SECOND EDITION

Understanding Environmental Health

How We Live in the World

Nancy Irwin Maxwell

Chapter 7
Living in the World We've Made

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7.1 The "Metabolism" of Communities

7.2 Management of Sewage Wastes

7.3 Drinking Water: Public Systems and Private Wells

7.4 Solid Waste and its Management

7.5 Urban Settings in Less Developed Countries

7.6 The Built Environment in More Developed Countries

7.7 Lifestyles: Things We Do, Things We Use

7.7 Sharing Global Impacts and Resources

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Urban Metabolism in the 19th Century

Community Metabolism Today

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Urban metabolism in the 19th century

- "Metabolism" of a community[1]: water supply, sewage, trash
- 19th century
  - Privy pits & cesspools
  - Tap water → water closet, larger volume of waste
  - Use of water to carry away sewage, at community level
  - Drinking water treatment
- Not until 20th century:
  - Sewage treatment
  - Trash as a large-scale phenomenon

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Urban Metabolism in the 19th Century

Community Metabolism Today

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Community metabolism today

- Three fundamental features:
  - Unified water supply
  - Use of potable water to carry away sewage
  - Large quantities of water, sewage, trash; with interconnections among these waste streams
- Municipal wastewater and municipal solid waste
  - Distinct, yet some overlap in contents →

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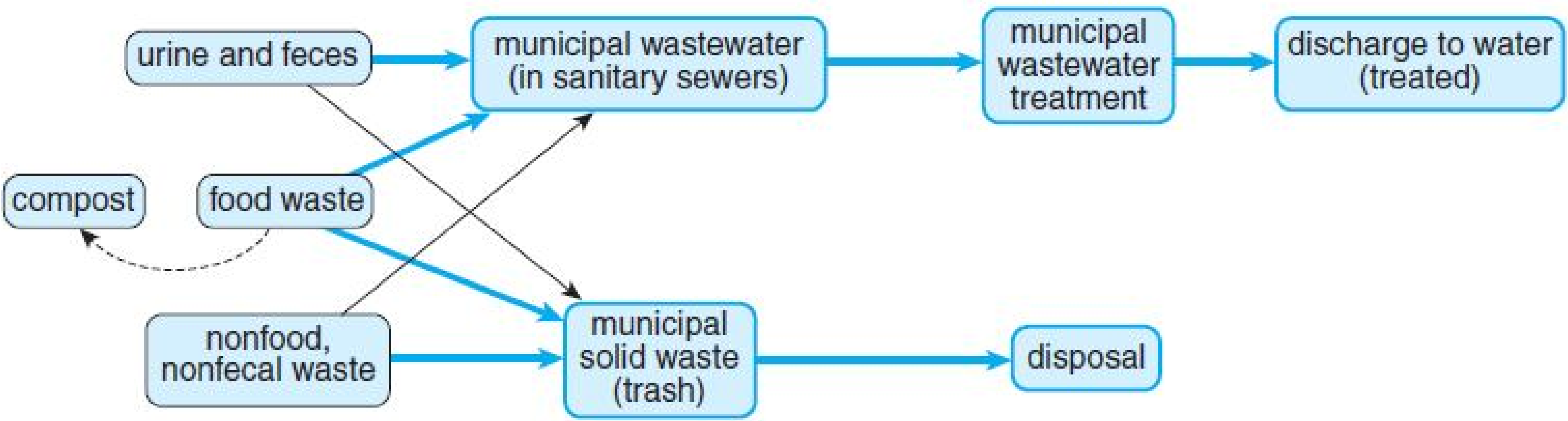

FIGURE 7.2 Contributors to municipal wastewater and municipal solid waste streams.

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Community metabolism today

- Municipal wastewater and storm runoff →
  - Different makeup
  - Constant vs. episodic flow
- Municipal wastewater and industrial wastes →→
  - Industrial wastes discharged directly; or indirectly via municipal wastewater

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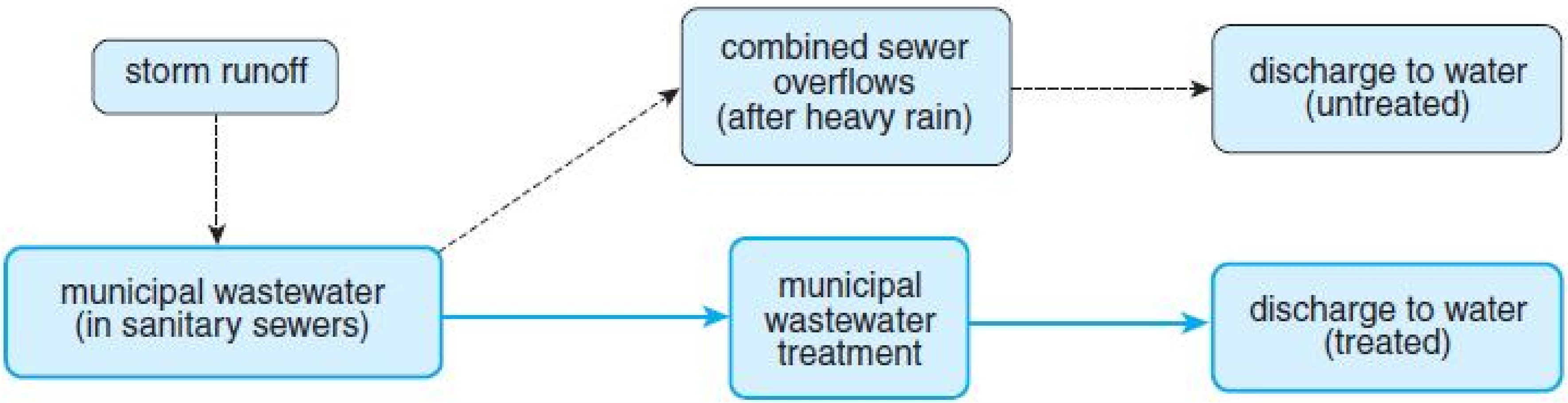

FIGURE 7.4 Use of combined sewer overflows to handle storm runoff.

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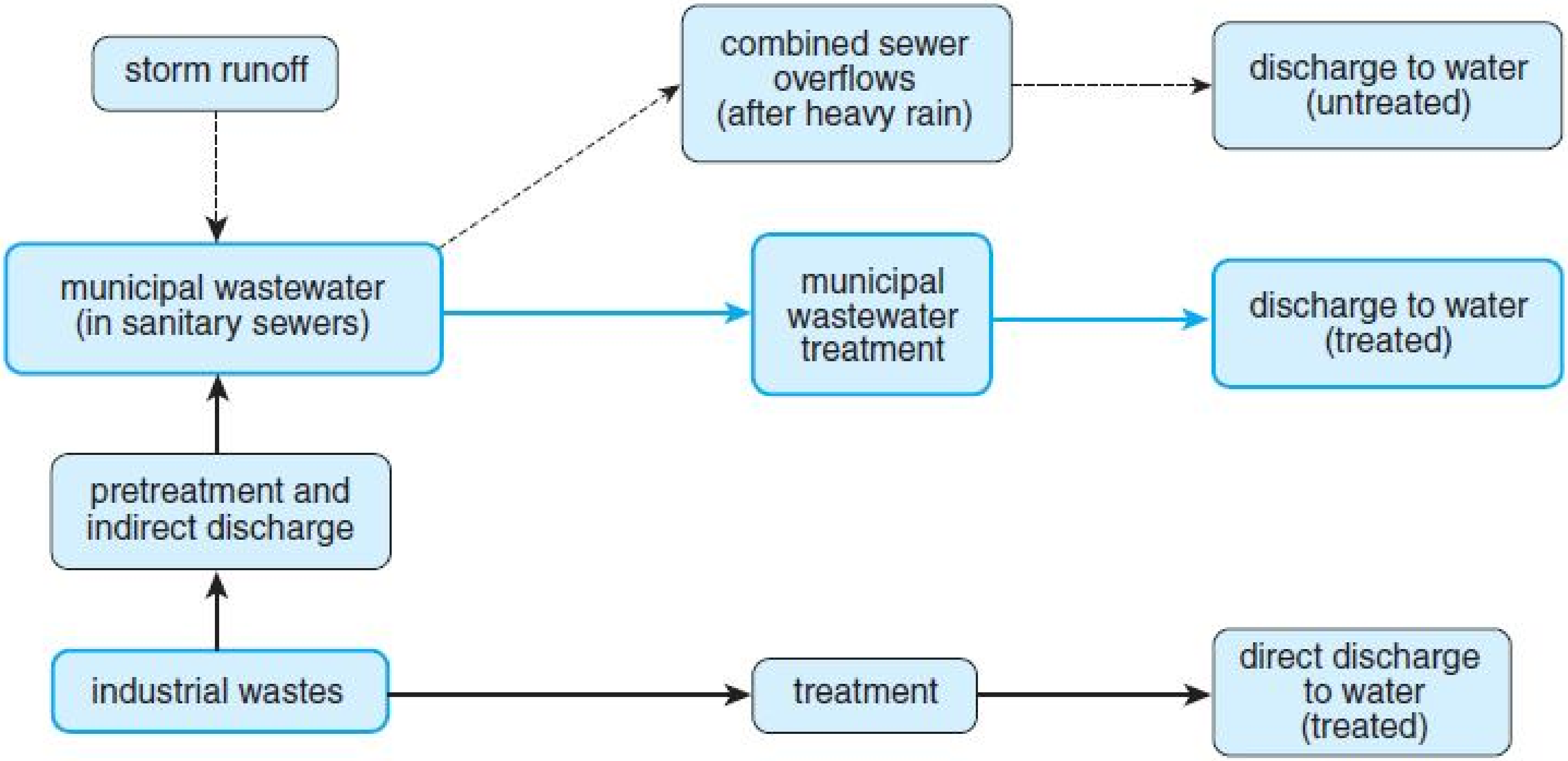

FIGURE 7.5 Direct and indirect discharge of industrial wastes.

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Municipal Wastewater Treatment

Smaller-Scale Systems for Sewage Treatment

Regulation of Municipal Wastewater Treatment in the United States

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Municipal wastewater treatment

- Three related objectives of sewage treatment
  - Remove pathogens
  - Remove organic matter (biochemical oxygen demand or BOD)
  - Remove suspended solids (turbidity)
- Basic processes of sewage treatment →
- How these processes achieve objectives of sewage treatment

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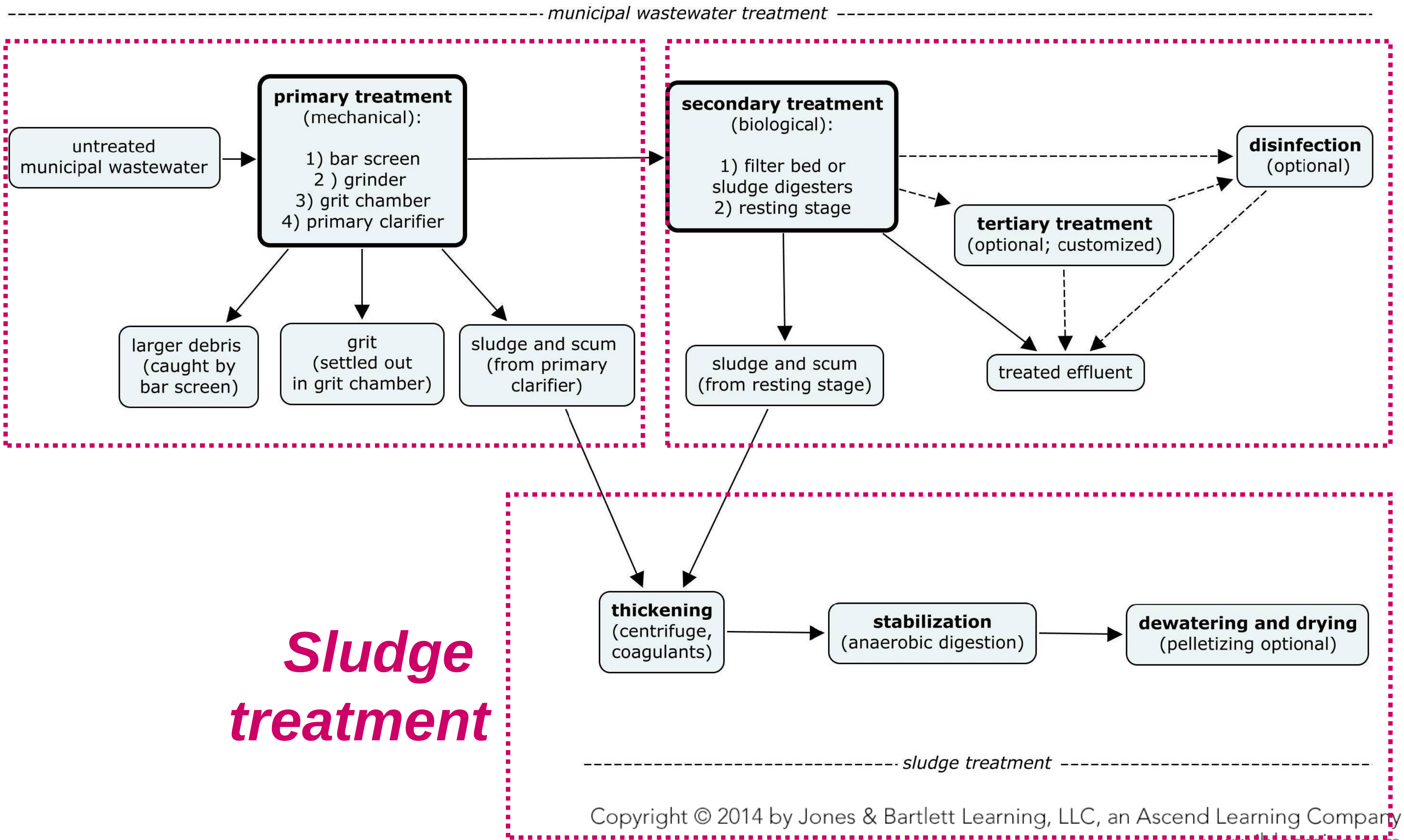
Primary sewage treatment

Secondary sewage treatment



Sludge treatment

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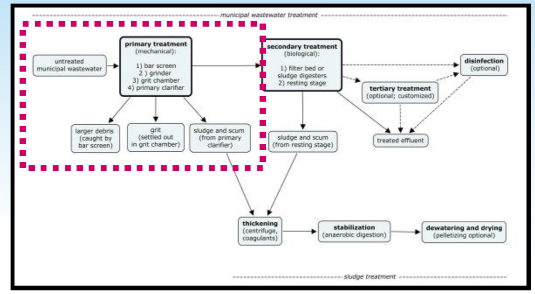
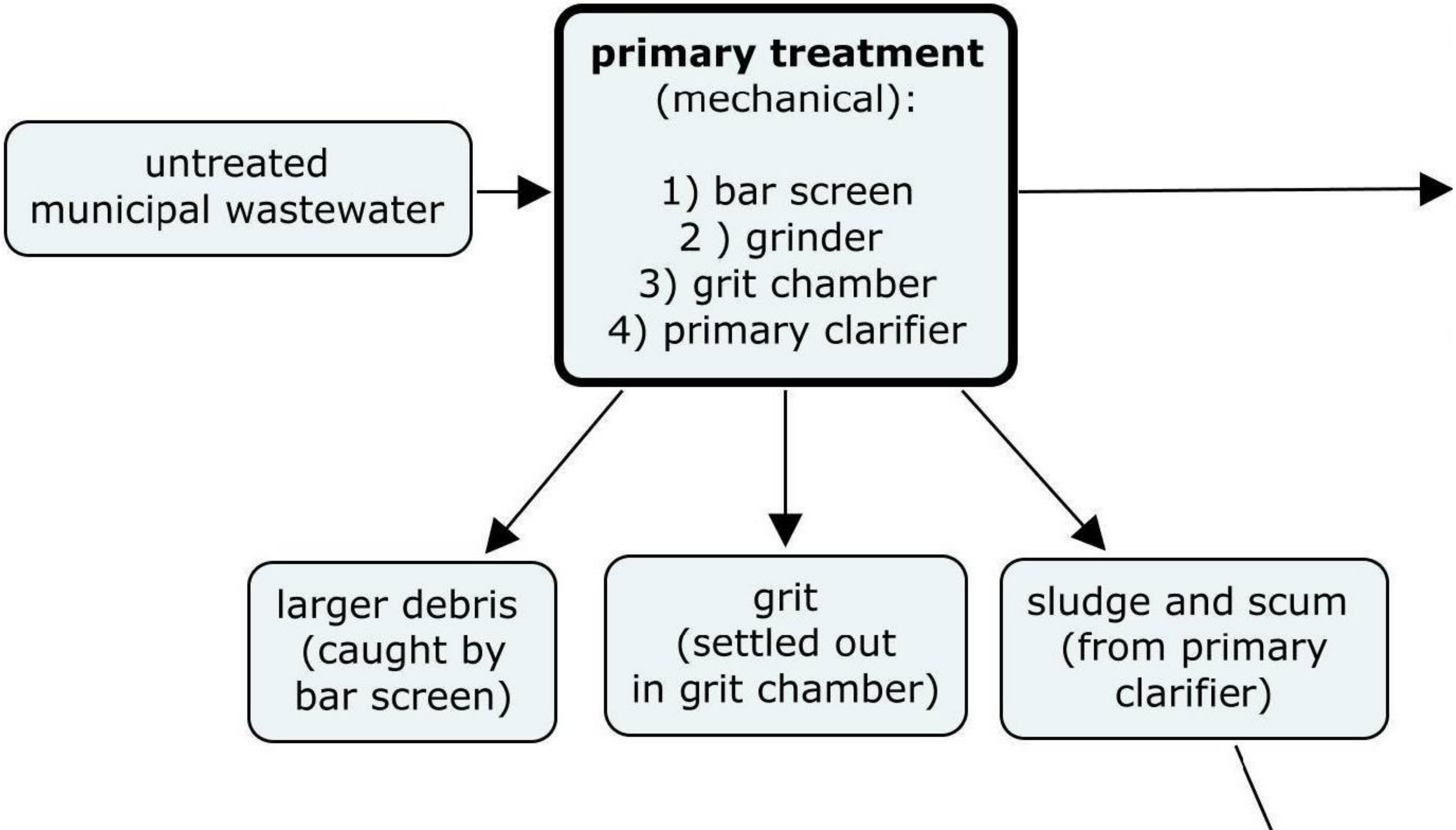
Primary sewage treatment





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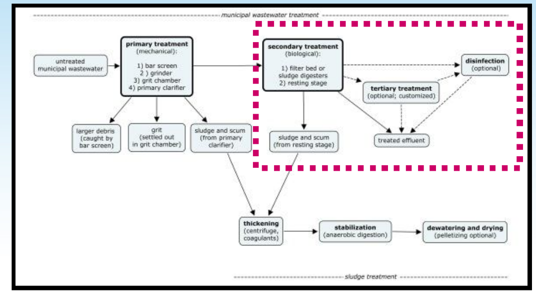
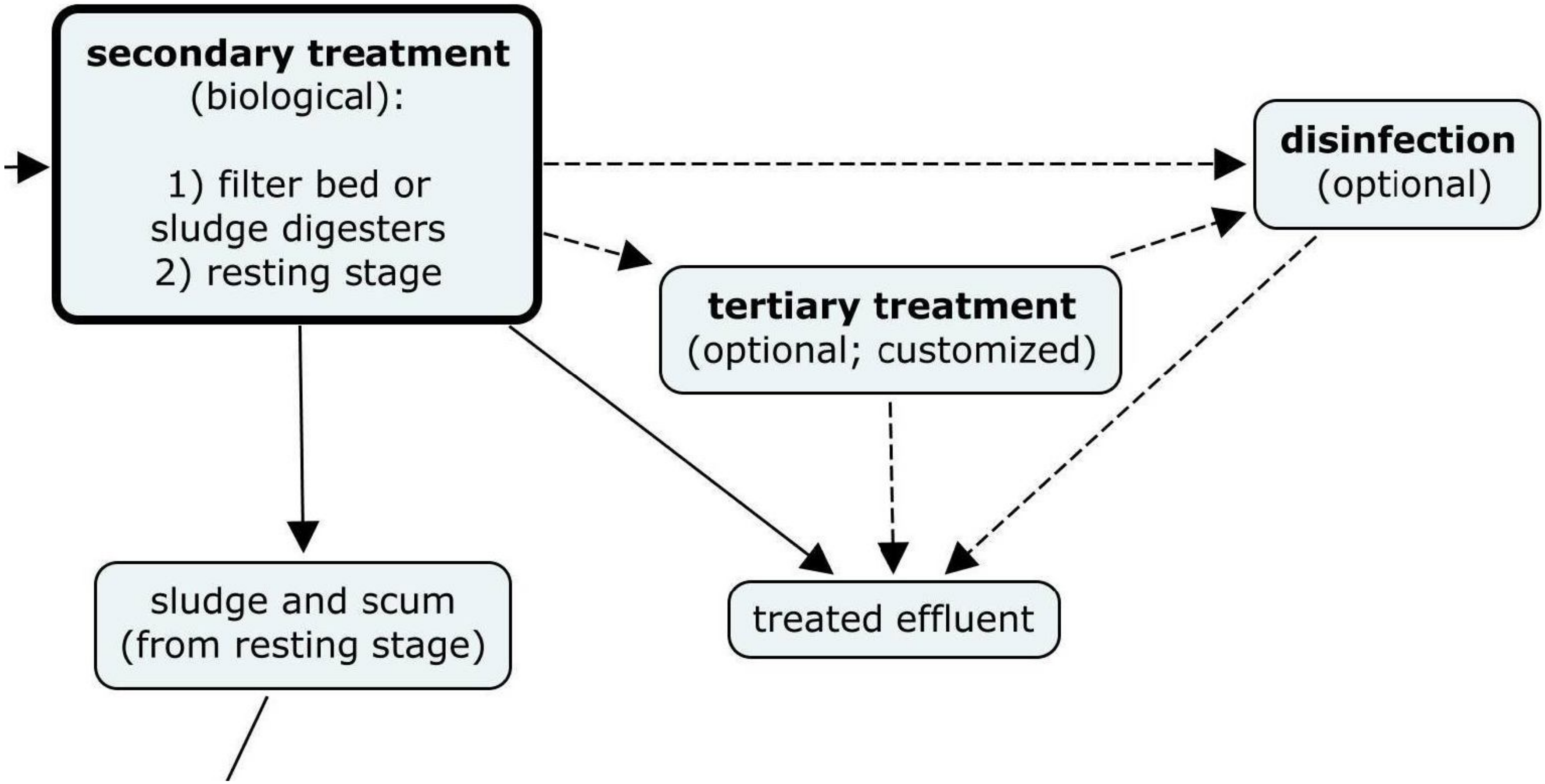
Secondary sewage treatment





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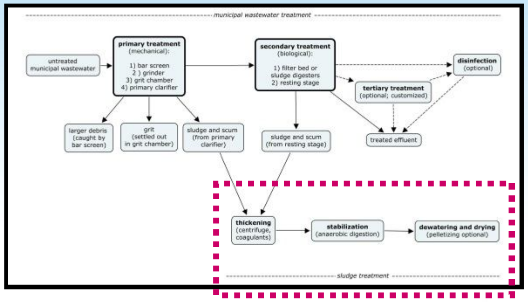
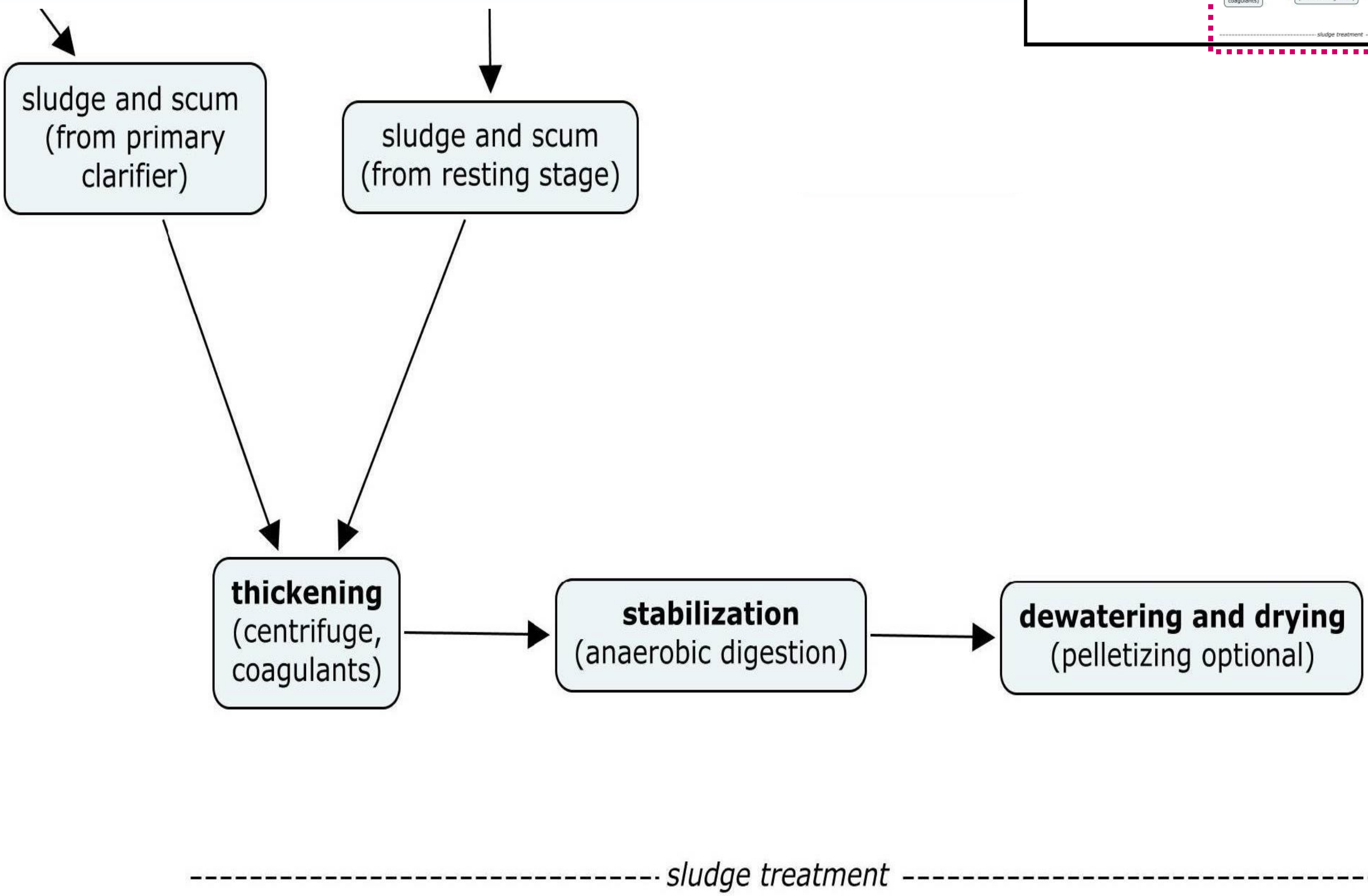
Sludge treatment





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Municipal wastewater treatment

FIGURE 7.8 Treated sewage sludge, shown here in pellet form, is often used as a fertilizer.

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Municipal wastewater treatment

Table 7.1 Objectives and Effects of Municipal Wastewater Treatment

	Effects of Steps in Municipal Wastewater Treatment			
	Basic Treatment Steps		*Additional Optional Steps*	
Objectives	**Primary (mechanical)**	**Secondary (biological)**	**Tertiary Treatment**	**Disinfection**
Remove pathogens	Most survive	Many die off	—	Is effective
Remove organic waste (BOD)	Some is removed	Most is removed	Depends on treatment	—
Remove suspended solids	Some are removed	Most are removed	Depends on treatment	—
Remove chemicals	—	—	Depends on treatment	—

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Municipal wastewater treatment

- Land application of treated sewage sludge
  - Organic waste, rich in nutrients; solves disposal problem
  - But: contaminated with pathogens, metals, organic chemicals

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Municipal Wastewater Treatment

Smaller-Scale Systems for Sewage Treatment

Regulation of Municipal Wastewater Treatment in the United States

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Septic systems and constructed wetlands

- Septic system = septic tank + leach field
  - Tank receives wastewater, material forms layers, all containing fecal bacteria →
  - Liquid flows to leach field, trickles into soil; pathogens gradually die off
  - Periodically clean out and dispose of sludge

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Septic systems and constructed wetlands

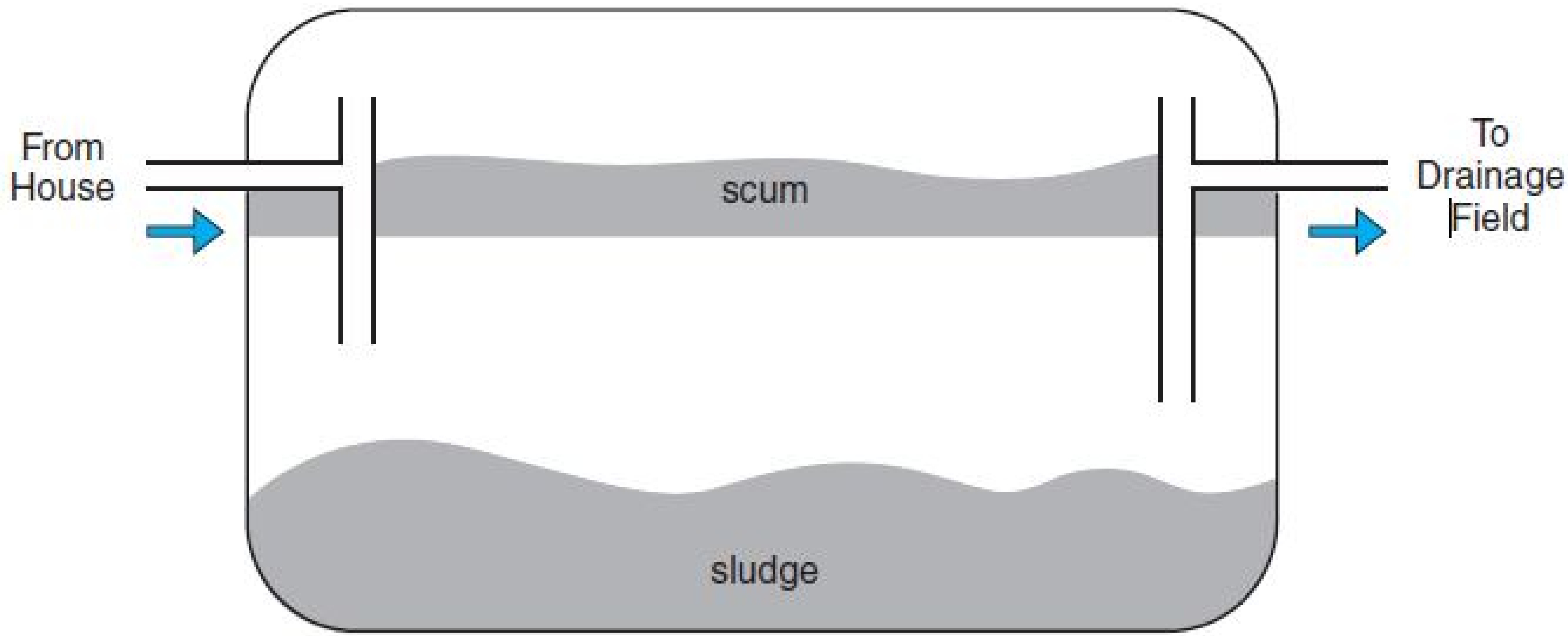

FIGURE 7.9 Schematic drawing of a septic tank (not to scale).

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Septic systems and constructed wetlands

- Constructed (artificial) wetland
  - – Between septic tank and leach field;
  - – Can serve cluster of households
- Enclosed artificial ecosystem →
  - – Microorganisms digest organic wastes
  - – Cleaned water recycled for use in toilets
- Composting toilet useful in some settings (e.g., parks, camps, green buildings)

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Septic systems and constructed wetlands

FIGURE 7.10 This artificial ecosystem, known as a Living Machine, treats toilet wastes at a rest stop on the Vermont Turnpike.

Source: Courtesy of Keith J. Maxwell.

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Municipal Wastewater Treatment

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Regulation of municipal wastewater treatment in the United States

- Clean Water Act
  - Standards for ambient water quality
  - Requirement to use secondary sewage treatment (not just primary)
  - Permitting requirements for discharges (National Pollutant Discharge Elimination System)
    - Standards for effluent
    - Requirements for control technologies

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Regulation of municipal wastewater treatment in the United States

- Effluent standards:
  - Fecal coliform organisms
  - Biochemical oxygen demand (BOD)
- Standards for treated sludge applied to land
  - Standards for metals and pathogens
  - No standards for organic compounds

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Public Water Supplies

Household-Level Water Supply or Treatment

Regulation of Drinking Water in the United States

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Public water supplies

- Water supply in U.S.
  - Average US family of four uses 400 gallons / day;[2,3]
  - Approximately 90% on public supplies[4]
  - 9+% have private wells
  - 0.5 to 1% have no piped water[5]
- About public water supplies
  - Delivers healthful water to many people
  - Large cities usually rely on surface sources

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Public water supplies

- Public system can also deliver a <u>hazard</u> to large numbers of people
  - Lead from lead pipe
    - Widely used in U.S. because malleable, not prone to corrosion
    - In light of lead's known health impacts, more recent shift to copper & plastic pipe
    - Requirements for testing and response
  - Waterborne illness
    - Primary focus of municipal water treatment

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Public water supplies

- Basic treatment steps for drinking water
  - Initial settling (creates sludge)
  - Coagulation and flocculation (of tiny suspended particles)
  - Sedimentation (more sludge)
  - Filtering; often sand filter
- “Sludge” is mostly water; often handled as municipal wastewater

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Public water supplies

- Disinfection of drinking water
  - Treatment specifically to kill pathogens
  - In US, chlorination most common
    - Effective against bacteria; less so against protozoa (*Giardia*, *Cryptosporidium*) and viruses
    - Residual disinfection in distribution system
      - Water pipes have pipes and rough patches →

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FIGURE 7.11 This 10-year-old water supply pipe has accumulated mineral deposits that make its internal surface rough.

Source: Courtesy of Keith J. Maxwell.

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Public water supplies

- Residual chlorine can combine with organic matter → disinfection byproducts
  - Trihalomethanes—with chronic exposure, increased risk of bladder cancer[6,7]
  - Chloramine as option for residual disinfection
- Fluoridation of drinking water
  - Goal is 0.7-1.2 mg/l;[8] prevents tooth decay
  - At higher concentrations, naturally occurring fluoride can cause fluorosis (mottling of teeth)

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Public Water Supplies

Household-Level Water Supply or Treatment

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Household-level water supply or treatment

- Private wells
  - No federal standards; but some state/local[9]
  - Naturally occurring contaminants, depending on geology (e.g., radon, arsenic)
  - Vulnerable to contamination by upgradient land uses (e.g., agriculture, septic systems)
- Devices for home water treatment
  - Point-of-use systems installed at tap (e.g., carbon filter at kitchen sink)

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Private wells, home water treatment, and bottled water

- Bottled water
  - Rapid increase in consumption[10]
  - Expensive; often groundwater source; not likely to be fluoridated[11]
  - Regulated not as drinking water, but as packaged food
  - Often disinfected using ozone or UV light[11] (no residual effect needed)

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Public Water Supplies

Household-Level Water Supply or Treatment

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Regulation of drinking water in the United States

- Safe Drinking Water Act
  - National Primary Drinking Water Regulations (standards for contaminants in public drinking water supply)
    - Maximum Contaminant Level Goal (MCLG)
      - No anticipated health effects
    - Maximum Contaminant Level (MCL) = enforceable standard
      - Considers health risks, benefits, costs

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Regulation of drinking water in the United States

- For certain pathogens, EPA has set MCLGs of zero and MCLs that consist of specific testing regimen and test results[12]
  - *Cryptosporidium*, *Giardia*
  - Coliform bacteria
    - Staged testing for coliforms, fecal coliforms, *E. coli.*
    - Fecal coliform bacteria as indicator organisms for fecal contamination

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Regulation of drinking water in the United States

- EPA has also set MCLGs & MCLs for turbidity, many chemicals
- Safe Drinking Water Act also calls for:
  - Watershed protection, regular monitoring of public supplies, public information on water quality
- Bottled water (FDA, Federal Food, Drug, and Cosmetic Act)—a packaged food
  - Requirements for labeling, quality, manufacturing practices

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About municipal solid waste

- Typical makeup →
- Mundane, but hard to manage
  - Large total quantity; produced by large number of individual households
  - Varied; may include hazardous items
  - Food waste must be removed quickly
- Management options:
  - Produce less waste ("waste prevention")
  - Recycle, incinerate, landfill →→

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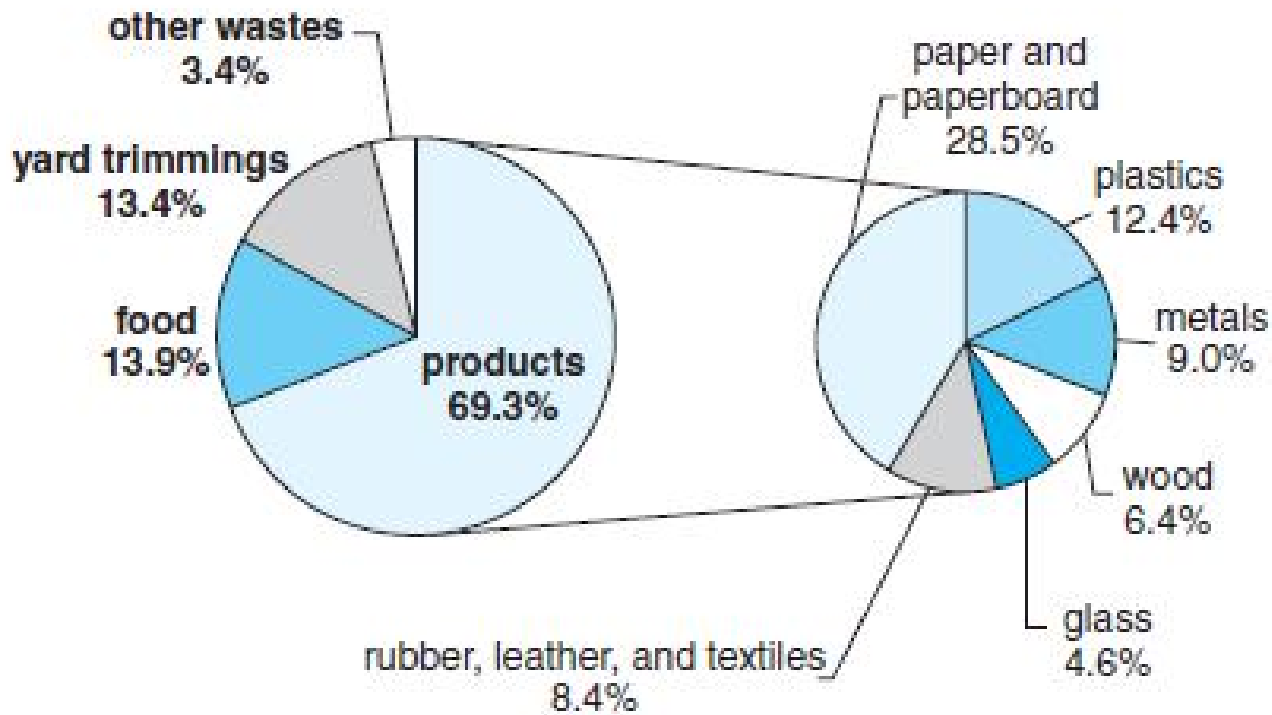

FIGURE 7.12 Makeup of municipal solid waste (by weight) in the United States, 2010.

Source: Data from EPA. Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2010. Available at: www.epa.gov/osw/nonhaz/municipal/pubs/msw_2010_rev_factsheet.pdf. Accessed May 7, 2012.

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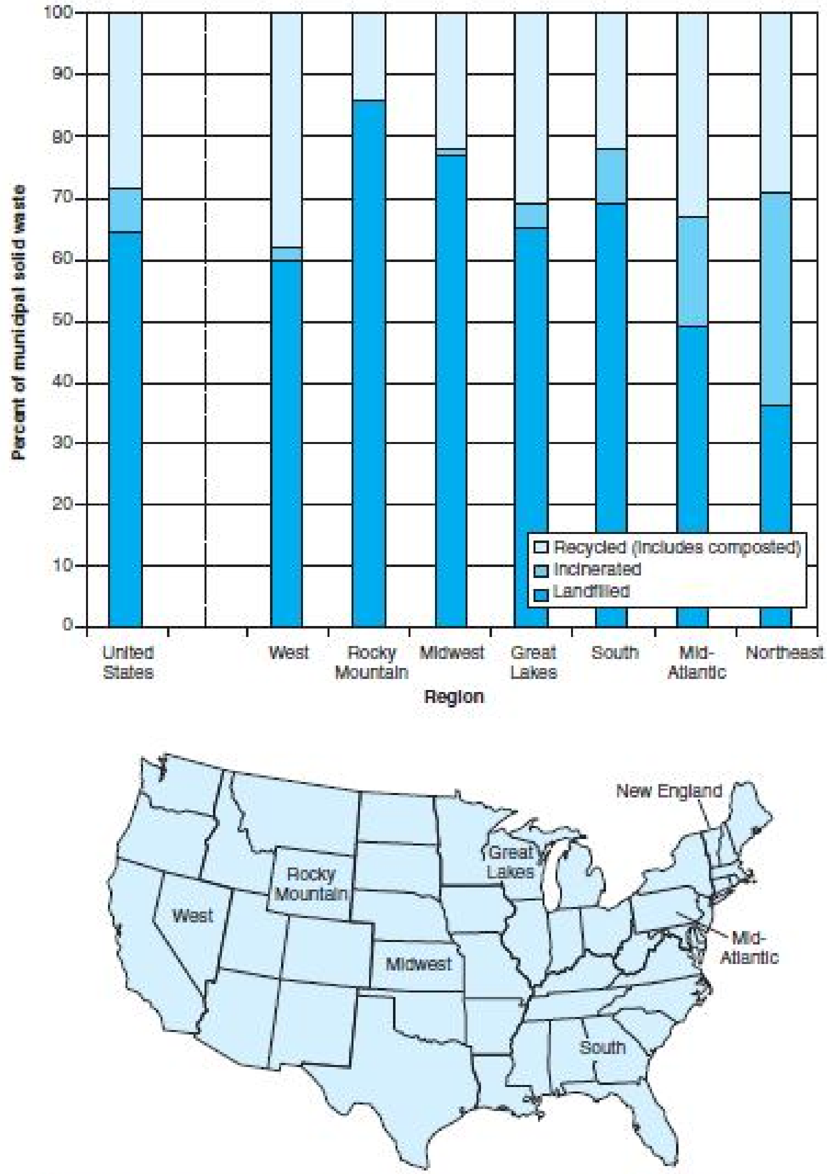

FIGURE 7.13 Fate of municipal solid waste (by weight) in the United States and by U.S. region, 2005.

Source: Data from Simmons P, Goldstein N, Kaufman S, Themelis N, Thompson J. The state of garbage in America. *BioCycle*. 2006;47(4):26.

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Recycling, including composting

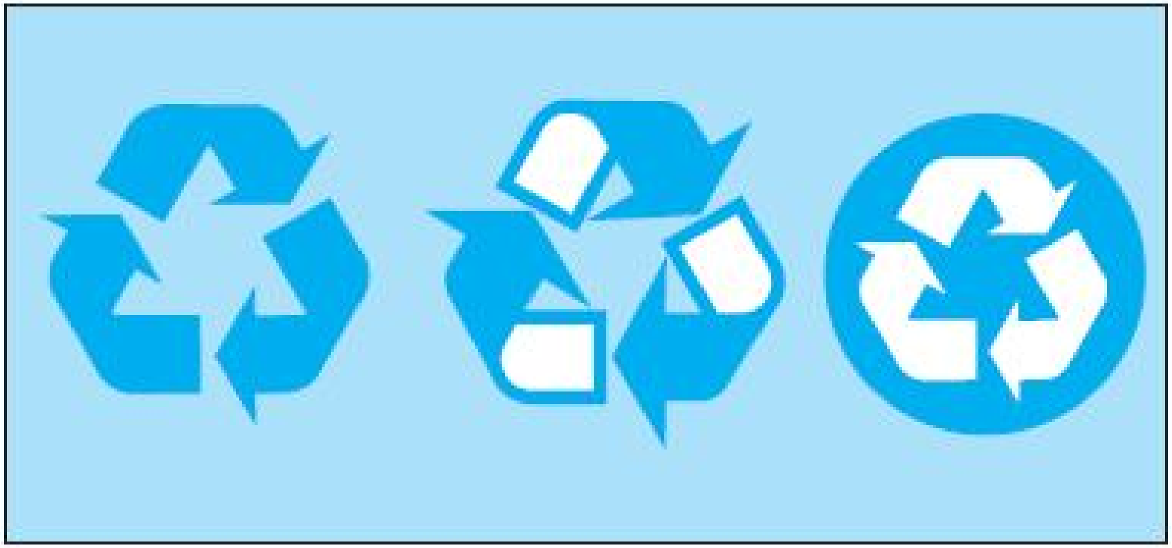

FIGURE 7.14 These and other variants on the basic image of three arrows in an endless loop are in use, indicating either that a product is recyclable or that it contains recycled materials.

Source: U.S. Environmental Protection Agency. EPA Communications: Development and Review/Seal and Logo Files. Available at: www.epa.gov/productreview/guide/seal_logo/index.html. Accessed January 14, 2012.

- Removes glass, metal, plastics, paper from waste stream before disposal
  - Sorted by consumers
  - Or sorted at materials recovery facility

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Recycling, including composting

- Composting—removes organic materials before waste disposal
  - Municipal composting (yard trimmings)
  - Household composting
    - Outdoors, composting bin or pile
    - Indoors, vermicomposting[13]

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Waste-to-energy incineration

- Incineration of waste to generate energy
  - Greatly decreases volume
  - Challenges:
    - Metals in waste stream → particulates (or mercury vapors) in emissions; must be captured
    - Plastics → dioxins & furans if temperature not high enough
    - Both fly ash and bottom ash must be captured and disposed of properly

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Disposal in landfills

- Modern MSW landfill →
  - Licensed, usually operated by corporation
  - Lined pit
  - Trash compacted in layers
  - Capped with clay
  - Systems collect & remove leachate, methane
  - Ongoing maintenance & monitoring

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Disposal in landfills

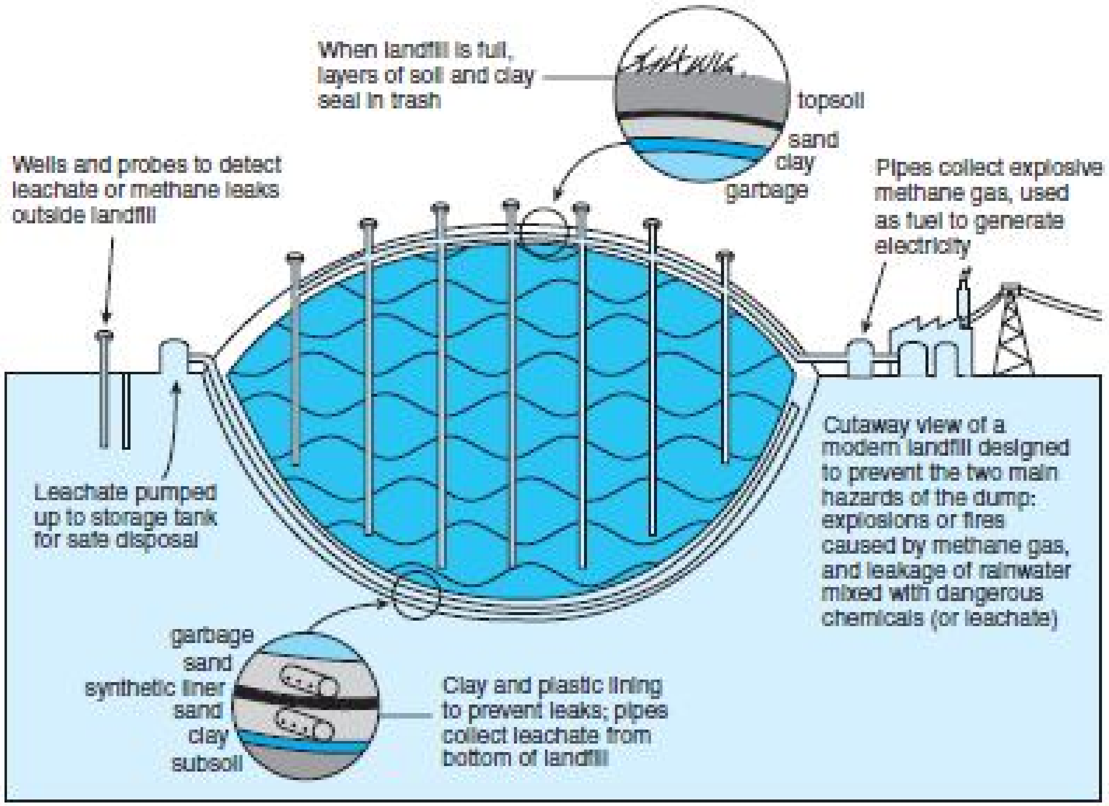

FIGURE 7.15 A schematic cross-section of a modern municipal solid waste landfill.
Source: Reprinted from U.S. Environmental Protection Agency, Resource Conservation and Recovery Act (RCRA). Available at: www.epa.gov/superfund/students/clas_act/haz-ed/ff_06.htm. Accessed December 13, 2007.

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Handling of household hazardous wastes

- Same criteria: corrosive, toxic, ignitable, reactive
- Exx:[14] Drain cleaners, rat poison, antifreeze, pesticides →
- Separate handling not required by federal law; many cities / towns do have programs

FIGURE 7.16 This bottle of liquid chlordane, which sat in a garage for 20 years after the sale of the pesticide was prohibited in the United States, was turned in at a municipal collection day for household hazardous wastes.

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Medical waste

- Produced by health care facilities
  - Infectious, hazardous, radioactive
  - Federal incinerator emissions limits; but much regulation is state or local

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Regulation of municipal solid waste in the United States

- Resource Conservation and Recovery Act
  - No open dumping; requirements for landfill features, groundwater monitoring
  - Encourages source reduction, recycling, waste-to-energy technologies
- Clean Air Act
  - Governs incinerator emissions

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Urban settings in less developed countries

- Global population > half urban →
- 3 billion people in cities; 1 billion in urban slums[15]
- Emergence of megacities > 10 million, most in less developed countries →→
- Estimate 37 megacities by 2025[16]

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Urban settings in less developed countries

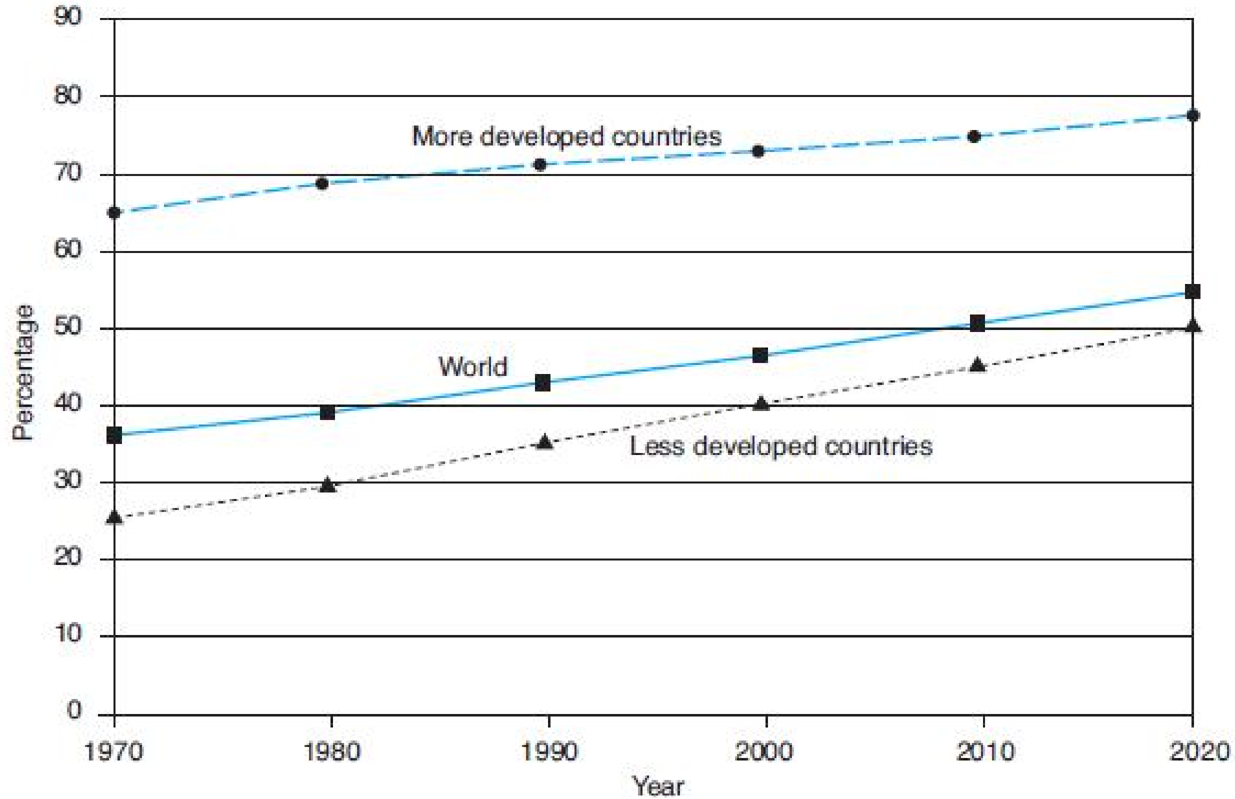

FIGURE 7.17 Percentage of the global population that is urban, 1970–2020.

Source: Data from United Nations. World Urbanization Prospects: The 2005 Revision Population Database; Table A.2. Available at: www.un.org/esa/population/publications/WUP2005/2005wup.htm. Accessed April 23, 2007.

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Urban settings in less developed countries

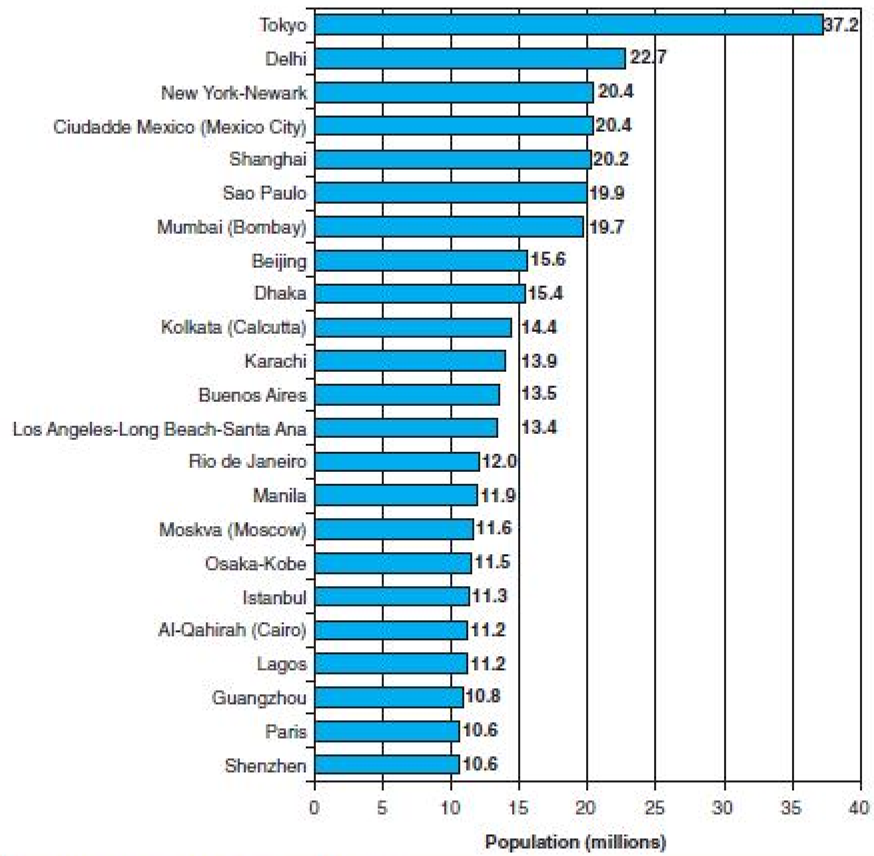

FIGURE 7.18 Population of the world's 23 megacities, 2011.

Source: Data from United Nations, Department of Economic and Social Affairs, Population Division (2012). World Urbanization Prospects: The 2011 Revision, CD-ROM Edition.

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Urban settings in less developed countries

- Poverty, crowding, poor housing, lack of sanitation & clean water[17]
- Air pollution, toxic wastes, fires, traffic accidents, violence[17]
- Conditions conducive to infectious disease →
  - Standing water, poor sanitation, crowding

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Urban settings in less developed countries

FIGURE 7.19 Slum dwellings in an Ecuadoran city perch over sewage-contaminated water.

Source: Reprinted courtesy of CDC Public Health Image Library. ID# 5323. Content provider: CDC. Available at: http://phil.cdc.gov/phil/home.asp. Accessed October 30, 2012.

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Electrical Transmission Lines

Suburban Sprawl

Construction Practices

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The built environment in more developed countries

- Electrical transmission lines
  - Emit extremely low frequency (ELF) radiation
  - IARC, NIOSH classify ELF electromagnetic fields as possibly carcinogenic to humans (Group 2B)[18, 19]

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Electrical Transmission Lines

Suburban Sprawl

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The built environment in more developed countries

- Suburban sprawl
  - Low-intensity construction; separation of land uses through zoning[20] →
  - Extensive road systems, heavy traffic[20]

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The built environment in more developed countries

FIGURE 7.22 Suburban residential developments like this one, with its curving cul-de-sacs and large homes, all similar in design, are found all across the United States.

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The built environment in more developed countries

- High per-capita energy use in suburbs (single-family homes, need car)
- High traffic fatalities[21] (heavy traffic at high speeds outside residential areas)
- Walking may be inconvenient or hazardous; perhaps contributing to obesity[22]
  - Note factors in <u>urban</u> settings (e.g., poverty) also linked to obesity[23]

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Construction Practices

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The built environment in more developed countries

- Construction practices. Important because:
  - Indoor settings are enclosed spaces
  - Americans spend[24]
    - 87% of their time indoors
    - 69% of their time in their homes
  - Working adults: time indoors at work
  - Children: time indoors at school

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Radon gas in buildings

- Natural hazard in some regions
  - Seeps into house, especially basement
  - Volatilizes from tap water (groundwater); accumulates in indoor air
  - Begins series of rapid breakdowns
  - Radon and some progeny are alpha emitters; lung cancer risk
  - Often simple to detect and remediate

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Unhealthy construction materials and sick buildings

- Asbestos
  - In industrialized countries, nearly everyone has asbestos fibers in lungs[25]
  - Some risk of cancer, not fibrotic disease
- Formaldehyde
  - Pressed wood products, crease-proof fabrics
  - Gas at room temp; moves into indoor air
  - Respiratory irritation, asthma, cancer

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Unhealthy construction materials and sick buildings

- "Sick building syndrome"
  - Nonspecific symptoms experienced by occupants of a building
- →"Sick building" designation
  - A building whose occupants experience such symptoms
- Building-related illness
  - Specific diagnosable illness, linked to specific feature of building

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7.1 The “Metabolism” of Communities

7.2 Management of Sewage Wastes

7.3 Drinking Water: Public Systems and Private Wells

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7.6 The Built Environment in More Developed Countries

7.7 Lifestyles: Things We Do, Things We Use

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Tobacco Smoke

Products used at Home

Sources of Ionizing Radiation

Sources of Non-Ionizing Radiation

Environmental Noise

Regulation Related to Hazards of Modern Life

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Tobacco smoke

- Tobacco smoke
  - Historically, smoking accepted and even encouraged (e.g., rations to soldiers[26])
  - 1950: smoking linked to lung cancer[27]
  - Evidence accumulated over decades
  - Settlement agreements between states and tobacco companies[28]
  - Even in 2010, about one-fifth of US adults were smokers[29]

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Tobacco smoke

- Evidence on health hazards of smoking
  - Emphysema, heart disease, heart attack, stroke[30]
  - Cancer: mouth, pharynx, larynx, lung, bladder; esophagus, stomach, kidney, pancreas, cervix; probably female breast cancer and primary liver cancer[30-33]
  - Hearing loss[34,35]
  - During pregnancy: increased risk of stillbirth, low birthweight, SIDS[36]

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Tobacco smoke

- Environmental tobacco smoke (secondhand smoke):
  - Adults: heart disease, heart attack, lung cancer;[37] hearing loss[34]
  - Children: SIDS, asthma;[37] hearing loss[35]
- Smoking is on the rise in less developed countries
  - More than 8 million people projected to die from smoking-related causes in 2030[38]

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Tobacco Smoke

Products used at Home

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Lead paint

- Lead paint: pigment ("white lead") added to paint for durability, brightness
  - By 1915, known to be neurotoxic[39]
  - By 1931, 11 European countries had banned white lead in indoor paints[39]
  - 1978: US banned white lead in interior & exterior paints

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Lead paint

- Children's exposure to lead in paint
  - Mainly incidental ingestion of house dust; also soil near house;[40,41] hand-to-mouth exposures
- Homes with significant hazard[42]
  - 1990: 64 million US housing units
  - 1998-2000: 38 million US housing units
- Remediation is difficult & expensive →
- Progress over time in reducing blood lead levels in US children → →
- But racial and ethnic disparities persist

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Lead paint

FIGURE 7.23 This worker wears protective gear as he demonstrates the use of a power sander to remove lead paint in 1999—a common renovation method at the time.

Source: Reprinted courtesy of CDC Public Health Image Library. ID# 7333. Content provider: CDC/Aaron L. Sussell. Available at: http://phil.cdc.gov/phil/home.asp. Accessed October 30, 2012.

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Lead paint

Table 7.7 Decline in Blood Lead Levels ($\mu g/dL$) in U.S. Children Ages 1 to 5 Years, Over a 30-Year Period

Percentile	1976–1980	1988–1991	1992–1994	1999–2000	2003–2004	2007–2008
50th	15	3.5	2.6	2.2	1.6	1.4
90th	25	9.4	7.1	4.8	3.9	2.8

Sources: Adapted from U.S. Centers for Disease Control and Prevention. America's Children and the Environment. Table B-1: Concentrations of Lead in Blood of Children Ages 5 and Under. Available at: www.epa.gov/ace/archives/datatables_07-08.html#bb. Accessed December 7, 2012; U.S. EPA, Report on the Environment/Blood Lead Level. Available at: http://cfpub.epa.gov/eroe/index.cfm?fuseaction=detail.viewInd&lv=list.listbyalpha&r=224030&subtop=208. Accessed April 27, 2012.

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Personal care products

- Deliberately applied to body; habitual use
  - Exposure hard to document
    - Individuals use a changing list of products
    - Products have a changing list of ingredients
    - Not all ingredients listed on label
  - Toxicity of many ingredients not well known
    - e.g., only recent attention to phthalates as endocrine disruptors
- Heavily marketed, especially to women
- Wide use of antimicrobial products[43] contributes to antibiotic resistance

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Products for housekeeping, including pesticides

- Products advertised to make home feel clean and smell good; many contain respiratory irritants
  - Cleaning products, laundry products
  - Air fresheners, toilet bowl cleaners
- Antibacterial sprays and soaps
- Pesticides used in the home
  - Special risk to children
  - Illegal household pesticides →

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Products for housekeeping, including pesticides

FIGURE 7.24 This illegal pesticide, known as Chinese chalk, resembles ordinary blackboard chalk.

Source: Courtesy of Dion Lerman, Pennsylvania Integrated Pest Management Program/ Pennsylvania State University.

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- *Tobacco Smoke*
- *Products used at Home*
- ***Sources of Ionizing Radiation***
- *Sources of Non-Ionizing Radiation*
- *Environmental Noise*
- *Regulation Related to Hazards of Modern Life*

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Sources of ionizing radiation

- Average annual exposure to medical X-rays in countries with at least one physician per 1000 population:[44]
  - –1.92 mSv per capita
- Global average annual exposure to radon:[45]
  - –1.15 mSv per capita

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Tobacco Smoke

Products used at Home

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Sources of non-ionizing radiation

- Cellular phones
  - Emit microwave radiation
  - Cell phone users estimated at 2/3 of global population (4.6 billion people)[46]
  - Concern is brain cancer (near ear); to date, inconclusive[46,47]
- Tanning salons / tanning beds
  - Emit mainly UV-A radiation; Group 1 carcinogen[48]

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Tobacco Smoke

Products used at Home

Sources of Ionizing Radiation

Sources of Non-Ionizing Radiation

Environmental Noise

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Environmental noise

- Recreational activities
  - Target shooting, rock music, motorcycle races
  - Personal music players[49,50]
- Prevalence of hearing loss in US adolescents:[51]
  - 15% in 1988-1994
  - 20% in 2005-2006
- Airport noise at school associated with impaired reading comprehension and long-term memory[52]

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Tobacco Smoke

Products used at Home

Sources of Ionizing Radiation

Sources of Non-Ionizing Radiation

Environmental Noise

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Regulation related to hazards of modern life

- The indoor environment
  - EPA: Technical assistance and education / outreach on lead hazards
  - EPA: Financial support and technical assistance for states' radon programs
  - Consumer Product Safety Commission: main focus on packaging and labeling

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Regulation related to hazards of modern life

- Cigarettes and cosmetics
  - Cigarettes:[28] no smoking on domestic flights; no ads on TV or radio; warnings on packages
  - Cosmetic products and ingredients
    - No premarket approval; safety review by trade group
    - As of 2006,10 ingredients prohibited in cosmetics
- Noise
  - Two federal laws, unfunded for nearly 30 years
  - Regulations at state and local levels

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Quantifying the Impacts of Development

Facing a Challenging Future

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Quantifying the impacts of development

- The impact equation:

Impact = Population x Consumption

or, $I = P \times C$

- *C* can be expanded, yielding the IPAT equation:

$$I = P \times A \times T$$

where A = affluence, T = technology

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Quantifying the impacts of development

- Carrying capacity = maximum impact an ecosystem (or the earth) can support for extended period
- Sustainable development = development whose impact can be maintained over many generations
- Ecological footprint (a measure of impact):[53] the area on the earth's surface required to provide resources for, and absorb the wastes of, a person or population with a given lifestyle.

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Quantifying the impacts of development

- Components of the ecological footprint:[53]
  - Built-up land area
  - Area needed to produce food on land
  - Area needed to produce food at sea
  - Forested area needed to produce wood products
  - Forested area needed to absorb CO_2 from burning fossil fuels (carbon footprint)

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Quantifying the Impacts of Development

Facing a Challenging Future

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Facing a challenging future

- Global carrying capacity in 2007
  – 1.8 hectares per capita[54]
- Global average ecological footprint in 2007 →
  – 2.7 hectares per capita[54]
- Key ecological and demographic realities:
  – Western-style development not sustainable globally
  – Enormous disparities between ecological footprints of richer and poorer countries
  – Future strain on global carrying capacity will be driven by regions with largest populations (China and India, both with increasing per capita footprints)

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Facing a challenging future

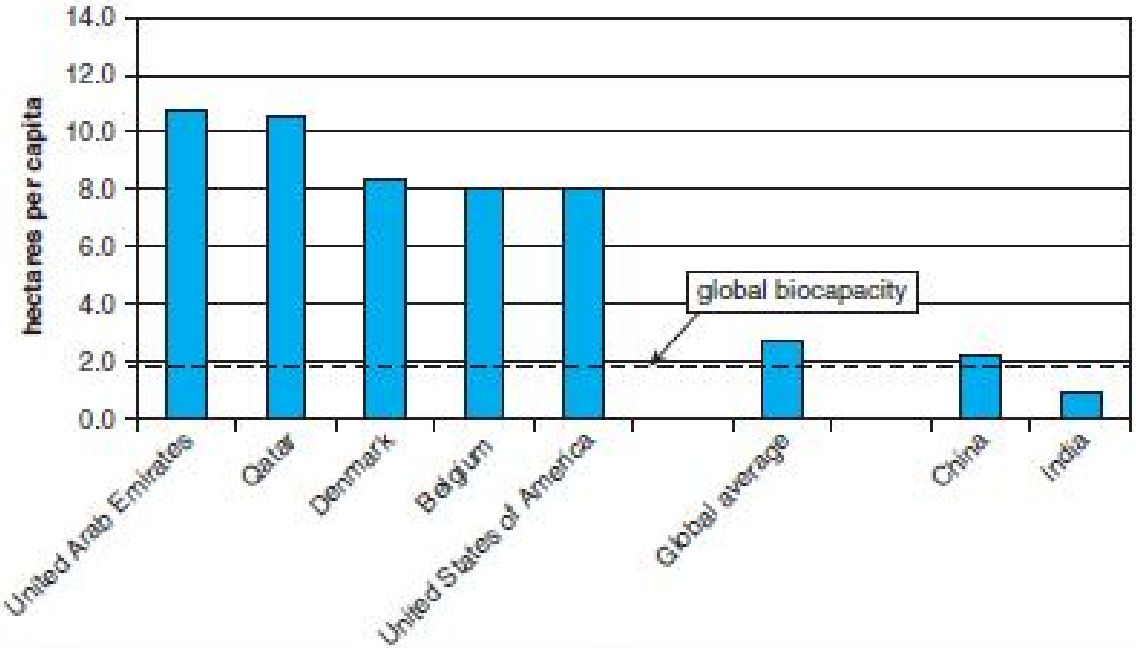

FIGURE 7.26 Per capita ecological footprints for the top five countries, the world as a whole, and two rapidly industrializing, high-population countries, compared to global biocapacity, 2007.

Source: Data from Global Footprint Network, Data and Results, 2010. Available at: www.footprintnetwork.org/en/index.php/GFN/page/ecological_footprint_atlas/. Accessed May 3, 2012.

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Facing a challenging future

- A daunting challenge: designing a global future that is both more sustainable and more equitable
- Technology, re-oriented towards the "green," may become part of the solution
- Compelling concerns
  - Growing burden of ecological debt
  - Reality of global connectedness
  - Global climate, hanging in the balance

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