

Catalytic afterburners, 357

Categorical exclusion, term (usage), 507

Cathode-ray oscillograph, usage. *See* Noise

Celestial observation, 398

Cellar occupancy, unlawfulness, 127

Cement

- bypass dust
 - alkalinity levels, 38
 - chemical analysis, 33f
 - disposal, 33
 - environmental/socioeconomic benefits, 39–40

chemical combinations, 31

cleaner production, natural resources (usage), 34

dry production, 32

industrial ecology approach, 34–36

industry, 31–40

kilns, usage, 32

natural stone slurry, incorporation, 45

passive composting technique, 38

process routes, 31–32

production

- emissions, 32
- process, 31–32
- techniques, core element, 33–34

recycling

- glass/ceramic glass, usage, 37
- opportunities, 36
- road pavement layers, usage, 39
- sewage sludge, composting, 37–38
- tiles/bricks/interlocks, usage, 37–39

utilization, production techniques, 33–34

wastes

- exchange, recycling, 69
- treatment/disposal, 33
- usage, 38–39

wet production, 32

Cement kiln dust (CKD), 32–33

addition, 65

collection, 33

Cement-based products, 50

Census data, 96

Centralized electric power, availability, 475

Centrifugal collection equipment, 328

Centrifugal scrubber, 355

Centrifugal wash collector, 356f

Ceramic glass, usage. *See* Cement

CERCLA. *See* Comprehensive

- Environmental Response,
- Compensation, and Liability Act of 1980

Certificate of occupancy, requirement, 118

CFCs. *See* Chlorofluorocarbons

Chemical additives, usage, 26

Chemical Emergency Center

- (CHEMTREC), operation, 301

Chemical recycling, 10

Chemical resistance

- properties, determination, 73–74
- test, 73–74

- Chemical Safety Information, Site Security and Fuels Regulatory Relief Act, 494
- CHEMTREC. *See* Chemical Emergency Center
- Chinese fixed dome, 29
 - digester, 29f
- Chloramines, impact, 157, 159
- Chlorobenzenes, organics, 351
- Chlorofluorocarbons (CFCs)
 - impact, 318–319. *See also* Ozone phaseout, 346
 - stratosphere existence, 318
- Chlorophenols, organics, 351
- Circular covers, movement, 21
- City planning
 - rational process, 429–430
 - usage, 431
- CKD. *See* Cement kiln dust
- Clark Spheroid of 1866, 398, 404
- Class I compost, metal concentrations (maximum), 230t
- Class II compost, metal concentrations (maximum), 230t
- Clean Air Act (CAA), 293, 295, 342, 495
 - amendments, 343
 - usage, 346
 - cost/benefit, EPA assessment, 311, 314
 - mean values, 314
 - Title IV, 345–346
 - Title V–XI, 346
 - Titles I–III, 345
 - usage, 345–346
- Clean dry air, composition, 310t
- Clean Water Act, 293, 295, 495
- Cleaning/inspection, sand molding process, 53
- Climate Change 2001*, 217
- Closed container, stationary compactor (connection), 200f
- Cloth screen filters, 352–353
- Cluster subdivision, advantages, 490
- Coal
 - burning, reductions (necessity), 317
 - coke transformation, 56
 - source reduction, 320
- Code of Federal Regulations*, Title 40, Parts 257–258, 242
- Coefficient of haze (COH), tape sampler (usage), 332
- Collection. *See* Solid waste
 - containers, examples, 203f
 - systems, container types/capacities (data), 205t
 - vehicles
 - application. *See* Manual loading
 - collection vehicles
 - examples, 203f. *See also* Commingled solid waste; Front-loaded collection vehicle; Mechanically loaded collection vehicles
- Collector-driver, usage, 204
- Colleges, sanitation, 163
- Combined direct-load/discharge load solid waste transfer stations, development, 210
- Combustible hydrocarbons, impurities, 325
- Combustion, 279. *See also* Waste-to-energy
 - combustion
 - chamber
 - gases, exit, 282
 - temperature monitoring, 286
 - essentials, 281–282
 - particulate emissions, 287
 - products/residues, 281–283
 - residues, 283
 - time/temperature/turbulence, impact, 281
 - units. *See* Modular combustion units
- Combustors, 283–287. *See also* Mass-fired
 - combustors; Refuse derived fuel
- Comfort zones, 147
- Commercial discount store, drop boxes (usage), 204f
- Commercial noise, 377
- Commercial solid waste
 - containers, usage, 200f
 - handling/storage, 199
 - placement, manual collection (example), 201f
- Commercial waste, 178
 - contamination, 189
- Commingled solid waste
 - MRF, usage, 218
 - examples, 219t–220t
 - rear-loaded collection vehicle, example, 206f
 - side-loaded right-hand standup drive collection vehicle, example, 206f

Community

- development objectives/goals, 467
- fiscal stability, 481
- physical development, plan, 436
- planning, environmental health
 - considerations, 503
- sanitary landfills, leachate, 252
- solid waste, sources, 186t
- zoning ordinances, 482

Community facilities, 101–102

- comprehensive plan requirement, 441
- plan component, 434
- plan element, 435

Compaction equipment, 272f

Completed landfill, use, 278–279

Composite material

- maximum flexural load, 73f
- tensile strengths, 82f

Composite pavement base material,

- steel-making/BG slag combination (usage), 60–61

Compost

- aeration, machine (usage), 234f
- chemicals, presence, 240
- definition, concepts/objectives, 230
- metal concentrations, maximum. *See* Class I compost; Class II compost
- microbial activity, 238
- odor control, 238–239
- operational considerations, 236–239
- organic material,
 - decomposition/stabilization, 231
- pathogen control, 236, 238
- pesticides/heavy metals/pathogens, toxic levels (determination/evaluation), 229–230
- pile, schematic. *See* Static aerated compost pile
- postprocessing, 232
- preprocessing, 231
- process design, 236–239
- product quality, 241
- salmonella repopulation, 238
- temperature, WHO recommendation, 238
- uses/constraints, 229–230

Composting, 178. *See also* Natural

- composting; Passive composting; Vermi composting
- applications, 226

biological odor management, 240

cost, 241–242

discussion, 225–242

facilities

- implementation, issues, 239–240
- odor production, 239
- public health issues, 240
- siting, 239

factors, 26

growth, 182

health hazard, 240–241

market analysis, 241–242

mechanical systems, 235–236

operation. *See* Windrow composting

heavy metal toxicity, 241–242

perception/usages, 182–183

process, 25, 230–232

design/operation, 239–240

diagram, 25f

steps, 231–232

systems, function/reactor configuration.

See Municipal composting systems

technologies, 232

discussion, 236

time, determination. *See* Total

composting time

Comprehensive Environmental Response,

- Compensation, and Liability Act of 1980 (CERCLA), 293, 295, 495

air quality issues, 343, 345

Comprehensive plan, 433–437

preparation process, 437f

preparation requirements, 439–443

public health element, 497–502

public participation, 465–466

Comprehensive planning

alternatives, development/evaluation, 444

development requirements, identification, 443–444

implementation, policy development (relationship), 445–447

inventory analysis, 438–443

objectives/standards, formulation, 443

process, 437–447

continuing nature, 466–467

value, 467

public participation process, 444

Comprehensive public planning,

469–470

Concrete
 compressive strength, 48–49
 elasticity, modulus, 49–50
 ground granulated BF slag, usage, 60
 marble slurry, usage, 47–50
 mix properties, 48t
 tensile strength, 49

Condensers, usage, 357–358

Conformal, term (usage/meaning), 401

Conformal projection, properties, 401

Conic projection, creation (concepts), 400f

Construction debris, 192–194

Consumer Products Safety Commission (CPSC), 296

Contagious diseases, containment, 497

Container types/capacities, data, 205t

Contaminants, 141–147. *See also* Air
 contaminants; Biological contaminants
 precipitation, 351
 separation, 223f

Contaminated water, backflow, 134

Continuous slag granulation system, 59f

Control survey, 409–410
 network, 409
 system, adoption, 409

Cork industry, 22–24
 cradle-to-cradle concept, process flow
 diagram, 23f

Correctional institutions
 food service sanitation, improvement,
 165
 overcrowding, elimination, 165
 sanitation, 163–167
 ventilation, usage, 149

Corridor planning stage, insertion. *See*
 Public infrastructure development
 projects

Cost internalization, 181

Cover material, usage. *See* Surface water

CPSC. *See* Consumer Products Safety
 Commission

Cradle-to-cradle approach. *See* American
 University in Cairo
 sustainability indicator, 65

Cradle-to-cradle concept, 4
 importance, 4–7
 material manufacture/recovery, 7
 usage, 36

Cradle-to-cradle principles, adoption, 7

Cradle-to-grave approach, shift (proposal),
 6

Cradle-to-grave concept, 3–4
 flowchart, 4f
 usage. *See* Sustainable development

Crawler tractor, bulldozer blade (usage),
 269

Cumulative impact, term (usage), 507

Curbside collection
 labor requirements, 209t
 service, 198

Curvilinear subdivision
 design, 488–489
 grading, 489
 layout, 488f

Cyclones
 dust flow, 352
 separator, diagram, 353f
 spiraling movement, 352

D

Dano composting, 236

Day-care centers, sanitation, 169

Day-Night Average Sound Level (DNL)
 system, 375

Decent home environment, 83
 realization, 83

Decibel (dB), 370. *See also* Sound

Demographics
 comprehensive plan requirement, 439
 plan component, 433

Demolition debris, 192–194

Densified RDF (d-RDF), costliness, 284

Department of Public Works, jurisdiction,
 105–106

Design noise level-land use relationships,
 386

Deterioration, first sign. *See* Housing

Development plans, requirements
 anticipation, 443–444

Development requirements, identification.
See Comprehensive planning

Dichlorodifluoromethane (Freon), CFC
 source, 318

Direct astronomic observation, 396

Direct discharge solid waste transfer station
 definition sketch, 213f
 stationary compactors, inclusion, 214f

Direct effects, cause, 507

Direct load solid waste transfer stations, 210–211
 uncompacted wastes, hauling (acceptance), 211

Direct reduction, 55
 method, 56

Direct waste recycling industry, 65, 66
 flowchart, 66f

DNL. *See* Day-Night Average Sound Level

Domestic wastewater, RCRA regulations (absence), 293

Double separated wall, usage, 383

Double-bottom composite liner system, 254f

Drag line, 270f
 suitability. *See* Trenches

Drainage area tributary, runoff (determination), 263

Drainage survey, 474–475

d-RDF. *See* Densified RDF

Drinking water, radon level (EPA proposal), 143

Drop boxes, usage, 204f

Dry adiabatic process lapse rate, 337

Dry scrubber technology, 356

Dry slag granulation, 60f

Dry slurry, atmospheric diffusion, 45

Duct injection technology, 356

Dust emission
 impact, 32
 reduction/control, 33

Dust flow. *See* Cyclones

Dwellings
 basic deficiencies (APHA), 93t
 survey, example, 98f

E

EAF. *See* Electrical arc furnace

Earth
 curvature, 399
 mover, 270f
 surface, features (location), 396
 topographic surface, 396
 geoid/reference ellipsoid, relationship, 397f
 warming, UV radiation (impact), 316

Earth cover
 leachate/methane control, 265–266
 recommendation, 266–267

EBICs. *See* Environmentally balanced industrial complexes

Eco-industrial parks
 concept, 6–7
 recognition, 35–36

Ecological factors grouping, 517t–518t

Economic base
 comprehensive plan requirement, 439
 plan component, 433

EEC. *See* European Economic Community

Effects, term (usage), 507

Egypt
 iron/steel waste materials, generation, 58t
 marble/granite deposits, 40–41
 slag cement, problems, 58

EIS. *See* Environmental impact statement

Eisensia Foetida. *See* Red wiggler

Ejector venturis, 355

Elasticity, modulus. *See* Concrete; Mortars

Electric power generation, proposal, 476

Electrical arc furnace (EAF), 56
 dust, zinc (presence), 56
 fume formation, reduction, 63
 slag
 production, 56
 usage, study, 62

Electrostatic precipitators, 354
 usage, 355

Electrostatic precipitator-type sampling devices, usage, 329

Ellipsoid latitude/longitude, 397f

Embankment, stone slurry (usage), 50

Emergency Planning and Community Right-to-Know Act (EPCRA), 495
 air quality issues, 345

Emergency storage capacity, 210–211

Emissions
 control equipment, 351
 impact, 146–147

Endangered Species Act (ESA), 495

Engineering. *See* Environmental engineering
 role, 502–503

Enterobacter spp., impact, 156

Entrainment scrubber, 355

Environmental assessment, 429
 conducting, 504
 impact statements, relationship, 505

term, usage, 507–508
value, 505

Environmental control officer, duties, 157

Environmental control programs, 102

Environmental corridors
assessment, 477–478
concept, advancement, 477

Environmental engineering
map requirements, 407–410
surveying/mapping, 396

Environmental impact analysis, 505–524
scoping, 508–509
terminology, 506–508

Environmental impact statement (EIS), 505
actions/activities, impact, 519f
aesthetic factors grouping, 517t–518t
air quality parameters, 520t–521t
alternatives, selection/analysis, 514
assessment, factors, 515
attention, 511
attributes, 522t–523t
comprehensive assessment, 515–524
content, 510–514
disciplines, requirement, 518
ecological factors grouping, 517t–518t
environmental impact categories,
522t–523t
factors, consideration, 511
format, recommendation, 509
impact description, 510–511
outline, recommendation, 513–514
physical/chemical factors grouping,
517t–518t
proposed action
alternatives, 511–512
description, 510
social/physical factors grouping,
516t–518t
term, usage, 508

Environmental inspection/report outline,
167–169

Environmental lapse rate, 337

Environmental protection, 68
cradle-to-grave approach, 5
LCA, usage, 5–6

Environmental quality, 102

Environmental sanitation. *See* Housing

Environmental survey, standard penalty
scores (APHA), 94t–95t

Environmentally balanced industrial
complexes (EBICs), 65, 69
development, 65

EPA. *See* U.S. Environmental Protection
Agency

EPCRA. *See* Emergency Planning and
Community Right-to-Know Act

Epoxy, 9

EPR. *See* Extended producer responsibility

Equal loudness contour, 374f

Equipment. *See* Landfills
shelter, 273–274

Erie County (New York), population trends,
84f

ESA. *See* Endangered Species Act

Ethylene, plant impact, 314

European Economic Community (EEC),
CFC phaseout, 318–319

Excess air combustion, 283

Extended producer responsibility (EPR), 7

Exterior paint, necessity, 123

F

Facilities. *See* Community facilities;
Individual facilities
environment inspection/report outline,
168
plans, 447

Fairfield-Hardy composting, 236

FDA. *See* Food and Drug Administration

Federal agency, term (usage), 508

Federal Aid Highway Act of 1962,
495–496

Federal Aviation Administration (FAA), 496

Federal Demonstration Cities and
Metropolitan Development Act of
1966, 495

Federal Food, Drug, and Cosmetic Act
(FFDCA), 495

Federal Highway Act of 1970, 384

Federal Housing Act of 1954, Section 701,
495

Federal Housing and Home Finance
Agency (HHFA), 495

Federal Insecticide, Fungicide, and
Rodenticide Act (FIFRA), 495

Federal model city planning enabling act of
1927, 432

Federal Water Quality Act of 1972, 496

- Fertilizer, restriction, 69
- FFDCA. *See* Federal Food, Drug, and Cosmetic Act
- Fiber-reinforced plastic (FRP) manholes, 21
- FIFRA. *See* Federal Insecticide, Fungicide, and Rodenticide Act
- Filters. *See* Particulates
- Final engineering/construction, 447
- involvement, 469
- movement, 467–468
- Financing clinic, usage, 113–114
- Finding of no significant impact, term (usage), 508
- Finished steel products, routes, 55
- Finishing/storage phase, sand molding process, 53
- Fired products, properties, 47t
- Fires, smoke (impact), 147
- Fish form, 69
- Fixture plumbing, details, 138f
- Fixture supply/drain, minimum sizes, 133t
- Fixture trap, vent distance, 133t
- Flexural test, 72–73
- Flood hazard, presence (determination), 474
- Floor tiles, compositions, 46t
- Floors, water protection, 121
- Fly ash, 178
- disposal, 287, 289
- reaction, 356
- FOIA. *See* Freedom of Information Act
- Food and Drug Administration (FDA), 296
- Food industry, 25–31
- Food Quality Protection Act (FQPA), 495
- Food waste, 178
- Forced aeration, 27
- Forests, burning (impact), 316
- Formaldehyde, 144–145
- occupational exposure, reduction, 145
- organics, 351
- sources, 144–145
- Fossil fuels, burning (impact), 316
- Fossil-fuel-fired electric generating stations/plants, 347
- Foundry sand, 53–54
- agricultural products, 54
- chemical composition, 55t
- geotechnical applications, 54
- manufactured products, 55
- maximum flexural load, 73f
- reinforcement. *See* Plastics
- tensile strengths, 72f
- usage, 67
- uses, 54–55
- FQPA. *See* Food Quality Protection Act
- Freedom of Information Act (FOIA), 495
- Freon. *See* Dichlorodifluoromethane
- Frequency. *See* Sound
- Fresh air makeup, reduction, 148
- Frontal inversion, 338
- Front-end loader, 270f
- bullclam, inclusion, 270f
- Front-loaded collection vehicle, example, 208f
- FRP. *See* Fiber-reinforced plastic
- Fugitive emissions, 321
- Furans, organics, 351
- Furnace flue, defect, 128

G

- GAC. *See* Granular activated-carbon
- Garbage, 178
- shed, dilapidation, 125–126
- storage, 125
- Gaseous collectors/treatment devices, 357–358
- Gases. *See* Landfills
- combustion products, 282–283
- extraction system, 264f
- extraction well, diagram, 265f
- impact. *See* Global warming;
- Greenhouse gases
- release, 357
- sampling, 329–331
- treatment, 354
- warming effect, 316
- Gas-monitoring wells, sampling, 278
- Gaussian air quality modeling, 361
- General obligation bonds, issuance, 446
- Geodetic Reference System ellipsoid of 1980, 404
- Geodetic Reference System of 1980, 398
- Geographic area, graphic representation, 396
- Geographic location, data (relationship), 396
- Geoid, 396–397
- Geology, study, 474–475

Geomatics, 395
 Geomembrane, 178
 placement. *See* Area-type landfill
 Glass, usage. *See* Cement
 Global warming
 carbon dioxide, impact, 316–318
 gases, impact, 316–318
 Goals, objectives (planner distinction), 443
 GOS. *See* Gravity oil separator
 Government surveyors, instructions, 407
 Granite
 environmental impacts/mitigation, 44–51
 industry, 40–51
 scrapes, 44
 semisolid/slurry waste, 43
 solid wastes, 43
 waste, 42–43
 application, 45
 distribution, 42t
 types, 43
 usage. *See* Polymer concrete
 Granular activated-carbon (GAC) filter,
 usage, 143
 Gravity oil separator (GOS), 66
 Gray-list projects/industries, environmental
 impacts, 2–3
 Green sand, 53
 Greenbelts, provisions, 361
 Greenhouse gases, impact, 317
 Ground granulated BF slag, usage. *See*
 Concrete
 Ground-level ozone issues, addressing, 346
 Ground-level pollutant concentration,
 variation, 359f
 Grounds, environment inspection/report
 outline, 167
 Groundwater, 178
 leachate contamination, 240
 source, adequacy, 472
 Growth/change (anticipation), plan
 component, 434
 Gutters, absence, 124–125
 Gyproc, 68

H

Habitable room, window (absence), 127
 Halons, phaseout, 346
 Handrails, absence, 125

Haul distances, impact. *See* Incineration;
 Sanitary landfill
 Hauled container systems (HCSs), 202
 personnel requirements, 204
 suitability, 202
 Hawkins, David G., 374
 Hazardous air pollutants, 345t
 Hazardous Materials Transportation Act,
 296
 Hazardous waste, 178, 292–305
 biological degradation, 305
 business/industry generation, examples,
 300t
 characteristics, 292–293
 chemical treatment, 305
 corrosivity, 292
 definition, 292–293
 generation, 296, 300
 ranking, 296
 ignitability, 292
 inclusion, 292
 in-place vitrification, 305
 land disposal, prohibition. *See* Untreated
 hazardous waste
 landfill burial, 305
 laws, 295–296
 legislation, 293
 lining materials,
 effectiveness/compatibility, 304
 long-term storage, 301, 304
 management, 300–305
 control principles, 304–305
 material, 75
 meaning, RCRA (usage), 292
 processing technologies, 301
 RCRA regulations, absence, 293
 reactivity (explosiveness), 292
 recycling, 301
 reduction, 300–301
 toxicity, 292
 identification, 296
 transportation, 301
 treatment methods, 302t–303t
 zero discharge, goal, 300
 HCFC, phaseout, 346
 HCSs. *See* Hauled container systems
 HDPE. *See* High-density polyethylene
 Health
 action, principles, 103

Health (*Continued*)

- criteria (APHA), 99–103
- department, impact, 106–107
- letters, landlord seizures, 113
- needs, principles, 102–103
- Hearing protection/conservation, criteria, 375
- Heating units, venting, 151–154
- Heavy metals, leachate, 74
- HFC. *See* Hydrofluorocarbon
- HHFA. *See* Federal Housing and Home Finance Agency
- High-density polyethylene (HDPE), 9
- High-rise apartments, solid waste
 - handling/storage, 198–199
- High-volume samplers, usage, 328
- Highway noise, reception (control), 381
- Hoist truck, example, 203f
- Horizontal axis mixing/heating furnace, 18f
- Horizontal axis shredders, usage, 14
- Horizontal control network, 403
- Horizontal survey control network, 402–403
- Hose Bibb vacuum breaker, 136f
- Hospitals
 - air quality standards, 162
 - construction, 157
 - environmental health survey form, 158f–159f
 - fire resistance, attention. *See* Non-fire-resistive hospitals/nursing homes
 - fire safety, concerns, 157
 - health care, providing, 159–160
 - hospital-acquired infection rate, 156
 - infection surveillance/control program
 - guidelines, 159
 - infectious/pathological wastes, disposal, 162
 - laundry, wash-water temperatures, 159
 - low-level radioactive solid waste, disposal, 163
 - sanitation, 156–160
 - survey/inspection, 160
 - wastes, 160, 162–163
- Hot paste, transfer, 16
- Hot water
 - absence, 119
 - demands/uses, 134t

Household hazardous waste, contamination, 189

Housing

- apartments, dirtiness, 126
- attic, refuse (presence), 125
- cellar occupancy, unlawfulness, 127
- codes, 445
 - enforcement program, staffing patterns, 112
 - plumbing code reference, 130
- conservation/rehabilitation ordinance, enforcement, 111–114
- criteria, consideration, 110–111
- deterioration, first sign, 86
- early/late disabilities, avoidance, 89
- economic factors, 96–104
- enforcement measures, summarization, 114–118
- enforcement procedures, 114–118
- enforcement program
 - contradictions, 112–113
 - steps, 111–112
- environmental control programs, 102
- environmental health aspects, 89
- environmental quality, 102
- environmental sanitation, 97
- estimates, obtaining, 129
- exterior paint, necessity, 123
- federal/state/local governmental leadership/support, 109
- first inspection, findings (form letter), 115f
- floors, water protection, 121
- form paragraphs, usage, 118–129
- furnace flue, defect, 128
- garbage
 - shed, dilapidation, 125–126
 - storage, 125
- gutters/rain leaders, absence, 124–125
- habitable room, window (absence), 127
- handrails, absence, 125
- health
 - criteria (APHA), 99–103
 - factors, 96–104
 - interrelationship, 88–89
 - principles, 99–103
- health hazards, example, 87f
- hot water, absence, 119
- human factors, 100

hygiene indices, 97
 improvements, financing, 113–114
 incomplete bathroom, 119
 lead paint, presence, 125
 life expectancy, 89
 major repairs, 129
 minor repairs, 129
 morbidity/mortality rates, 89
 ordinances. *See* Minimum standards
 housing ordinance
 enforcement, 86–87
 plan component, 434
 planning, 96–97
 plaster, looseness, 124
 plumbing, 129–137
 premature deaths, avoidance, 89
 problems
 complexity, 87
 elimination, 86
 factors, 87–88
 resolution, 104–105
 solutions, 108–110
 program, 104–118
 approach, 104–105
 community short-term/long-term plans,
 perspective, 110
 components, 105–107
 outline, 107–108
 quality
 rating, 93
 scores (APHA), 95t
 radon, presence, 143
 rat infestation, 128
 reinspection letter, sending, 115
 roach infestation, 128
 roof, leakage, 124
 rotted/missing siding, 123
 rubber-hose gas connection, 128
 safety/injury prevention, 101
 sanitation/maintenance, 100–101
 sewage disposal system, overflow, 128
 sewer, clog, 127
 sleeping room, overcrowdedness,
 126–127
 social factors, 96–104
 stairway details, 121f
 structural safety, 119
 survey
 methods, 97–99

 results, 113
 third-floor occupancy, unlawfulness, 127
 unvented heater, usage, 127
 wall
 construction, 120f
 sag, 123–124
 water closet
 flush tank, operation problem, 125
 leakage, 121
 tank, diagram, 126f
 wellwater supply, protection (problem),
 129
 WHO definition, 83
 window details, 124f
 yard/vacant lot debris, 126
 Housing Act of 1949, 386
Housing and Health APHA-CDC
 Recommended Minimum Housing
 Standards, 104
 Housing and Urban Development Act of
 1968, 386
 Human environment, term (usage), 508
 Human misery, expense, 117
 Hydraulic press, 19f
 Hydrocarbons
 complete combustion, 286–287
 NAAQS, 343
 Hydrofluorocarbon (HFC) 23, impact, 316
 Hydrogen fluoride, plant impact, 314
 Hygiene indices. *See* Housing

I

Illnesses, transmission (possibilities), 155
 Impact statements, usage, 503–505
 Impacts, term (usage), 507
 Impingement scrubber, 355
 Impingers, usage, 328
 Incarceration, health care services
 (increase), 165
 Incineration, 76, 279–291
 building design, 289–290
 attractiveness, 290
 cost comparison, 211f
 disposal cost, haul distances (impact),
 210f
 draft pressure measurements, 286
 economics, 291
 electric power, availability/cost, 290
 emissions, management, 291

Incineration (*Continued*)

- facilities
 - implementation issues, 290–291
 - siting, 290–291
 - gaseous emissions, 287
 - industrial solid waste/ash production, 76–77
 - instrumentation, necessity, 286
 - odor control, 286–287
 - particulate emissions, 287
 - plant layout, 289–290
 - arrangement, 290
 - process, control, 286
 - public health issues, 291
 - site selection, 289–290
 - site suitability, 290
 - smoke density, 286
 - smoke emission, control, 286
 - temperature monitoring, 286
 - wastes, handling method/cost, 290
 - water supply, availability/cost, 290
 - weight station, usage, 286
- Incinerators, 178. *See also* On-site commercial/industrial incinerators
- air pollution control equipment, requirement, 280
 - ash/fly ash, exit, 287
 - capacity, 285
 - constraints, 183
 - operation
 - definition sketch. *See* Mass-burn incinerator
 - description. *See* Municipal solid waste residue management, 287, 289
 - solid waste, physical/chemical characteristics, 281t
 - stack heights, 285
 - types, 283–287
- Income property, ownership, 86
- Incomplete bathroom, 119
- Incremental noise reduction, 382
- Indian floating cover, 30–31
 - diagram, 30f
- Indirect effects, cause, 507
- Indirect waste piping, 137
- Individual facilities, 101–102
- Indoor air
 - air pollutants, determination methods, 151t

- contaminants, sources/exposure guidelines, 139t–140t
 - pollution, causes/sources, 137–140
 - quality, 136–154
- Indoor radon, entry sources, 142–143
- Industrial development/modernization, characterization, 4
- Industrial discharges, RCRA regulations (absence), 293
- Industrial ecology, 6–7
 - concept, usage, 35
- Industrial noise, 377
 - control, 380–381
 - factors, 380
- Industrial solid wastes utilization/disposal, 1
- Industrial sources, solid waste generation rates, 192t
- Industrial waste, 7, 178
 - disposal, 76–77
- Industrial/commercial waste landfill line configuration, 256f
- Industries
 - classification, 1–3
 - methodology, 3
 - definition, 1
 - environmental impact, 2
 - negative impacts (reduction), system-oriented approach (usage), 35
- Inertial collection equipment, usage, 328
- Infants, respiratory illness, 147
- Infectious medical wastes, collection, 194–195
- Infectious wastes
 - source, 194
 - treatment, 194
- Informational meetings, usage, 466
- Infrastructure quality, impact, 470
- Inhalable particulates, sampling, 327–328
- Institutions
 - environment, 83
 - environmental health inspection form, 166f
 - sanitation, 155–169
 - small communities, 155–156
 - solid waste handling/storage, 199
- Integrated solid waste management, 179
 - definition sketch, 181f
 - implementation, 184–185

Integrated steel production, 55
involvement, 56
Integrated waste management (IWM),
180–185
hierarchy, interpretation, 180
Interlocks
application, 20f
development, 20f
plastic rejects, usage, 21
Internal combustion engine, air pollutant
producer, 350
International Organization for
Standardization (ISO), LCA standards,
5
International treaties, necessity, 364
Interstate compacts/agreements, necessity,
364
Inventory analysis. *See* Comprehensive
planning
focus/scope/depth, 442
Inversion, 337. *See also* Frontal inversion;
Radiational inversion; Subsidence
inversion; Surface
impact. *See* Stacks
In-vessel composting system, 235–236
In-vessel methods, composting, 232
Iron industry, 55–64
environmental impacts, 56–58
waste materials, 58t
Iron slags, application, 61
Irregular surface, survey computations, 398
Irrigation waters, RCRA regulations
(absence), 293
ISO. *See* International Organization for
Standardization
IWM. *See* Integrated waste management

J

Japan, natural resources consumption, 5

K

Kalundborg Industrial Estate, 68
Kalundborg system, 35–36
Kemira, sulfuric acid production, 69
Kidney dialysis machines, precautions, 157,
159
Kiln dust, collection, 33
Klebsiella spp., impact, 156

L

Lakes/streams, acid rain (impact), 320
Lambert projection, 399, 401
Land
development projects, planning/design
(map requirements), 407–410
feasible use, 360
Land subdivision, 480–494
design, 482–484
assumptions, 490–491
comparative analysis, 488f, 489t
types, alternative, 486–492
design/development, regulation, 482
fiscal analysis, 494
impact, 481–482
information, importance, 483
layouts, 487
plans, 503–504
proposal, 482–483
site analysis, 487f
site selection/assessment, 484, 486
field inspection, 486
Land use
comprehensive plan requirement,
440–441
plan component, 434
plan element, 435
regulation
comprehensive plan requirement, 442
plan component, 434
Landfills, 183–184
access roads, maintenance, 277
accessibility, 251
area policing, 275
biodegradable organic matter, waste
biodegradation/stabilization,
255–256
burning/salvaging, absence, 275
cap. *See* Multi-layer landfill cap
closure requirements, 278
compactor, illustration, 270f
cutoff walls/barriers, usage, 260
design issues, 251–257
dust/paper, control, 277
equipment
requirements, 269
requirements, minimum, 271t
shelter, 273–274
usage. *See* Sanitary landfill

Landfills (*Continued*)

- excavating/spreading/compaction
 - equipment, usage, 269, 273
- facilities/equipment, usage. *See* Sanitary landfill
- fill stabilization, acceleration, 256
- final cover, 267f
- fire protection facilities, 268–269
- full-time supervision, 274
- gas
 - constituents, 258t
 - control, 258
 - migration, control, 260
 - production, early stages, 263
 - recovery/utilization, 258
- gas generation, 258–260
 - acid phase, 259
 - initial adjustment phase, 258
 - maturation phase, 260
 - methane fermentation phase, 260
 - phases, diagram, 259f
 - transition phase, 259
- geomembrane placement. *See* Area-type landfill
- hauling, cost comparison, 211f
- infiltration, determination, 252
- insect/rodent control, 275–276
- inspection maintenance program, 277
- irrigation system, inclusion, 268f
- land area/volume, requirement, 251–252
- leachate
 - control, 252–255
 - generation, 252
 - migration, problem, 254–255
 - recirculation, 255–256
 - treatment, 252, 256–257
- liners, objective, 254
- location, 251
- maintenance, 276
- methane recovery/utilization, 260–263
- mining, 267–268
- monitoring well, diagram, 253f
- operation, 274–276
 - control, 274
 - practices, 276–278
- passive gas vent, usage, 267f
- personnel, operation (relationship), 274–275
- rats/flies/vermin, breeding (control), 278

- resource, 184
- salvaging, conducting, 277
- site
 - closure, 256, 278–279
 - conversion, 278–279
 - hydrogeological investigation, 268
 - location, 251
- space/energy, recycling (impact), 217
- supervision, 274–276
- technology/operation, 183–184
- types, schematic view, 249f
- usage, types, 243t
- use. *See* Completed landfill
- vegetation, usage, 266–267
- weight station construction, 269
- working fill, face, 276

Land-use development, placement, 484, 486

Land-use plan

- adoption, 473
- execution, 436
- relationship, 510

Land-use planning efforts, 477

Lapse rate, 337. *See also* Dry adiabatic process lapse rate; Environmental lapse rate; Prevailing lapse rate

Large-scale cadastral maps, 408

Large-scale topographic maps, 408

Latitudinal lines, 405

LCA. *See* Life cycle assessment

LDPE. *See* Low-density polyethylene

Leachate, 179

- control. *See* Earth cover; Landfills
- generation. *See* Landfills
- recirculation. *See* Bioreactor type landfill
 - control, 256
 - example, 257f
- release, minimization, 287
- treatment. *See* Landfills
- wells, sampling, 278

Leachate test, results, 74t

Lead, contribution. *See* Air pollution

Lead paint, presence, 125

Legal plan implementation actions, prerogative, 446–447

LGC. *See* Low-grade clay

Life cycle assessment (LCA), 3–4

- cradle-to-cradle basis, 4
- flowchart, 6f
- flowchart, 4f

identification. *See* Products
 importance, 4–7
 standards. *See* International Organization
 for Standardization
 sustainability indicator, 65
 usage. *See* Environmental protection
 Living unit/structure,
 housing/environmental principles,
 99–101
 Loan insurance, construction stimulation,
 106
 Local government, role, 364
 Local health/environmental protection
 agencies, planning/plan
 approval/regulatory responsibilities,
 503
 Local topography/meteorology, study, 361
 Location, appreciation. *See* Property
 Location selection criteria, cost-oriented
 factors. *See* Sites
 Long-term, term (usage), 512
 Loudness. *See* Sound
 contour. *See* Equal loudness contour
 Low-density polyethylene (LDPE), 9
 Low-grade clay (LGC), 46
 Low-interest loans, arrangement, 118
 Low-level radioactive solid waste, disposal.
 See Hospitals; Nursing homes
 Low-rise apartments
 containers, usage, 198f
 solid waste handling/storage, 198
 Low-rise residential areas, solid waste
 handling/storage, 196, 198
Lumbricus Rebellus, usage. *See* Red worm
 Lung disease, 310

M

Magnetic observation, 398
 Malodorous gases, impact, 315–316
 Manholes
 cover/base, 21f
 rejects application, 21–22
 Manual loading collection vehicles,
 application, 204
 Manually loaded collection vehicles
 examples, 206f
 one-person crew, labor requirements,
 209t
 Manufacturing processes
 cradle-to-grave materials flow, 5
 private sector redesign, 181
 Manure, usage, 26
 Mapped soils, characteristics
 (interpretations), 472
 Mapping
 definitions/concepts, 396–405
 system, 409–410
 Maps
 comprehensive plans, 439
 creation, foundational elements, 396–398
 importance, 396
 projections, 398
 usage, 408
 requirements, 407–410
 types, requirements, 408
 Marble. *See* Agglomerate marble; Cast
 marble
 components, 40–41
 cutting, 42
 end user distribution, 42
 environmental impacts/mitigation, 44–51
 industry, 40–51
 inventory management, 42
 lifting/transportation, 42
 polishing, 42
 production process, 41f
 quarry extraction, 41
 scrapes, 44
 semisolid/slurry wastes, 43
 slurry, chemical analysis, 43
 list, 44t
 slurry, usage. *See* Concrete; Mortars
 solid wastes, 43
 waste, 42–43
 applications, 45
 distribution, 42t
 types, 43
 usage. *See* Polymer concrete
 Marine Protection, Research, and
 Sanctuaries Act, 295
 Mass-burn incinerator, operation (definition
 sketch), 280f
 Mass-burn municipal waste combustion
 facility, energy production facilities
 (schematic), 284f
 Mass-fired combustors, 283–284
 furnace walls, description, 284

- Materials degradation, measurement, 333
- Materials flow
 - closed-loop system, 7
 - open system, 3
- Materials recovery, 217–218
 - methods/equipment, 220
 - processing technologies, 218
 - relationship. *See* Waste reduction
- Materials recovery facility (MRF)
 - capacity ranges, 221t
 - feasibility analysis, 227t
 - final design, 229t
 - flow diagrams, 220–221, 224
 - functions/operations, usage (example), 219t–220t
 - functions/system components,
 - mechanization degree basis, 221t
 - implementation, 218–224
 - materials, usage (examples), 219t–220t
 - planning/design, technical considerations, 224–225
 - issues, 227t–229t
 - preliminary design, 228t–229t
 - process flow diagram, 224f. *See also*
 - Mixed paper/cardboard separation types, 218
 - list, 221t
 - usage, 202. *See also* Commingled solid waste; Source-separated material waste components, manual separation, 223f
- Materials recovery/transfer facility (MR/TF), 218
- Materials recycling, 217–218
- Materials separation, methods/equipment, 220
- Mean Sea Level Datum, 404–405
- Mechanical noises, 384
- Mechanical recycling, 10
- Mechanically loaded collection vehicles
 - examples, 208f
 - one-person crew, labor requirements, 209t
- Mechanically loaded stationary container
 - systems, labor requirements, 207
- Media
 - sound speed, 369t
 - sound travel, 368
- Medical wastes
 - collection, 194–195
 - regulation, 194–195
- Medium-rise apartments
 - containers, usage, 198f
 - solid waste handling/storage, 198
- Melamine, 9
 - usage, example, 14
- Melting, sand molding process, 52
- Mercator projection, 401. *See also*
 - Transverse Mercator projection
- Meridional lines, 405
- Metal foundry industry, 51–55
- Metals
 - casting, 51
 - RCRA Toxicity Characteristic Rule regulation, 294t
- Meteorology, 334–338
 - study, 476
 - usage, 341
- Methane
 - characteristics, 261–262
 - control. *See* Earth cover
 - fermentation phase. *See* Landfills
 - production, 260–261
- Methane-utilizing bacteria, impact, 266–267
- Methyl chloroform, phaseout, 346
- Microcline, marble component, 40
- Micrometeorology, application, 333
- Milamean thermoset, recycling inability, 67
- Minimills. *See* Secondary processing
- Minimum standards housing ordinance, 103–104
- Mining sites, coal desulfurization, 320
- Mixed MSW, materials separation, 223f
- Mixed paper/cardboard separation, MRF
 - process flow diagram (usage), 225f
- Mixed plastics wastes, 13–22
 - photo, 13f
- Mixed solid waste, composting, 232
- Mixed wastes, combustion, 287
- Mobile home parks, 154–155
- Modular combustion units, 285
- Moisture
 - content, composting factor, 26
 - requirements. *See* Ventilation
- Monitoring well, diagram. *See* Landfills
- Montreal Protocol on Substances that Deplete the Ozone Layer, 318–319

- Mortars
 compressive strength, 48–49
 elasticity, modulus, 49–50
 marble slurry, usage, 47–50
 tensile strength, 49
- Motor grader, 270f
- Moving-bed scrubber, 355
- MRF. *See* Materials recovery facility
- MR/TF. *See* Materials recovery/transfer facility
- MSW. *See* Municipal solid waste
- MSWLFs. *See* Municipal Solid Waste Landfills
- Multi-layer landfill cap, 266f
- Multiple waste recycling industry, 66–67, 70–75
 case study, 70
 environmental tests, 73–75
 mechanical tests, 71–73
 mixes, combination, 71t
 relationship, 67f
 waste integration, 65
- Municipal composting systems,
 function/reactor configuration, 233t
- Municipal emergency repair program,
 funding, 118
- Municipal plan commission
 function/duty, 433–437
 plan elements, 435–436
- Municipal Solid Waste Landfills (MSWLFs)
 configuration, schematic diagram, 244f
 criteria, 242, 244
- Municipal solid waste (MSW), 179, 185
 compost usage, percentage, 241
 incineration emission design/operation
 guidelines, 288t–289t
 incinerator operation, description,
 279–281
 organic portion
 co-composting, 226
 composting, 226
 oxidation/combustion, reactions, 282
 percentage distributions, estimates, 187t
 physical composition, estimates. *See*
 Residential MSW
 processing/recovery, methods/equipment
 (usage), 222t
 transfer stations, usage, 212t
 transformation, 290
- Municipal wastewater sludge (MWWS),
 usage, 38
- ## N
- NAD-27. *See* North American Datum of 1927
- NAD-83. *See* North American Datum of 1983
- National Acid Deposition Program of 1978,
 data, 320
- National ambient air quality standards
 (NAAQS), 343. *See also* Carbon monoxide; Hydrocarbons; Nitrogen oxide; Particulate matter; Photochemical oxidants; Sulfur oxide
 usage, 344t
- National Environmental Policy Act of 1969
 (NEPA), 494, 505–506
 terminology, 506–508
- National Geodetic Survey (NGS), 398, 403
 Control System, 403–405
 horizontal survey readjustment, 4040
- National Geodetic Vertical Datum of 1929
 (NGVD-29), 404–405
- National Institute for Occupational Safety
 and Health (NIOSH), 296
- National Plumbing Code*, 129
- National Pollutant Discharge Elimination
 System (NPDES), 246
 CAA, Title V (similarity), 346
 permit
 considerations, 295
 usage. *See* Sanitary landfill
- National primary ambient air quality
 standards (NAAQS), state approval,
 344
- National Weather Service, information
 source, 334
- Natural additives, usage, 26
- Natural Carrara marble powder, mixture, 51
- Natural composting, 26–28
 process, 27f
- Natural drainage basins, considerations, 438
- Natural ecosystems, principles (basis), 6–7
- Natural resource base
 comprehensive plan requirement,
 439–440
 plan component, 433
 survey, 476–477

- Natural resources, conservation strategy, 4
- Natural stone slurry, 43
incorporation. *See* Cement
usage. *See* Red ceramic bricks/tiles
- Natural ventilation, 148
- Naturizer composting, 236
- NAVD-88. *See* North American Vertical Datum of 1988
- Neighborhood
pride, resurgence (stimulation), 117
unit design, 485f
unit plan, 483
- Neighborhood Environmental Evaluation and Decision System (NEEDS), 97–99
stages, 99
- Nemerow, Nelson (EBIC development), 65
- Neutral lapse rate, turbulence (association), 359
- Neutral stability, 337
- New PVC production, scrap PVC
production (cost comparison), 24f
- New urbanism design, 484
- New urbanism design type subdivision
layout, conceptual basis, 491–492
- New urbanism subdivision layout, 488f
- New York City, commercial waste
placement (manual collection), 201f
- New-generation nuclear reactors, benefits, 317
- Newton (N), force requirement, 371
- NGS. *See* National Geodetic Survey
- NGVD-29. *See* National Geodetic Vertical Datum of 1929
- Nitrogen, release, 319
- Nitrogen dioxide (NO₂), determination, 330
- Nitrogen oxide (NO)
chemiluminescence analyzer, usage, 330
NAAQS, 343
ozone reaction, luminescence, 330
- Noise. *See* Ambient noise; Background noise
cathode-ray oscillograph, usage, 378
control. *See* Industrial noise; Transport noise
methods, 378–380
preventive measures, WHO Expert Committee, 379–380
regulations, EPA regulations, 387
regulations, involvement, 379
dosimeter, 378
exposure level, EPA report, 375
federal regulations, 384–387
health hazard, 374–375
impact, 375–376
interference, absence, 473
level, 369–370
land use relationships. *See* Design
noise level-land use relationships
measurement, 377–378
octave-band analyzer, usage, 378
pollution, 369
reaction, 375
reception, control. *See* Highway noise
source control, 378–379
sources, 376–377
consideration, 372
state/local regulations, 387–388
term, usage, 369
- Noise control, 309–310
discussion, 367–388
health impact, 310–311
- Noise Control Act of 1972 (P.L. 92–574), 384–385
amendments, 385
- Noise reduction (NR), 381–384
decibel measurement, 382
- Non-fire-resistive hospitals/nursing homes, attention, 160
- Nongovernment agencies, role, 118
- Nonincinerable wastes, handling
method/cost, 290
- North America Industrial Classification System (NAICS), industry
classification, 1–2
- North American Datum of 1927 (NAD-27), 398, 404
basis, 402
- North American Datum of 1983 (NAD-83), 398
creation, 404
NAD-83(91), 404
- North American Vertical Datum of 1988 (NAVD-88), 405
- Northings, 402
- Nosocomial infections, prevention, 157
- Noys, 374

NPDES. *See* National Pollutant Discharge Elimination System

NR. *See* Noise reduction

Nuclear reactors, benefits. *See*

New-generation nuclear reactors

Nuclei counters, usage, 329

Numerical air quality modeling, 361

Nursing homes

air quality standards, 162

construction, 157

fire resistance, attention. *See*

Non-fire-resistive hospitals/nursing homes

fire safety, concern, 157

health care, providing, 159–160

infectious/pathological wastes, disposal, 162

inspection form, 162f–163f

low-level radioactive solid waste, disposal, 163

sanitation, 156–160

survey/inspection, 160

O

O₃. *See* Ozone

Occupational Safety and Health Act, 296, 495

Occupational Safety and Health

Administration (OSHA)

establishment. *See* Airborne exposure limit

regulations, setting/enforcement, 384

Octave-band analyzer, usage. *See* Noise

Odor-producing operations, 357

Off-site recycling, 66

Oil burning, reductions (necessity), 317

Oil Pollution Act of 1990 (OPA), 495

Old orchards, presence (pesticide presence), 474

On-site commercial/industrial incinerators, 285

On-site recycling, 66

On-site well water, availability, 493

OPA. *See* Oil Pollution Act of 1990

Opacity. *See* Air opacity

determination. *See* Percent opacity

Open industrial system, 3–4

Open spaces

provisions, 361

system, connection/contiguousness, 491f

Open top container, lids (inclusion), 200f

Operational planning, 496–502

Operational soil maps, U.S. Natural

Resources Conservation Service preparation, 474–475

Organic chemicals, RCRA Toxicity

Characteristic Rule regulation, 294t

Organic material,

decomposition/stabilization, 231

Organic solid waste,

decomposition/stabilization, 232

Ortho photographs, 471

Orthoclase, marble component, 40

Orthometric height, 397f

Owners, office consultations, 116

Ownership, registration/reregistration (requirement), 118

Oxygen (aeration), composting factor, 26

Ozone (O₃)

chemiluminescence analyzer, usage, 330–331

destruction, CFCs (impact), 318

formation, 319, 324–325

impact, 318–319

NAAQS restriction, EPA proposals, 346

ozone-depleting chemicals, phaseout, 346

plant impact, 314

P

Packed-bed scrubber, 355

Parasites, temperature/exposure time (requirement), 238t

Partially processed commingled MSW, composting, 226

Particles, impingement, 351

Particulate matter

impact, 32

NAAQS, 343

restriction, EPA proposal, 346

Particulates

collectors/separators, 351–356

emissions, 146–147

filters, 352, 354

Partitions, rejects (usage), 22f

Pascal (Pa), pressure unit, 371

Passive composting, 27

process, 28f

technique. *See* Cement

- Passive gas control, permeable trench (usage), 262f
- Passive gas control synthetic membrane, 261f
- Passive gas vent, usage. *See* Landfills
- Pathogens
control. *See* Compost
destruction, temperature/exposure time (requirement), 238t
- Pathological medical wastes, collection, 194–195
- Pavement, stone slurry (usage), 50
- PC. *See* Polycarbonate; Polymer concrete
- PCA. *See* Portland Cement Association
- PCBs. *See* Polychlorinated biphenyls
- PE. *See* Polyethylene
- Pebble bed systems, 317
- Perceived noise level (PNL), 373
- Percent opacity, determination, 331–332
- Permeable soils, rainwater absorption ability, 472
- Permeable trench, usage. *See* Passive gas control
- Personal hygiene, importance, 168
- Pesticides
agricultural spraying, 321
RCRA Toxicity Characteristic Rule regulation, 294t
- PET. *See* Polyethylene terephthalate
- Phenolics, 9
- Phons, specification, 373
- Photochemical oxidants
NAAQS, 343
production, 325
- Photogrammetric methods, usage. *See* Topographic maps
- Phthalates, usage, 8
- Physical air quality modeling, 361
- Physical development, engineering (necessity), 502–503
- Physical factors grouping, 516t
- Physical/chemical factors grouping, 517t–518t
- Pitch (sound), 367
determination, 370
- Plan alternatives, development/evaluation, 444
- Plan commissions
function/duty. *See* Municipal plan commission; Regional plan commission
state enabling legislation, impact, 432
- Plan elements, 435–436
- Plan implementation, 436
policy development, relationship, 445–447
- Plan report, components, 433–437
- Plan selection/adoption, 444
- Plane surveying procedures, 398
- Plane waves, emission, 368
- Planning. *See* Comprehensive planning;
Operational planning; Program planning; Project planning; Sites; System planning
area, definition, 438
assessment, 429
board, impact, 105
classification, 430
criteria. *See* Urban planning
data, reliability (importance), 438
database, usage, 471–472
process, 437–447. *See also* Comprehensive planning
stage. *See* Systems planning stage
term
appropriation, 431
usage, 430–431
- Plants, air pollution (impact), 314–315
- Plaster, looseness, 124
- Plasterboard production, 68
- Plastic red clay (PRC), 46
- Plastics
benefits/detriments, 8
industry, 7–24
cradle-to-cradle concept, process flow diagram, 23f
mix, recycling, process flow diagram, 17f
recycling
benefits, 9
process flow diagram, 12f
stages, 11
rejects, 70
application, 19, 21
foundry sand reinforcement, 72–73
usage, 8f
wastes. *See* Mixed plastics wastes
mixing, recycling system, 16

- Plate scrubber, 355
- Plate-type electrostatic precipitator,
 - diagram, 355f
- Plumb lines, 397
- Plumbing, 129–137
 - code, 129–134
 - impact, 130
 - details, 137. *See also* Fixture plumbing
 - facilities, minimum number, 131t–132t
 - fixture, 130
 - systems, plans (approval), 130
- PNL. *See* Perceived noise level
- Pollen samplers, usage, 329
- Pollutant standards index (PSI), 347
 - values, comparison, 348t–349t
- Pollutants. *See* Air pollutants
 - concentrations/health effects, 348t–349t
 - discharge, high stacks (impact), 319–320
 - emission, high stacks (usage), 359
- Polluted water, backflow, 134
- Pollution, causes/sources. *See* Indoor air
- Pollution Prevention Act (PPA), 495
- Polycarbonate (PC) blends, 66
- Polychlorinated biphenyls (PCBs), 145
 - organics, 351
- Polycyclic aromatic hydrocarbons, organics, 351
- Polyethylene (PE), usage, 10
- Polyethylene terephthalate (PET), 9
- Polymer concrete (PC), marble/granite
 - waste (usage), 50
- Polymerization, 13
- Polypropylene (PP), 9
 - conversion. *See* Recycled PP
 - usage, 10
- Polystyrene (PS)
 - foam, recycling, 67
 - usage, 10
- Polyvinylchloride (PVC)
 - case study, 22–24
 - manufacture, 8
 - plastic offcuts, recycling, 22
 - production, cost comparison. *See* New PVC production
 - usage, 10. *See also* Scrap PVC
- Population
 - growth, 85–86
 - trends, 84f
- Portable kerosene heaters, fire hazard, 152–153
- Portland cement, chemical composition, 31
- Portland Cement Association (PCA)
 - kiln information, 32
 - operating plants, report, 31
- POTW. *See* Publicly operated treatment works
- Pouring, sand molding process, 53
- PP. *See* Polypropylene
- PPA. *See* Pollution Prevention Act
- PRC. *See* Plastic red clay
- Precalciner, usage, 32
- Precipitation, 338
- Preliminary engineering, 447
 - movement, 467–468
- Preprocessing, 11
- Pressure gradient, impact, 339
- Pressure vacuum breaker, 136f
- Pressure-type vacuum breaker, 136
- Pretrial hearing, providing, 117
- Prevailing lapse rate, 337
- Primary sector, 3
- Prime movers, 270f
- Principal landfill gases, generation, 258–260
- Private construction, 107
- Processed waste, composting process, 231f
- Processing
 - stage, 11
 - technologies. *See* Materials recovery
- Products
 - development, mix plastic waste recycling (usage), 16–17
 - environmental impact, LCA
 - identification, 5
 - final preparation phase, sand molding process, 53
- Profit, discouragement, 117
- Program planning, 494–496
- Project planning, 467–469
- Property, location (appreciation), 476
- Proteus* spp., impact, 156
- PS. *See* Polystyrene
- PSI. *See* Pollutant standards index
- Public areas, ventilation (usage), 148–149

Public facilities
 community provision, 480–481
 site development, 471
 Public Health Service Pub. 1038, 130
 Public health services, necessity, 502
 Public housing and urban development, 106
 Public infrastructure development projects,
 corridor planning stage (insertion),
 468
 Public participation, 465–466. *See also*
 Comprehensive plan
 achievement, 466
 process. *See* Comprehensive planning
 Public sewerage, availability, 473
 Public utilities, plan component, 434
 Public works
 construction, consideration, 446
 development process, 447–465
 facilities
 integrated systems, 447
 support, map requirements, 407–410
 Publicly operated treatment works
 (POTW), 295
 Pulsed fluorescent analyzer, usage,
 329–330
 Pure tone, 367
 hearing, 374
 sine wave, 368f
 PVC. *See* Polyvinylchloride

Q

Quality of living
 APHA appraisal method, 91–95
 appraisal, 91–96
 Quarry location, exploration/identification,
 41
 Quartz, marble component, 40
 Quiet Communities Act of 1978, 385–386

R

Radiational inversion, 337
 Radon
 contamination, 143
 entry sources. *See* Indoor radon
 exposure, measurement, 144
 hazard, 142
 impact, 142–144
 level, EPA proposal. *See* Drinking water

Rain leaders, absence, 124–125
 Ramp method. *See* Sanitary landfill
 Range lines, 406f
 Rat infestation, 128
 Ravine area method. *See* Sanitary landfill
 Ravine landfill, 249f
 development, 250f
 Raw material, usage, 23f
 Raw PVC, product creation (example), 24f
 RCRA. *See* Resource Conservation and
 Recovery Act
 RDF. *See* Refuse derived fuel
 Real estate, purchases (advice), 505
 Real property boundaries
 description, 407
 legal descriptions, interpretation,
 408–409
 lines, correlation ability. *See*
 Topographic data
 Rear-loaded collection vehicle, example.
 See Commingled solid waste
 Recreational use sites, 473
 Rectified aerial photographs, 471
 Recycled glass, melting temperature, 217
 Recycled HDPE, end uses, 11
 Recycled LDPE, end uses, 11
 Recycled PET, uses, 10
 Recycled plastic, product creation
 (example), 24f
 Recycled PP, conversion, 66
 Recycling, 179
 growth, 182
 opportunities. *See* Cement
 perception/usage, 182–183
 problems, 182
 public education, impact, 183
 Red ceramic bricks/tiles, natural stone
 slurry (usage), 45–47
 Red wiggler (*Eisensia Foetida*), usage, 28
 Red worm (*Lumbricus Rebellus*), usage, 28
 Refuse, 179
 Refuse derived fuel (RDF)
 burning, 217
 costliness. *See* Densified RDF
 energy content, 284–285
 RDF-fired combustors, 284–285
 Regional organizations, input (necessity),
 364
 Regional plan commission

function/duty, 433–437
 plan elements, 435–436
 Regional planning, rational process,
 429–430
 Regulatory requirements, compliance
 assessment (determination), 504
 Reinforced fiber plastic (RFP), usage, 21
 Reinspection letter, sending, 115
 Rejects, application, 21–22
 Rent controls, impact, 87–88
 Rental housing gross income, total costs
 (contrast), 88f
 Reradiated heat, trapping, 316
 Residential environment, 83
 community/individual facilities, 101–102
 housing/environmental principles,
 101–102
 human factors, 100
 safety/injury prevention, 101
 sanitation/maintenance, 100–101
 Residential MSW, physical composition
 (estimates), 188t
 Residential solid waste
 collection, containers (usage), 197f
 completed landfill, usage, 263
 IWM implementation, 184–185
 flowchart, 184f
 Residuals, 179
 Residue management. *See* Incinerators
 Resource Conservation and Recovery Act
 (RCRA), 495
 air quality issues, 343, 345
 amendments, 293
 usage, 293, 295
 Subtitle D, 242
 usage. *See* Hazardous waste
 Resource recovery, 179
 municipal operation consideration, 217
 partial waste disposal/reclamation
 process, 217–218
 Resources
 planning, impact, 430–431
 term, usage, 512
 Respiratory diseases
 smoking, impact, 311
 spread, 141
 Respiratory illness
 control, 150–151
 NIOSH recommendations, 150

Resurveys, survey markers (recovery), 399
 Returnable bottle deposit law, interest, 214,
 217
 RFP. *See* Reinforced fiber plastic
 Rigid plastic, size (reduction), 14
 Rigid thermoplastic waste, shredder
 (usage), 14
 Ringelmann smoke chart
 replacement, 331–332
 usage, 331
 Roach infestation, 128
 Road pavement layers, usage. *See* Cement
 Road paving, 69
 Roof, leakage, 124
 Rotted/missing siding, 123
 Rubber-hose gas connection, 128
 Rubbish, 179

S

Safe, Accountable, Flexible, Efficient
 Transportation Equity Act of 2005,
 496
 Safe Drinking Water Act (SDWA), 495
 Sand. *See* Foundry sand; Green sand; Spent
 sand
 maximum flexural load, 73f. *See also*
 Foundry sand
 tensile strengths, 72f. *See also* Foundry
 sand
 Sand and mold preparation, 52
 Sand molding technology, processes, 51–53
 Sand-casting system, 53
 Sanitary code, 445
 Sanitary landfill, 179
 area method, 248, 250
 area policing, 275
 burning/salvaging, absence, 275
 compaction equipment, 272f
 construction guidelines, 247t–248t
 county agency/joint municipal survey
 committee, impact, 246
 design, 242
 guidelines, 247t–248t
 issues, 251–256
 disposal
 cost, haul distances (impact), 210f
 landfill facilities/equipment, usage,
 268–274

- Sanitary landfill (*Continued*)
 excavating/spreading/compaction
 equipment, usage, 269, 273
 insect/rodent control, 275–276
 inspection maintenance program, 277
 intermunicipal cooperation, 242,
 244–245
 leachate. *See* Community sanitary
 landfills
 legal requirements, 242, 244
 long-term planning/design issues, 242,
 245–246
 machines, size/type usage, 273
 maintenance, 276
 methods, 242, 246–250
 NPDES permit, 246
 operation, 242
 equipment, usage, 270f
 guidelines, 247t–248t
 practices, 276–278
 operation, direction, 274
 plan, provisions, 278–279
 planning, 242–246
 engineering project, 276
 ramp method, 248, 250
 rats/flies/vermin, breeding (control), 278
 ravine area method, 250
 site closure/conversion, 278–279
 social/political factors, 242, 245
 supervision, 274–275
 total area, study, 244
 trench method, 246
 valley area method, 250
 Sanitary wastes, treatment/disposal
 (provision), 492–493
 SARS. *See* Severe acute respiratory
 syndrome
 SC. *See* Shale clay
 Scale and sea level reduction factor, 402
 Scale factor, 402
 Schools
 sanitation, 163
 inspection form, 164f–165f
 ventilation, usage, 148
 Scoping. *See* Environmental impact
 analysis
 Scrap PVC
 production, cost comparison. *See* New
 PVC production
 usage, 23f
 Scrapes. *See* Granite; Marble
 characteristics, 44
 Scrubbers, 355
 SCSs. *See* Stationary container systems
 SDWA. *See* Safe Drinking Water Act
 Sea level reduction factor, 402
 Secondary processing (minimills), 55, 56
 Secondary sector, 3
 Sedimentation/settling devices, usage. *See*
 Ambient air
 Septic tank treatment/disposal systems, 493
 Setting chambers, 352
 Severe acute respiratory syndrome (SARS),
 497
 Sewage disposal system, overflow, 128
 Sewage sludge, composting. *See* Cement
 Sewer, clog, 127
 Sewerage facilities planning report, outline,
 447–453
 Shale clay (SC), 46
 Shanty towns, development, 85
 Sheet-making process, 23–24
 Shelter, environment inspection/report
 outline, 167–168
 Short-term, term (usage), 512
 Shower addition, alteration, 123f
 Shredders, usage, 16
 Shredding crushing machine, 14f
 Side-loaded right-hand standup drive
 collection vehicle, example. *See*
 Commingled solid waste
 Side-loading vehicle
 dual compartment, inclusion (example),
 208f
 example. *See* Source-separated materials
 Single transfer trailer, drop bottom
 (inclusion), 216f
 Sites
 area, size, 473
 assessment, 471–472. *See also* Land
 subdivision
 inspection, inclusion, 472
 design, 478–480
 team, components, 479
 development, 471
 features, 472–473
 improvements, necessity, 478
 inventory, 473–478

- investigation, 504
- location
 - selection criteria, cost-oriented factors, 470
 - stages, 469–471
- plan, display, 479
- planning, 469–480
 - introduction, 469–470
 - process, professional advice, 479–480
- selection, 470–471. *See also* Land subdivision
 - process, 471
 - professional advice, 479–480
- suitability assessment, 471
- survey, 473–474
- SIWM. *See* Sustainable industrial waste management
- Slag
 - concrete, compressive strength development, 61t
 - generation, 56
 - granulation, 59–60. *See also* Dry slag granulation
 - system. *See* Continuous slag granulation system
 - processing, importance, 59
 - recycling, 57
 - replacement levels, 63f
 - types, utilization (investigation), 62–63
 - utilization, potential, 58–64
- Sleeping quarters, noise levels, 387t
- Sleeping room, overcrowdedness, 126–127
- Sludge, particle size distribution, 46
- Slums, 85
 - development, public (impact), 85
- Slurry. *See* Granite; Marble; Natural stone slurry
 - atmospheric diffusion. *See* Dry slurry
 - particles, dimension, 43
 - physical/chemical properties, 43–44
 - presence, 48
- Small direct-discharge solid waste transfer stations, 215f
- Smog, plant impact, 314
- Smoke, measurement, 331–332
- Social factors grouping, 516t–518t
- Soil amendment, salmonella repopulation, 238
- Soil fertility (pH reduction), marble particles (impact), 45
- Soil moisture retention (improvement), compost (usage), 229
- Soil survey, 474–475
 - information, usage, 471–472
- Soiling
 - measurement, 331–332
 - tape samplers, usage, 332
- Solid brick groups, compressive strength (development), 63f
- Solid uncompacted wastes, vehicles (usage), 211
- Solid waste, 179
 - characteristics, 185–189
 - collection, 199–209
 - service, type, 199
 - systems, types, 202–204
 - combination, 292
 - composition, 185, 187
 - depth, 277
 - disposal
 - availability, 473
 - facilities, investment, 275
 - sites, number (reduction), 209
 - generation, 191t
 - generation rates, 190t–191t
 - industrial sources, 192t
 - health issues, 207
 - on-site handling/storage, 195–199
 - personnel requirements, 204–207
 - quantities, 185, 187–189
 - reduction/recovery/recycling, extent, 214
 - sources, 185. *See also* Community solid waste
 - specific weight, 189
 - transfer, 209–213
 - landfill haul, cost comparison, 211f
 - operations, economic analysis, 209
 - trailers, examples, 216f
- transfer stations. *See* Direct load solid waste transfer stations; Storage load solid waste transfer stations
 - definition sketch, 213f
 - development. *See* Combined direct-load/discharge load solid waste transfer stations
 - siting issues, 213

- Solid waste (*Continued*)
 - types, 210. *See also* Municipal solid waste
 - transport, 209–213
 - treatment facilities, investment, 275
 - weight, 193t
- Solid Waste Disposal Act of 1965, purposes (expansion), 293
- Solid waste management, 177
 - complexity, 177
 - definition, 179
 - terms, definitions, 178–180
- Solid waste slag, generation, 56
- Sones
 - loudness unit, 374
 - specification, 373
- Sonic collectors, usage, 352
- Sound
 - absorption, 381–383
 - analyzer, 378
 - average transmission coefficient, 383–384
 - decibel, 370
 - energy
 - absorption, 381–382
 - travel, 382
 - frequency, 370
 - intensity, 372
 - distance, doubling, 369
 - measurement, 373
 - inverse square law, 368
 - levels
 - combination, 373t
 - human response, 376t
 - maximum, 385t
 - loudness, 373–374
 - pressure, 367
 - decibel values, 372t
 - level, change, 371
 - levels, American Conference of Governmental Industrial Hygienists (recommendation), 386t
 - term, usage, 371–373
 - source/receptor, separation distance, 384
 - speed. *See* Media
 - terms/properties, definitions/explanations, 367–375
 - transmission, 383–384
 - travel, 368. *See also* Media
 - wave
 - distance, 368
 - intensity, 373
- A-weighting, 371
- weighting networks, 377
- Sound transmission class (STC), 383
- Sound-absorptive materials, 382–383
- Sound-level meter, 377–378
 - time response, 377
- Source reduction, 180
 - encouragement, 181
 - focus, 180–181
 - practice, 181
- Source separation, 180
- Source-separated compostable wastes, separation, 223f
- Source-separated materials
 - MRF, usage, 218
 - side-loading vehicle, example, 207f
- Source-separated recyclable materials, 197f
- Source-separated recyclable materials, MRF
 - examples, 219t–220t
- Source-separated waste (processing), MRF (usage), 224f
- Southeastern Wisconsin Regional Planning Commission, environmental corridor concept, 477
- Specifications for Sound Level Meters*, 377
- Spent green foundry sand, physical properties, 54t
- Spent sand, 53
- Spherical waves, 368
- Spirit level, usage, 397
- SPL, increase, 374
- Spray towers, 355
- Spring cleaning, community service, 199
- Stacks
 - emissions, inversion, 338
 - heights. *See* Incinerators
 - inversion, impact, 338
 - sampling, 332–333
- Stairway details, 121f
- Standard lines, 046f
- Standard Plumbing Code (Southern Code)*, 129
- State administrative codes, impact, 482
- State health/environmental protection agencies, planning/plan

- approval/regulatory responsibilities, 503
- State Plane Coordinate grid values, 404
- State Plane Coordinate Systems, 398
 - basis, 401
 - creation, 403–404
 - grid
 - coordinates, 404
 - creation, concepts, 400f
 - spherical coordinate conversion, 402
- State plane grid distances, ground level distances (relationship), 400f
- Static aerated compost pile, schematic, 235f
- Stationary combustion installations, 347
- Stationary compactors, inclusion. *See* Direct discharge solid waste transfer station
- Stationary container systems (SCSs), 202, 204
 - manually loaded collection vehicles, examples, 206f
- Statistical air quality modeling, 361
- STC. *See* Sound transmission class
- Steel industry, 55–64
 - environmental impacts, 56–58
 - wastes
 - disposal, cost, 59
 - materials, generation, 58
- Steel plant dust, transformation, 63–64
- Steel products, routes. *See* Finished steel products
- Steel slags, applications, 61
- Stoichiometric combustion, 283
- Stone slurry
 - substitution, 49
 - usage, 47–50. *See also* Embankment; Pavement
- Storage load solid waste transfer stations, 210, 211
- Storage-discharge solid waste transfer station, definition sketch, 213f
- Stormwater management facilities planning report, outline, 453–460
- Straight lines, constant bearing, 399
- Streets
 - hierarchy, 492
 - right-of-way, 480–481, 492
- Structural safety, 119
- Structures, environment inspection/report outline, 167
- Subdivision. *See* Land subdivision
- Subgrade road pavement layer, usage, 39
- Subsidence inversion, 337
- Substandard housing
 - critical period, 86–88
 - effects, 90t–91t
 - health/economic/social impact, 88–89
 - impact, 84–91
 - problem, growth, 84–86
 - local government control, 85
 - restoration, 110
- Suitable living environment, 83
- Sulfur dioxide
 - contribution. *See* Air pollution
 - emissions, reductions (EPA-phased-time basis), 345–346
 - plant impact, 314
- Sulfur oxide
 - NAAQS, 343
 - release, 319
- Sulfur removal, 356
- Superfund
 - air quality issues, 345
 - list, landfills (presence), 184
- Superfund Amendments and Reauthorization Act (SARA), 495
- Superfund Amendments and Reauthorization Act Title III (SARA Title III), air quality issues, 345
- Surface
 - inversions, 339
 - uneven heating, occurrence, 334
- Surface Mining Control and Reclamation Act, 296
- Surface water
 - cover material, usage, 263–266
 - drainage, 276
 - leachate contamination, 240
 - management, 263–267
- Surface-water source, adequacy, 472
- Surge capacity, 210–211
- Survey. *See* Control survey
- Survey control networks, 402–403. *See also* Horizontal survey control network; Vertical survey control network
- Surveying, definitions/concepts, 396–405

Sustainability indicators, 65
 Sustainable development (promotion),
 cradle-to-grave concept (usage), 6
 Sustainable environment, achievement, 36
 Sustainable industrial waste management
 (SIWM), importance, 7
 System planning, 447
 movement, 468–469
 Systems planning stage, 468

T

Tangent plane projection, 398–399
 surveys, usage (limitation), 399
 Tangent projection maps, bearings
 (display), 399
 Tape sampler, usage. *See* Coefficient of
 haze; Soiling
 Tax foreclosure proceedings, permission,
 118
 Temperature, composting factor, 26
 Tensile strength test, 71–72
 Thermal afterburners, 357
 Thermal decomposition, 305
 Thermal requirements. *See* Ventilation
 Thermoplastics, 9–11
 coding, 11f
 recycling, 10
 U.S. production/recycling, amount, 9f
 Thermosets, 9, 12–13
 recycling inability. *See* Milamean
 thermoset
 Thermosetting plastics, mechanical
 properties, 13t
 Third-floor occupancy, unlawfulness, 127
 Three-piece bathroom, dimensions, 122f
 Till frame, drop box (unloading), 203f
 Tobacco smoke, 145–146
 Toilets/bathrooms, ventilation (usage), 149
 Topographic data, real property boundary
 lines (correlation ability), 409–410
 Topographic maps. *See* Large-scale
 topographic maps
 overlay processes, 408
 preparation, photogrammetric methods
 (usage), 408–409
 usage, 471
 Topography, 338–340
 survey, 473–474
 usage, 341

Topography, term (usage), 333
 Topsoil, porosity/permeability (reduction),
 44
 Total composting time, determination, 230
 Total suspended particulate (TSP), 328
 measurement. *See* Ambient air
 Township lines/subdivisions, 406f
 Toxic pollutants
 Council on Environmental Quality
 identification, 297t–299t
 identification, 296
 Toxic Substances Control Act of 1976
 (TSCA), 295, 495
 Track compactor, trash blade (inclusion),
 272f
 Tracked bulldozer, 270f
 Tractor
 life, estimation, 269, 273
 trailer combination, example, 216f
 Traffic problems, interference (absence),
 473
 Transfer station, 180. *See also* Solid waste
 Transfer trailers. *See* Solid waste
 Transport noise, control, 381
 Transportation
 facilities, considerations, 438
 plan component, 434
 plan element, 435
 Transverse Mercator projection, 401
 system. *See* Universal Transverse
 Mercator projection system
 Trash blade, inclusion. *See* Track
 compactor; Wheeled compactor
 Trench landfill, 249f
 Trench method. *See* Sanitary landfill
 Trenches (digging), drag line (suitability),
 273
 Tropical rain forests, destruction (control),
 316–317
 TSCA. *See* Toxic Substances Control Act
 of 1976
 TSP. *See* Total suspended particulate
 Turbulence, 335
 impact. *See* Air flow

U

UNAMAP. *See* User's Network for
 Applied Modeling of Air Pollution
 Uncompacted wastes, vehicles (usage), 211

Uncontrolled contaminant emissions, 350t
Uniform Plumbing Code, 129
 Universal testing machine (UTM), usage, 72
 Universal Transverse Mercator (UMT) projection system, 401–402
 Universities, sanitation, 163
 Untreated hazardous waste, land disposal (prohibition), 293
 Unvented heater, usage, 127
 Urban areas, congestion, 85
 Urban cluster subdivision layout, 488f
 Urban development/redevelopment, guidance/shape, 438–439
 Urban heat island effect, 340
 Urban noise, 377
 Urban planning
 comprehensiveness, 431
 criteria, 431–432
 geographic area, control, 431
 implementation devices, 433
 institutional structure, 432–433
 long-range perspective, 431
 objectives/principles/practices, understanding, 429
 Urban redevelopment funds, eligibility, 109–110
 Urban sprawl, 480
 U.S. Bureau of Public Roads, 496
 U.S. Bureau of the Census, data, 96
 U.S. Coast and Geodetic Survey (USC and GS), 403
 U.S. Environmental Protection Agency (EPA)
 air pollutant concern, 344
 air quality criteria, development, 342–343
 ambient monitoring program, 327
 District of Columbia Circuit Court, agreement, 346
 EPA-phased-time basis. *See* Sulfur dioxide
 high-volume sampling, 328
 planning support, 496
 reference methods, 327
 standards, 341
 U.S. Geologic Survey, 1-to-24,000 scale quadrangle maps (usefulness), 472

U.S. Natural Resources Conservation Service. *See* Operational soil maps
 U.S. Public Land Survey, one-quarter section corners, 399
 U.S. Public Land Survey System (USPLSS), 405–407
 creation, 403
 Used tires, collection, 195
 User's Network for Applied Modeling of Air Pollution (UNAMAP), 362
 USPLSS. *See* U.S. Public Land Survey System
 Utilities
 environment inspection/report outline, 167
 necessity, determination, 475–476
 plan element, 435
 services, 492–494

V

Vacuum, nonpressure-type siphon-breakers, 135f
 Vacuum breakers, types, 136f
 Valley area method. *See* Sanitary landfill
 Vapors
 conservation, 358
 release, 357
 Ventilation, 147–150. *See also* Natural ventilation
 air change, measurement, 149
 air infiltration/fresh air makeup, reduction, 148
 monitoring, 149–150
 prevention factors, 152
 thermal/moisture requirements, 147
 usage. *See* Correctional institutions; Public areas; Schools; Toilets/bathrooms
 Venting
 details, 153f
 ensuring, 152
 prevention, factors, 152
 Venturi scrubbers, 355
 diagram, 357f
 Vermi composting, 28
 Vertical axis mixing/heating furnace, 18f
 Vertical mixing, diurnal/nocturnal mixing, 339f
 Vertical survey control network, 403

Vibration control, preventive measures
 (WHO Expert Committee
 recommendation), 379–380
 Volatile organic compounds (VOCs), 146
 contribution. *See* Air pollution

W

Wall
 construction, 120f
 sag, 123–124
 Warm dry air, cooling rate, 337
 Washbasin addition, alteration, 123f
 Waste exchange network industry, 65,
 67–69
 Kalundborg Industrial symbiosis, 68f
 waste-related industry, integration, 65
 Waste industrial sector, classification, 65
 Waste industry, 65–69
 Waste oil, collection, 195
 Waste reduction, 214, 217
 materials recovery, relationship, 213–225
 Wastes
 biodegradation/stabilization. *See*
 Landfills
 collection, 11
 concentration, treatment (usage), 305
 conservation, 70
 generation, quantities (data), 189
 materials, unloading (example), 215f
 recovery/reuse/recycling, 305
 separate collection, 193–195
 source elimination/reduction, 304
 Waste-to-energy combustion, 183
 Waste-to-energy incineration, 180
 Wastewater collection/treatment, cost
 (estimation), 475
 Water and sewer divisions, responsibility,
 106
 Water closet
 flush tank, operation problem, 125
 leakage, 121
 tank, diagram, 126f

Water Pollution Control Act, 293
 Water quality, 522t–523t
 Water supply availability, 473
 consideration, 475
 Water supply facilities planning report,
 outline, 460–465
 Water-cooled slag, grinding, 69
 Watershed area tributary, extension, 474
 Wellwater supply, protection (problem),
 129
 Wet collectors, usage, 355–356
 Wetlands, consideration, 438
 Wheeled compactor, trash blade (inclusion),
 272f
 White goods, recycling (avoidance), 274
 White-list
 industries/projects/establishments,
 environmental impacts, 2
 Wind
 impact, 334–336
 speed, increase, 357
 Wind rose, 334
 example, 335f
 Wind speed, impact. *See* Air pollutants
 Window details, 124f
 Windrow, anaerobic conditions, 234
 Windrow composting, 233–236
 operation, 231f
 technology, 232
 Wood stoves, air pollution contribution, 321
 Woodlands, consideration, 438
 Work areas, selection, 110–111
 Working fill, 276

X

Yard wastes, composting, 226
 preparation, 231f
 Yard/vacant lot debris, 126

Y

Zero discharge, goal. *See* Hazardous waste