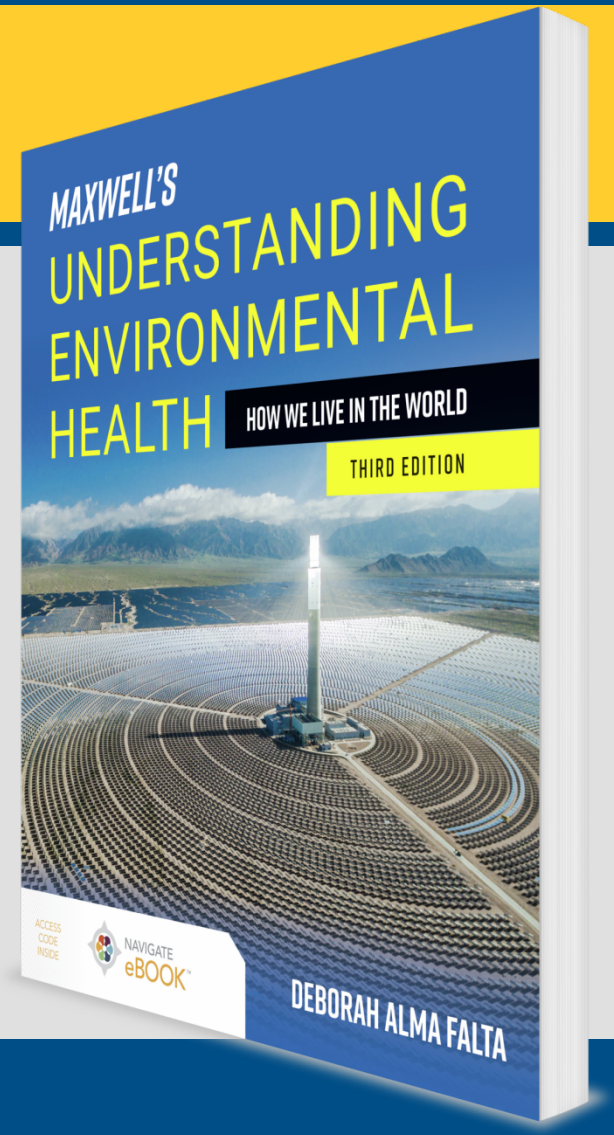
CHAPTER 2

The Science of Environmental Health



Overview of Chapter 2 Topics

- Characteristics of pollutants in our air and water
- Fate and transport characteristics
- Principles of toxicology
- Applied science of exposure assessment
- Environmental epidemiology
- Quantitative risk assessment

Pollution on Our Planet

The story of human exposure to environmental contaminants begins with the fate and transport of these agents: their transformations and movements: through the atmosphere or aqueous environment.

The Atmosphere

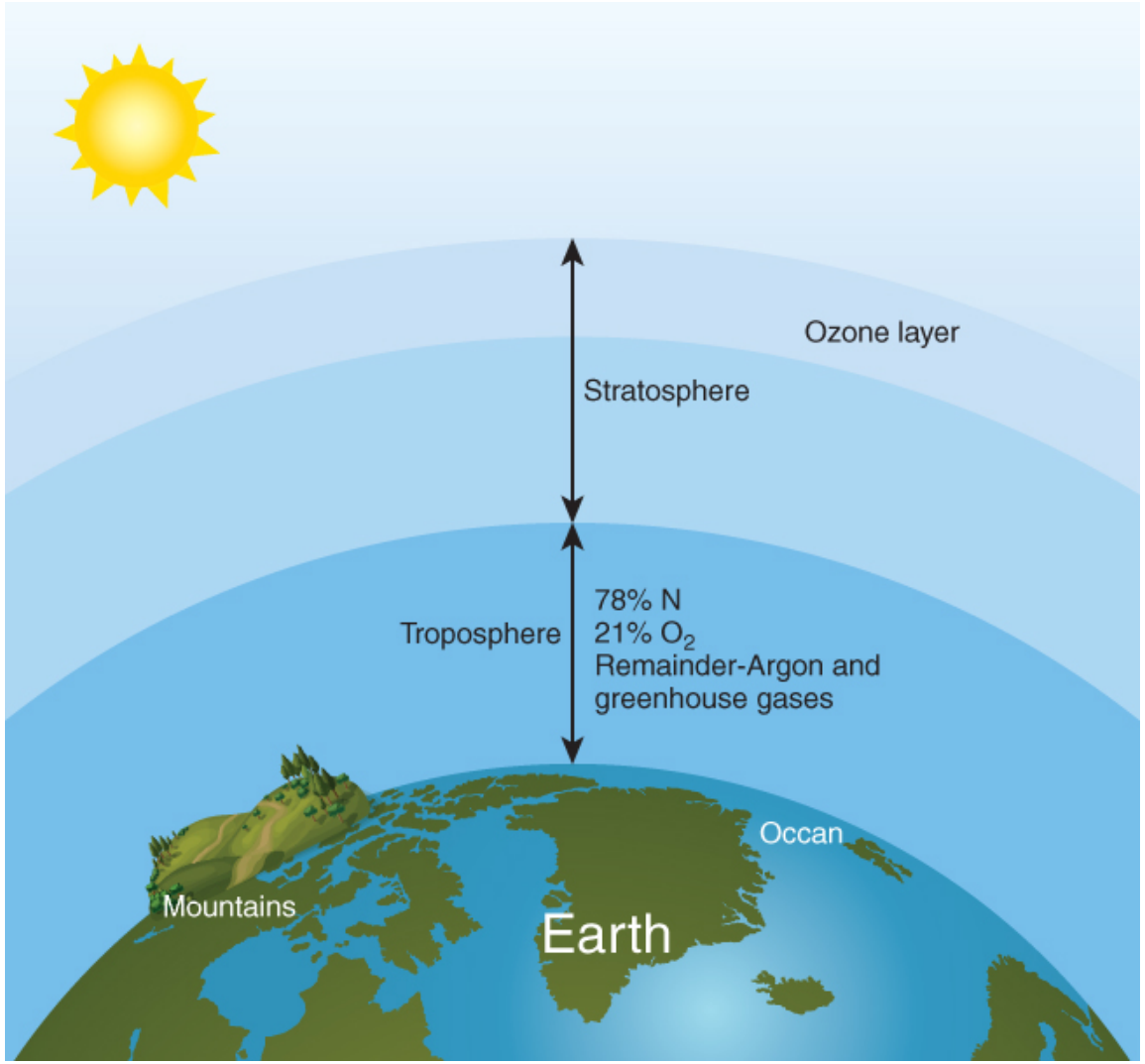


FIGURE 2.1 The atmosphere.

Composition of Air (by Weight) in the Troposphere

- Nitrogen (76%)
- Oxygen (23%)
- Argon (1%)
- Carbon dioxide (0.03%)
- Variety of other gases in lesser amounts
- Water vapor

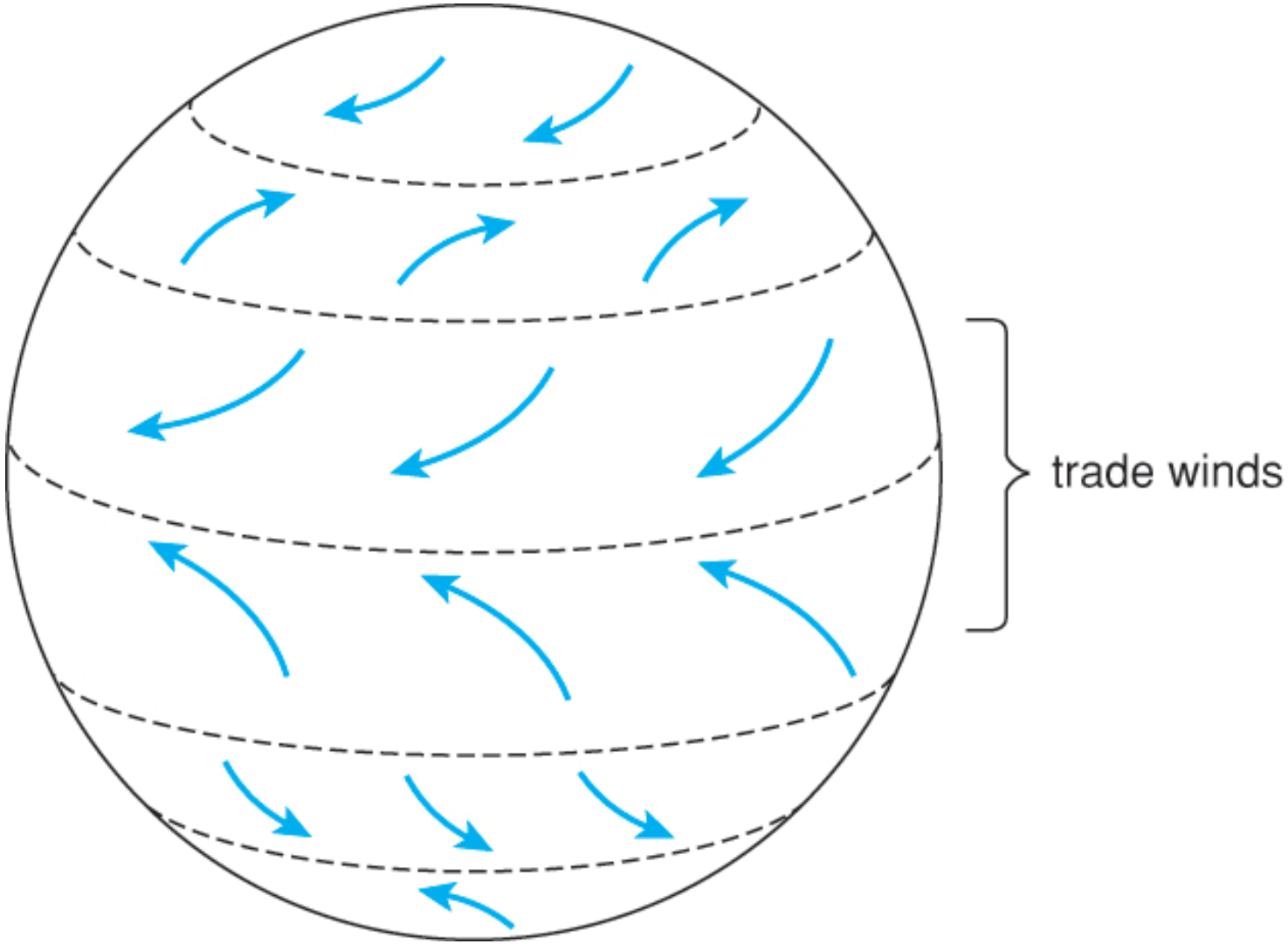
Energy Budget

- Earth receives energy from the sun, in the form of ultraviolet and visible radiation.
- Earth emits terrestrial radiation in the form of infrared energy.
- These two major energy fluxes must balance (e.g. be in equilibrium)!

However, We'd Be Very Cold on Earth Without the Greenhouse Effect!

- Greenhouse gases (carbon dioxide, methane, nitrous oxide, and water vapor)
- Allow short-wave solar radiation to pass through unimpeded
- BUT, trap (absorb) most of the long-wave terrestrial radiation
- Earth would be 33°C colder without the greenhouse effect

Global Winds Transport Pollutants



Temperature Inversions

- Normally, surface air, warmed by earth, rises, and cooler, denser air above sinks; thus, continuous mixing and low pollutant concentrations

- **Temperature inversion** occurs when cooler surface air is trapped below warmer air above; thus, little mixing and high pollutant concentrations at ground level

Sources of Air Pollution

- Natural sources include dust; forest fires; volcanos; and materials of biologic origin, such as molds and pollen
- Anthropogenic sources include:
  - Stationary sources
  - Mobile sources

Stationary Sources

- Electric-generating plants
- Factories and manufacturing complexes
- Oil refineries
- Chemical plants
- Incinerators

FIGURE 2.2 Stationary sources of air pollution.

Mobile Sources

- On-road vehicles (e.g., cars, trucks, buses)
- Off-road vehicles (e.g., dune buggies, snowmobiles)
- Nonroad vehicles (e.g., airplanes, ships, trains)

Global Hydrologic Cycle

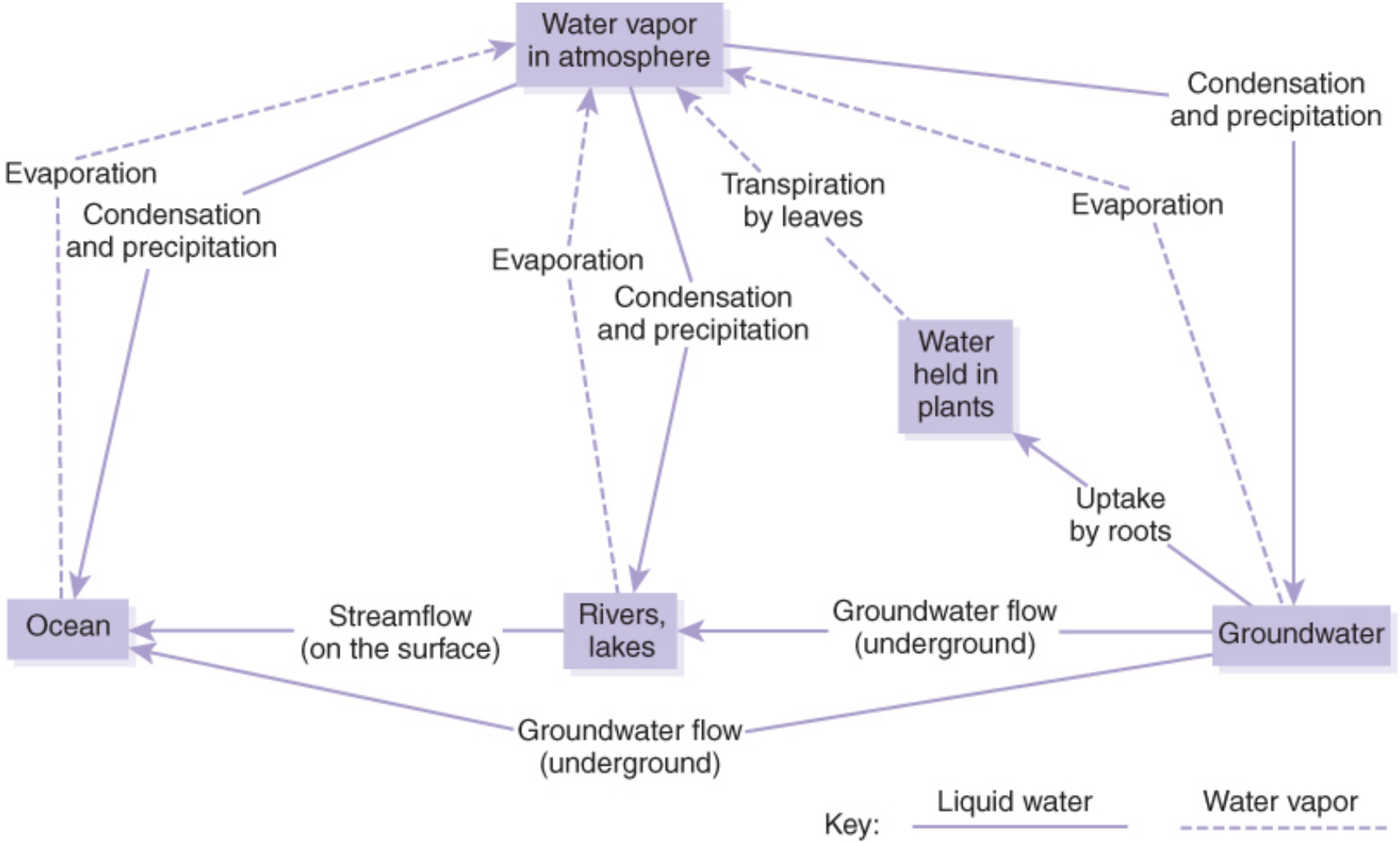


FIGURE 2.3 Hydrologic cycle.

Drinking Water Availability

- Although the earth's surface is covered largely by water, most of this water is non-potable ocean water.
- Approximately 3% of all water is freshwater, of which the majority (70%) is unavailable for human use (e.g., frozen in icecaps).
- Of the remaining freshwater, only 1% is readily accessible from surface sources.

Ocean Waters

- **Gyre:** any large system of circulating ocean currents
  - Refer to NOAA video for information about major marine gyres
- Marine debris collects in eddy-like areas within these gyres.
  - **Plastic garbage patches**
  -

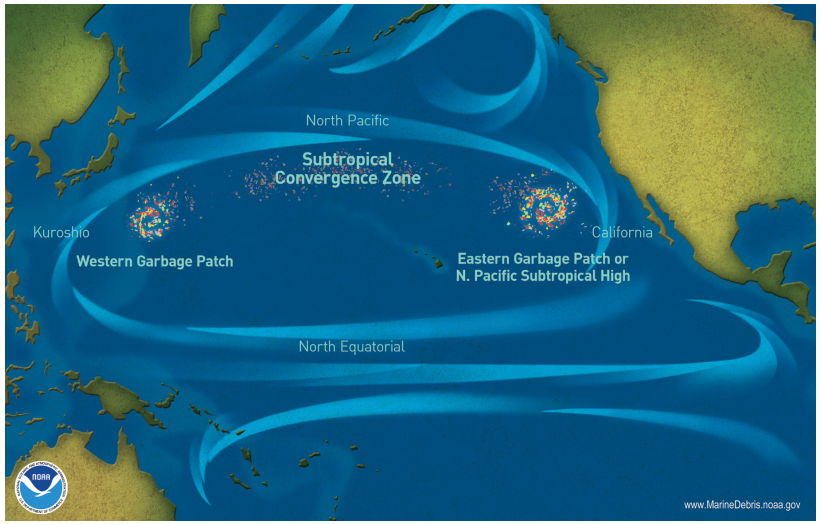


FIGURE 2.4 Plastic garbage patch.

National Oceanic and Atmospheric Administration. https://oceanservice.noaa.gov/facts/garbagepatch.html

- **Thermohaline circulation** in deep ocean waters driven mainly by differences in the density of the water related to temperature and salinity

Fresh Water Available from Surface and Groundwater Sources

- Surface sources includes water from lakes, streams, rivers, and surface springs
- Recommend using “free” photos of rivers and lakes here, if possible

Groundwater Features

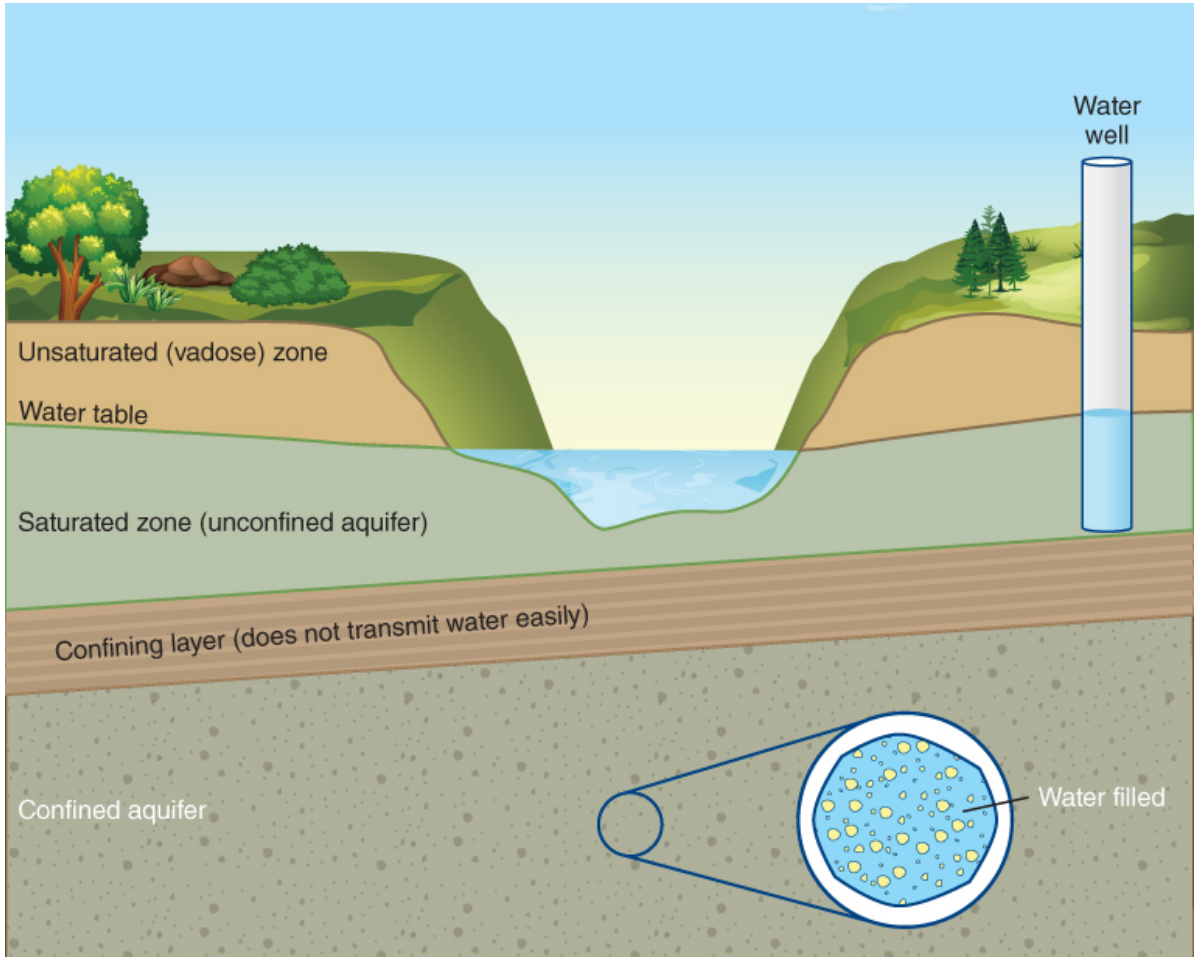


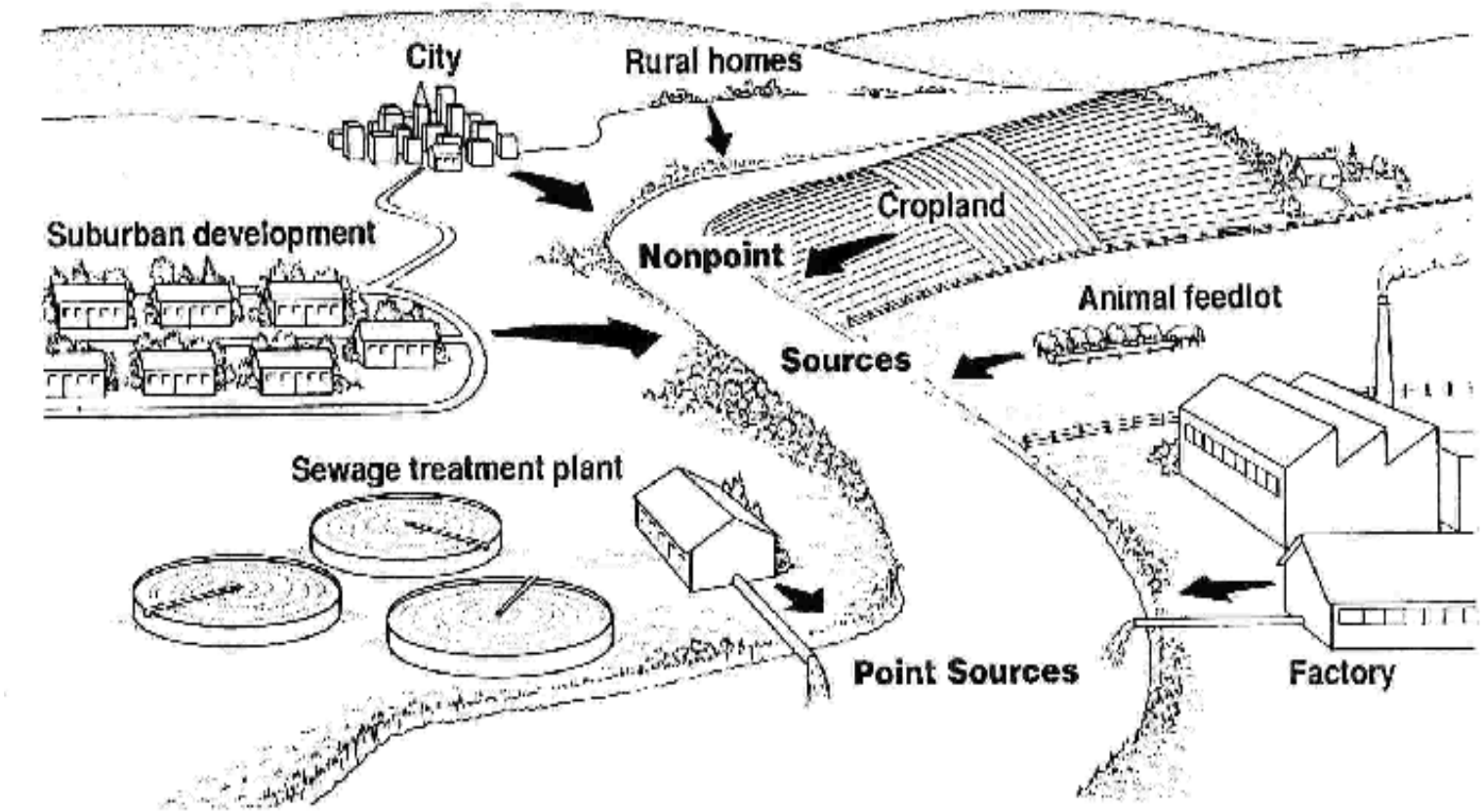
FIGURE 2.5 Groundwater features.

Special thanks to Ronald W. Falta, Jr.

- **Aquifers:** geologic material that is porous enough to hold and transmit water through the pore spaces between the geologic material
- The area above the water table is called the **vadose or unsaturated zone,** where the pore spaces are partly filled by water, compared to the **saturated zone**, in which all pore spaces are filled with water

Sources of Water Pollution

- Pollution may come from either a single **point source** or accumulate from multiple **nonpoint** sources of contamination.
- Surface water supplies are more vulnerable to pollution, both chemical and microbial, than are groundwater supplies.
- However, once a groundwater aquifer has been contaminated by **leaching** of contaminants from the surface or purposeful deep well injection, such as that associated with hazardous waste disposal, it is very difficult and expensive to clean up.



Point and nonpoint sources of water pollution.

Fate and Transport of Environmental Pollutants

- Human exposure depends upon the transformation and movements of contaminants through the environment.
- A contaminant's environmental fate and transport depends upon its physical and chemical properties. Human exposure depends upon the transformation and movements of contaminants through the environment.
- A contaminant's environmental fate and transport depends upon its physical and chemical properties.

Types of Environmental Hazards

- Chemical
- Physical
- Biological

All “pollutants” demonstrate differential affinity for air, water, or soil deposition.

Physical–Chemical Properties of Pollutants

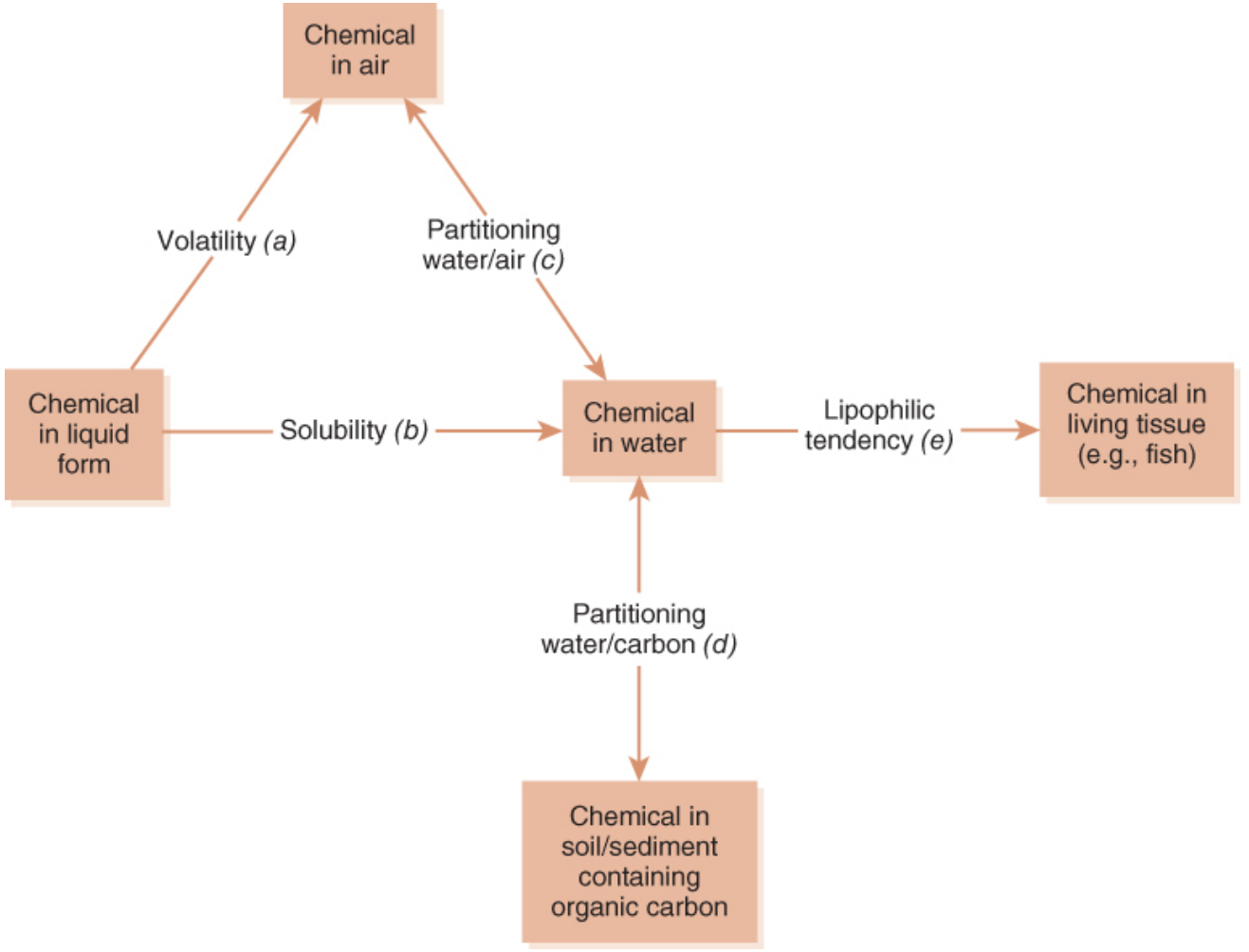


FIGURE 2.6 Physical-chemical properties of chemicals.

Physical–Chemical Properties

- Volatility
- Solubility
- Partitioning coefficients (water/air or water/carbon)
- Lipophilic: affinity for fats

Environmental Contaminant Concepts

- **Bioconcentration:** consequence of a chemical's lipophilic tendency
- **Bioaccumulation:** buildup of a chemical in an individual organism's tissues over its lifetime as the organism continues to take in more than it excretes
  - **Xenobiotic** substances bioaccumulate in the same tissues as the human substances they resemble.
- **Biomagnification:** process by which a chemical becomes more concentrated in the tissues of organisms at each higher trophic level in a food chain
  - **Note:** In contrast to bioconcentration, bioaccumulation and biomagnification are not just properties of individual chemicals, but rather processes that take place in organisms and ecosystems.
- **Persistence:** often quantified as its half-life in air, water, or soil

Bioaccumulation

- Concentrations in the body increases over time (in specific tissues)
- This type of magnification occurs within the same trophic level!
- *Bioconcentration "preferences" influence where contaminants accumulate!*

Biomagnification (Also Called Bio-amplification)

- Substances become concentrated as they move up the food chain, reaching lethal doses in higher trophic levels

Example with DDD in Clear Lake, CA

Organism	PPM
• Phytoplankton	• 5
• Herbivorous fish	• 40–300
• Carnivorous fish	• Up to 2500
• Western grebe, a type of waterfowl	• 1600

Principles of Toxicology

Introduction to Toxicology: the Science of Poisons

- Toxicology: the science of the effects of toxic substances, and of their “fate and transport” in the body
- Major routes of exposure
  - Inhalation, ingestion, dermal contact
- Toxins versus toxicants

Exposure and Dose

- The human envelope: boundary that separates the interior of the body from the exterior environment
- Exposure: contact with the human envelope
- Dose: a quantification of exposure with units of the rate of milligrams of contaminant ingested per kilograms of body weight

Disposition of Chemicals in the Body (1 of 3)

- Toxicokinetics: the disposition of toxicants in the body
  - Absorption
  - Distribution
  - Metabolism
  - Storage
  - Excretion
- Toxicodynamics: effects in the body

Disposition of Chemicals in the Body (2 of 3)

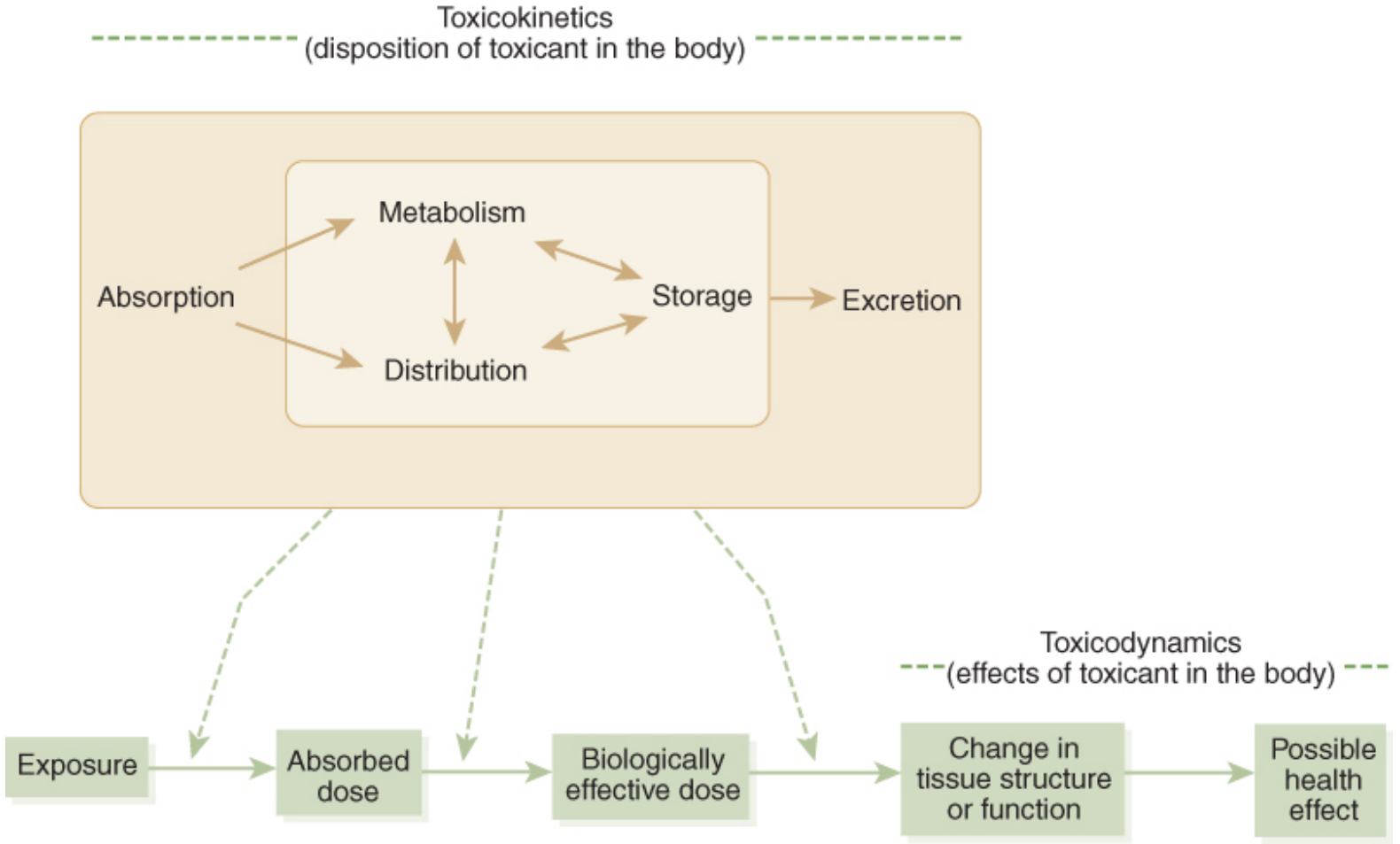


FIGURE 2.7 Disposition and effects of toxicants in the body.

Special thanks to Wendy Heiger-Bernays and Michael McClean.

Disposition of Chemicals in the Body (3 of 3)

- More on toxicokinetics
  - Body burden
  - Absorbed dose: quantity that passes through the human envelope
  - Biologically effective dose: quantity available to interact with a vulnerable tissue
  - Synergism, antagonism

Gene-environment Interaction

- Models of gene-environment interaction
  - Genetic makeup increases exposure to environmental risk factor.
  - Genetic makeup increases susceptibility to environmental risk factor.
  - Genetic makeup and environmental factor are independent risk factors.

Mutations and Epigenetics

- Genetic code is found in molecules of **deoxyribonucleic acid (DNA)** present in the nucleus of each cell.
- Mutation is a change to the DNA of a cell.
- **Epigenetics** refers to the concept that some foreign or environmental substance adheres upon the genetic surface, resulting in either the suppression or expression of different protein enzymes.

Carcinogenesis

- Cancer: a disease in which cells multiply without restraint
  - Tumor invades tissue of origin
  - And metastasizes into other tissues
- Cancer results from an accumulation of mutations
  - Mutation: change to the DNA of a cell

Carcinogenesis (1 of 2)

- Key mutations in carcinogenesis
  - Increase the activity of genes that instruct the cell to divide (oncogenes); or
  - Decrease the activity of genes that instruct the cell to stop dividing (tumor suppressor genes)
- Carcinogen: any agent that increases cancer risk at any stage in process

Carcinogenesis (2 of 2)

- Simple view of stages in carcinogenesis
  - Initiation: initial mutation in a cell; either
    - Enhances instructions to cell to divide; or
    - Dampens instructions to stop dividing
  - Promotion: initiated cell is stimulated to divide, becoming a benign tumor
  - Progression: mutations → cascading cell division → malignant tumor

Toxicity Testing

- Dose-response curves developed for cancer and various noncancer effects.
- Reproductive vs developmental effects:
  - *Reproductive* toxicity: effect on reproductive capacity of organism
  - *Developmental* toxicity: effect on developing organism, including teratogenesis
- **Teratogenesis** refers specifically to the occurrence of a structural defect in the developing organism resulting from an exposure that occurs between conception and birth, and a teratogen is a substance that produces such defects.

The Dose–Response Relationship (1 of 3)

- Quantitative relationship between dose and effect (response)
  - Often summarized in graph
  - Dose on x-axis; response on y-axis
- Two key characteristics:
  - Slope (potency of effect)
  - Threshold (potential for safe dose)

The Dose–Response Relationship (2 of 3)

- A schematic representation

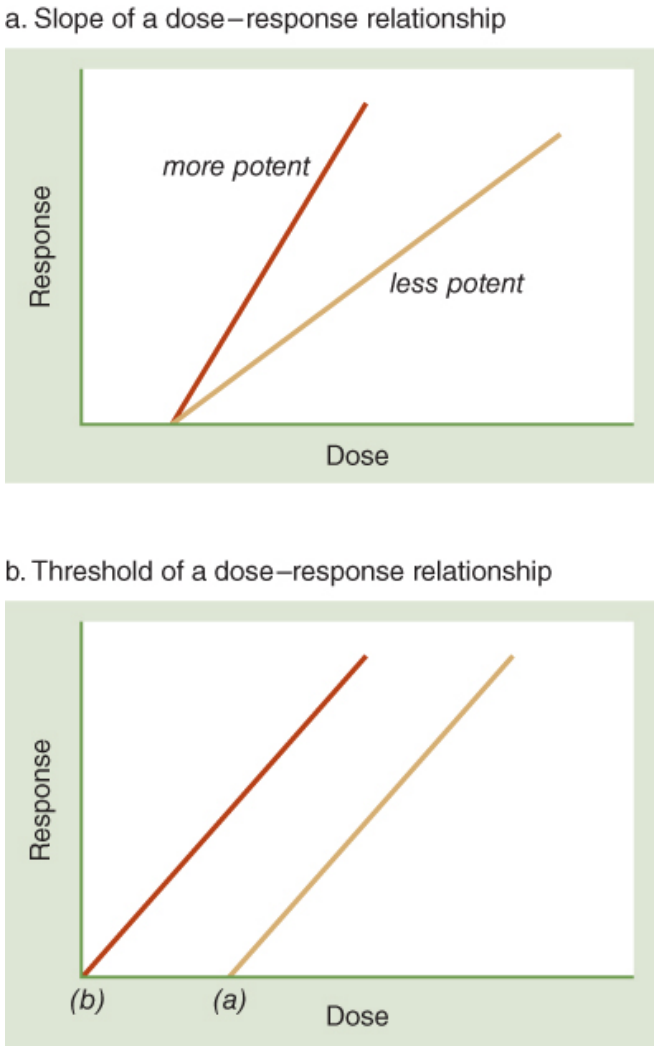


FIGURE 2.9 A schematic representation of the basic dose–response relationship.

The Dose–Response Relationship (3 of 3)

- A more realistic flattened *S*-shape

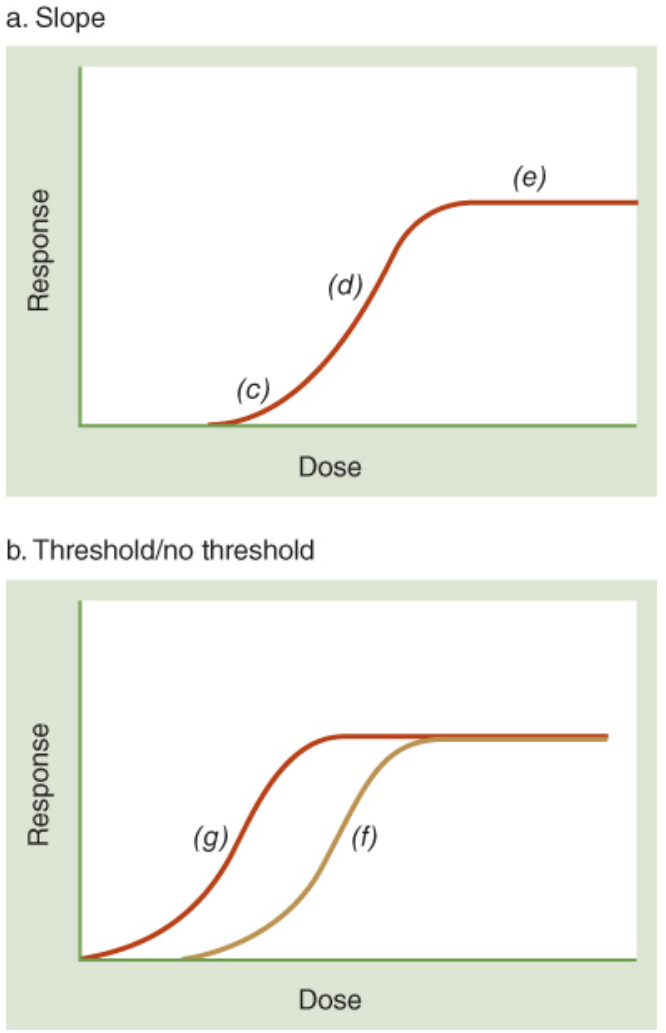


FIGURE 2.10 The dose-response curve.

Toxicity Testing (1 of 4)

- Regulatory toxicology
  - Tests chemicals' toxicity in living things
  - Done to support regulatory decision making
- Preliminary testing
  - Test of mutagenicity in bacteria
  - Study of acute toxicity in rodents yields LD_{50}
  - Subchronic rodent bioassay (90 days)
    - Suggests doses for chronic bioassay
    - Identifies target organ and range of effects

Toxicity Testing (2 of 4)

- Chronic rodent bioassay (2 years)
  - Three exposure levels, ideally including:
    - Dose high enough to test for cancer
    - Dose low enough to reveal no-effect level
  - Unexposed control group
  - Results used to create dose–response curves for various health effects

Toxicity Testing (3 of 4)

- Some doses are given special names
  - *Highest* non-zero dose at which *no* effect was observed = No Observed Adverse Effect level (NOAEL)
  - *Lowest* dose at which an effect *was* observed = Lowest Observed Adverse Effect Level (LOAEL)
- If a study shows both a NOAEL and a LOAEL, can infer that the threshold is between them

Toxicity Testing (4 of 4)

- Two dose-response curves

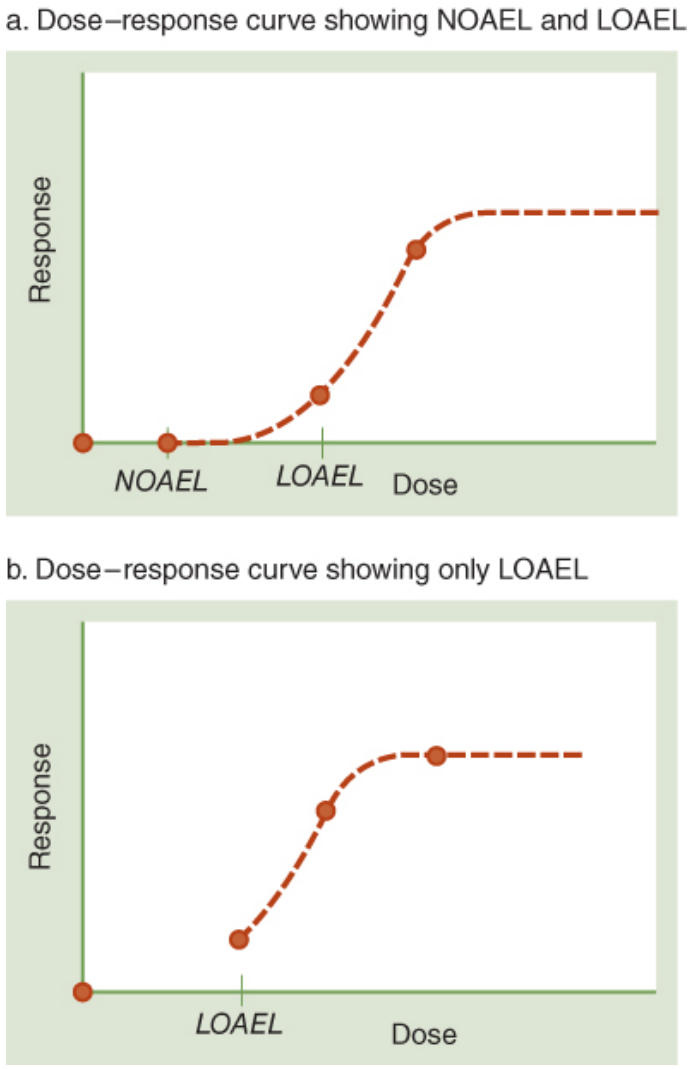


FIGURE 2.11 NOAEL and LOAEL in a dose–response curve.

Introduction to Exposure Assessment: An Applied Science

- Goal is to quantify exposure.
- Methods draw on understanding of both:
  - Environmental science (fate and transport of toxicants in environment)
  - Toxicology (fate and transport of toxicants in the body)

Completing the Conceptual Model of Exposure (1 of 2)

- Conceptual model of exposure begins with source of exposure.

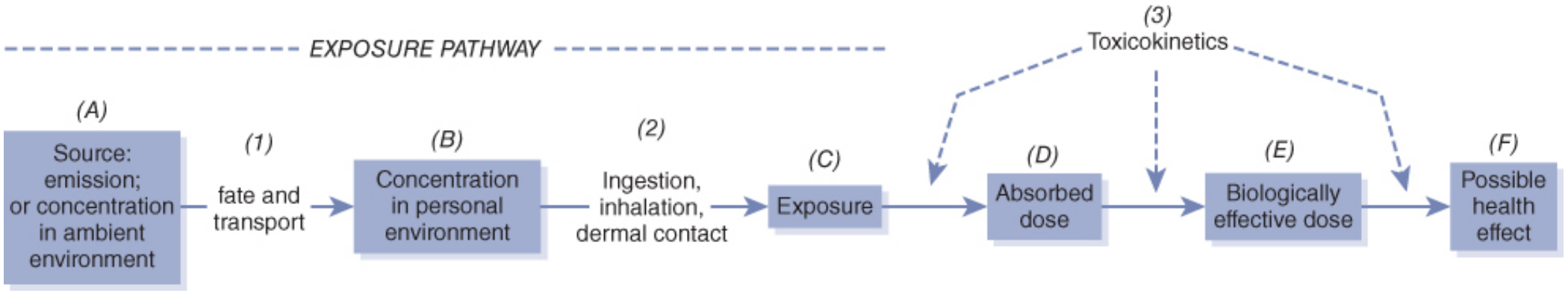


FIGURE 2.12 Exposure with body disposition.

Special thanks to Wendy Heiger-Bernays and Michael McClean.

Completing the Conceptual Model of Exposure (2 of 2)

- . . . and concludes with toxicokinetics and effects in the body.

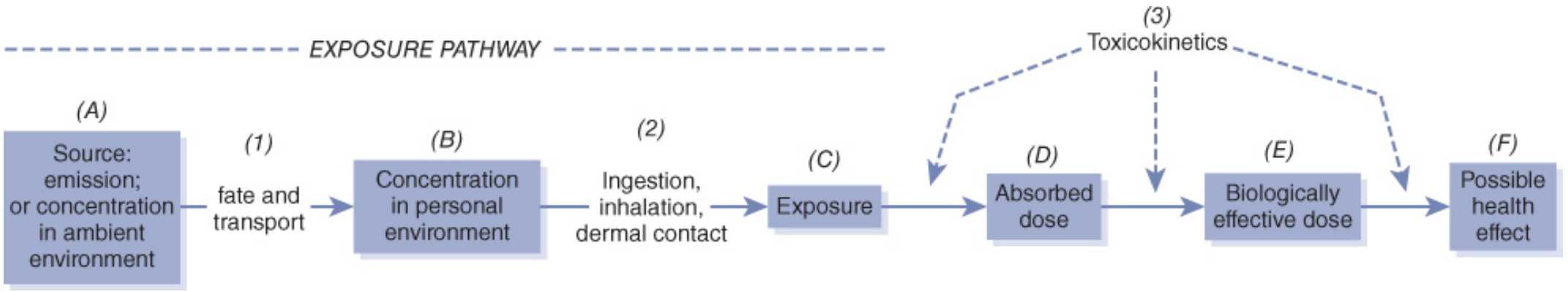


FIGURE 2.12 Exposure with body disposition.

Special thanks to Wendy Heiger-Bernays and Michael McClean.

Epidemiology: Human Research Studies

- Provides specific information on health risks from environmental hazards impacting humans
- Defined as the scientific study of the distribution and determinants of disease and the application of this study to protect public health
- Ethically must primarily rely on observational data where people have either been accidently exposed or exposed at higher occupational levels than those associated the ambient environment
- Key approach is to compare characteristics of the sick to the healthy

Key Measures of Health Status of Populations

- Mortality
- Prevalence: proportion of population with disease at given point in time
- Morbidity (non-fatal outcomes)
- Incidence: new cases of disease during given time period
- Also, newer measure: disability-adjusted life year (DALY)

Descriptive Epidemiology

- Describes patterns of disease in populations
- Case series: noteworthy set of cases
- Ecological study: utilize group level aggregated rates
  - Beware of ecological fallacy
- Surveillance: tracks and compares disease rates across places, diseases, and time
  - Surveillance biomonitoring: use of biomonitoring to document rates of exposure or disease in populations

Crude, Specific and Adjusted Rates

- Crude rates for different populations, or same population at different times, are not comparable.
- Solution: use specific or standardized rates
  - Specific example: calculate rates separately for M and F
  - Age-adjusted or standardized example: make populations comparable by using a third population as a reference
    - Overall rate of female breast cancer that would occur in Location A if it had the age distribution of the reference population

Observational Analytic Epidemiology

- Goal is to test *a priori* hypotheses regarding specific exposures with a specific outcome of interest
- **Cross-sectional studies** are primarily prevalence surveys.
- **Cohort studies** identify subjects based on their exposure status, then determine and compare incidence rates between exposure groups.
- **Relative risk** (RR) ratio quantitatively provides the strength of the association.

Case-Control Study Design

- Recruits subjects into a study based on their disease status (as a case or subject free of the disease being studies).
- The study then determines past exposure for all study subjects.
- The odds ratio (OR) quantifies the degree of association between exposure rates for cases and controls.
  - OR serves as an appropriate surrogate for the RR.

Summary of Observational Analytic Epidemiologic Study Designs

- Cohorts typically used for common exposures (prospective cohorts) or rarer occupational exposures (if access to employment records exist to conduct retrospective cohort).
- Case-control studies useful for assessing risk factors for rare diseases.
- Experimental studies, such as clinical trials, not typically appropriate for environmental health hypotheses
  - Except for community trials, such as study of fluoride in drinking water and the development of dental cavities

Evaluating Epidemiologic Associations

- Once quantified, the association must be assessed for internal and external validity.
- The assessment for internal validity determines if the association might be due to random chance, a systematic error during the conduct of the study (**bias**), or the influence of a third variable that **confounds** the observed association.
- Finally, in judging whether a causal connection has been shown, as opposed to merely a valid and statistically significant association, researchers generally consider several factors:
  - Strength of the association
  - Consistency
  - Temporal relationship
  - Biological plausibility

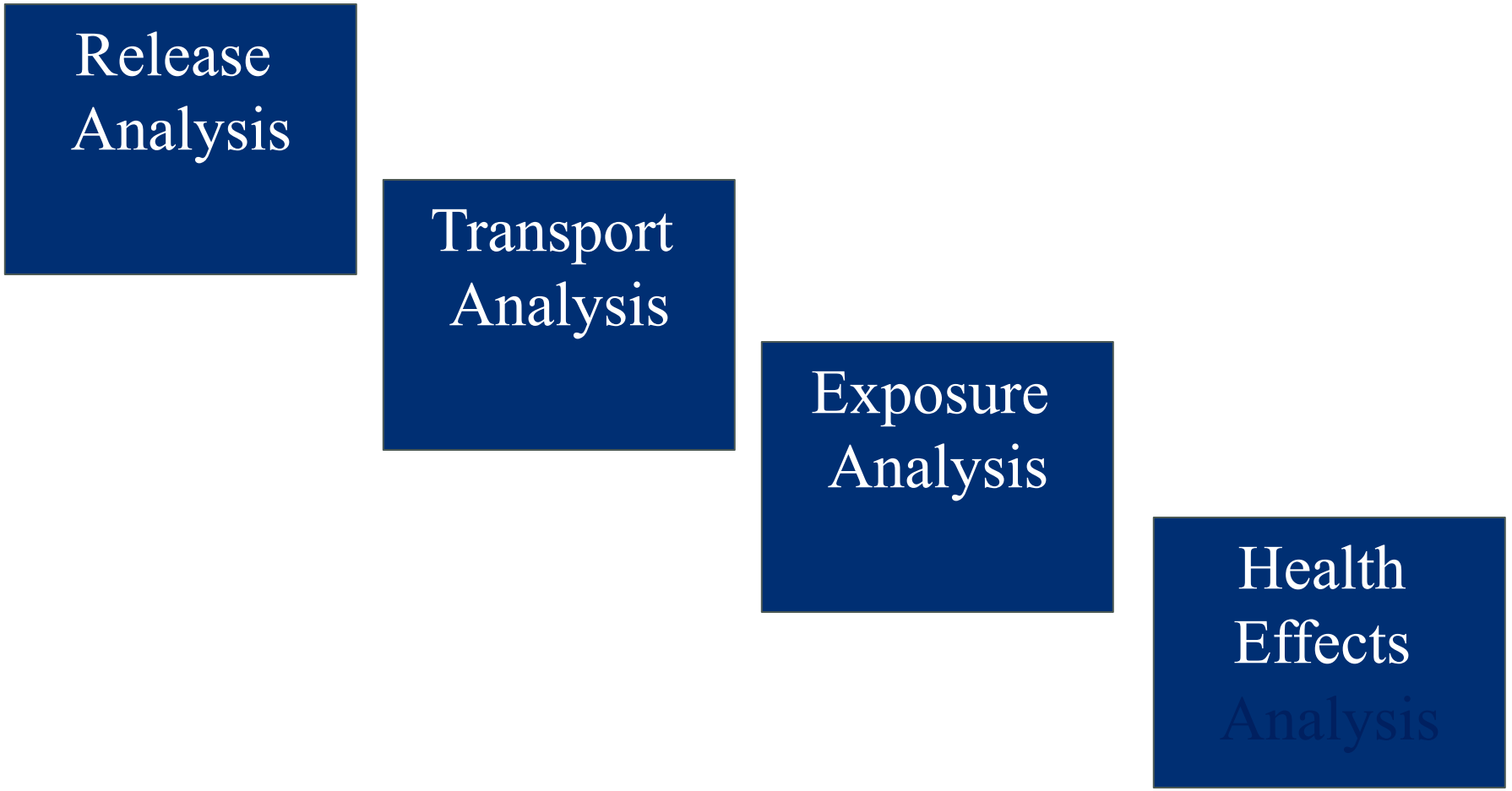
Why Risk Assessment?

- Must sometimes take action without full scientific understanding of hazard
- Risk assessment sets default procedures for bridging gaps in scientific understanding.
- Basic framework: evaluate exposure and toxicity; bring this information together to characterize health risk

“Strictly Speaking”

- The field of environmental risk assessment focuses on the (actual or potential) release of contaminants to the environment.
- Attempts to **quantitatively** describe the impact (effect and chance that it happens) of this release upon either human or ecological health

Risk Assessment Steps



Release Analysis

- Identification of contaminants
  - Organic compounds, inorganic gases, metals, radionuclides, pathogens, particulate matter, etc.
- Quantification of emission rate
  - Measurement
  - Process knowledge

Transport Analysis

- Identification of pathways
  - Atmospheric
  - Aquatic (surface and subsurface)
  - Food chain
- Determination of contaminant concentrations
  - Air
  - Water
  - Food

Exposure Analysis

- Identification of exposure scenarios
  - Human or ecological population
  - Specific sensitive individual(s)

- Determination of dose
  - Chemical dose (mg/kg/d)
  - Radiological (Sv)

Possible Exposure Scenarios

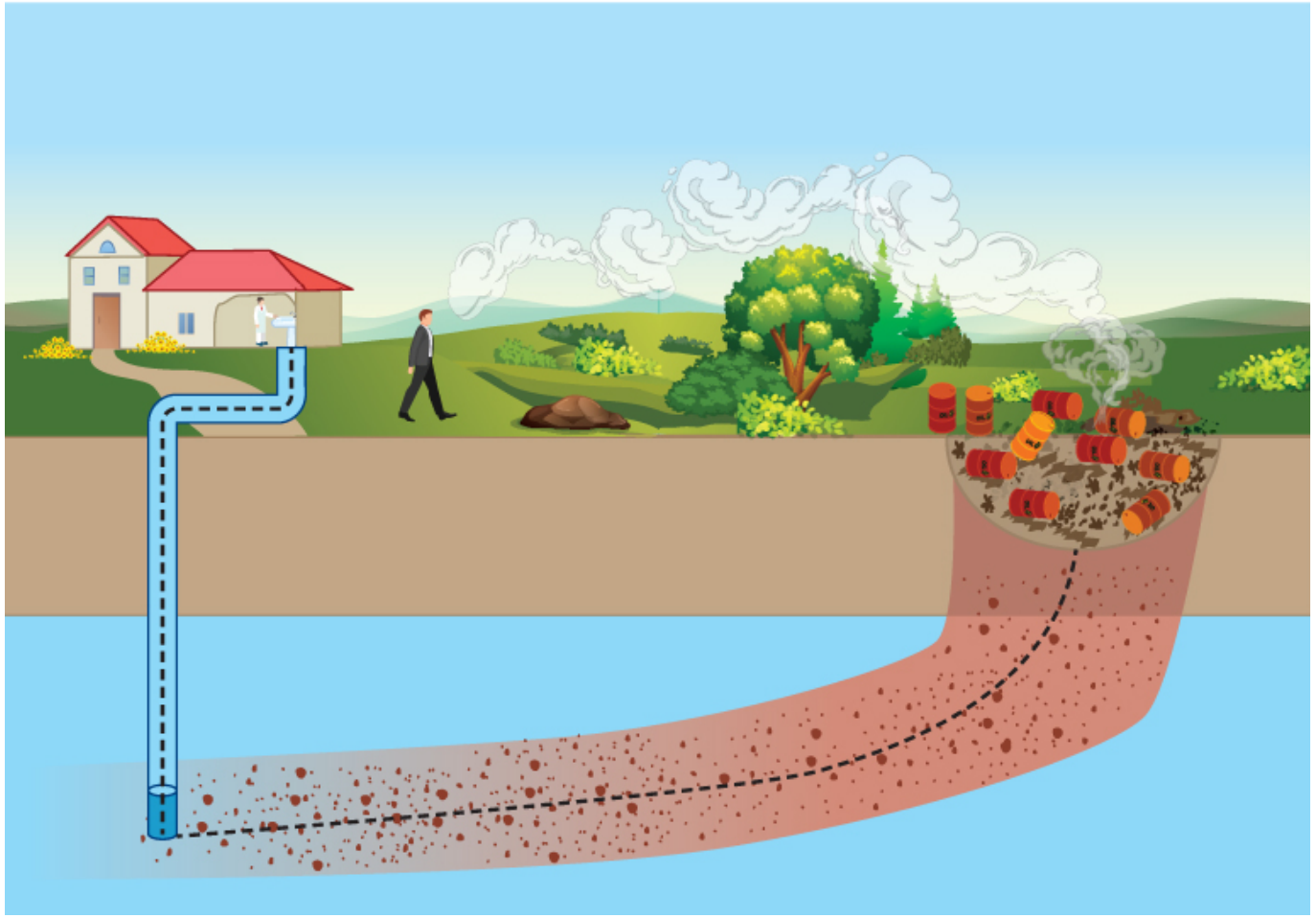


FIGURE 2.15 Exposure scenarios.

Health Effects Analysis

- Human health effects
  - Noncancer, deterministic effects
  - Stochastic cancer outcomes

Summary of Risk Assessment Steps

Release Analysis (Source emission concentration, such as gallons per minute)

Transport Analysis (Contaminant concentration, mg/L, for example)

Exposure Analysis (Absorbed dose, mg/kg x day)

Health Effects Analysis (Cancer risk or hazard quotient)

Deterministic Effects

An effect whose SEVERITY depends on dose

- Systematic toxicity
  - Organ dysfunction
  - Irritation and sensitization
  - Behavioral impairment
- Teratogenesis
  - Fetal development

Noncancer, Deterministic Effects

- A **hazard quotient (HQ)** is a ratio comparison of average daily dose to a reference dose, a value expected to pose no appreciable effects (think “threshold” akin to NOAELs)
- The EPA’s IRIS website, as well as the TERA website, provide contaminant reference dose values, RfD, and other risk metrics.

Hazard Quotient Example

- Carbon tetrachloride's reference dose,

  (RfD): 0.007 (mg/kg*d)

- If well has concentration = 100 µg/L, determine the deterministic (liver damage) risk to an adult well user
- Dose = $\frac{\text{daily uptake (2 l/d)*Conc.}}{\text{body wt. (70 kg)}}$

  = 2.857 µg/kg*d or .0028 mg/kg*d

HQ = Dose / RfD = .0028/.007 = .4

Stochastic Effects

- An effect whose PROBABILITY depends on dose (no threshold level without some risk)
  - Cancer examples
    - Benzene: leukemia
    - Vinyl chloride: liver
    - Radiation: leukemia, lung, skin, etc.

Table 2.3 Weight-of-the-Evidence Categories for Carcinogenicity, as Defined by the International Agency for Research on Cancer and the U.S. Environmental Protection Agency

International Agency for Research on Cancer	U.S. Environmental Protection Agency
Group 1: Carcinogenic to humans	Carcinogenic to humans
Group 2A: Probably carcinogenic to humans	Likely to be carcinogenic to humans
Group 2B: Possibly carcinogenic to humans	Suggestive evidence of carcinogenic potential
Group 3: Not classifiable as to carcinogenicity to humans	Inadequate information to assess carcinogenic potential
Group 4: Probably not carcinogenic to humans	Not likely to be carcinogenic to humans

Toxicity Assessment for Stochastic Effects

- The probability of a cancer either occurring or causing a fatality during a lifetime is estimated using ρ, the cancer slope factor (CSF)
- Also called potency factor or nominal probability coefficient

Pertinent Stochastic Equations

- An average **daily dose** is computed as

  D, dose = $\{(U*C)/BW\}*(t_e/t_{ave})$,

  where U = uptake, C = concentration, BW = body wt., t_e = exposure time, and t_{ave} = average lifetime

- Cancer risk probability = $D^* \rho$

  (if $D^* \rho < 0.01$)

Cancer Risk Example

- A hypothetical well down gradient from an abandoned gas station is sampled with ethylene dibromide (EDB) values between 5 and 50 µg/L, and a family has used this well for 20 years.
- Average daily dose (adult) =

$$\frac{\{2\ (l/a)*5(\ \mu g/L)*20(a)*.001\ mg/\mu g\}}{\{70(kg)*70(a)\}}$$

- EDB's ρ or CSF = 85 mg/kg*d (or 2!)
- Cancer risks range from 3.5×10^{-3} to 3.5×10^{-2} (or 8.2×10^{-5} to 8.2×10^{-4})

Final Product Goal for a Risk Assessment

- Quantitatively summarize the cancer risk and noncancer hazards associated with exposure to the contaminants of concern under the exposure scenarios considered
- Characterization should include a discussion of the uncertainties embedded in the risk assessment.
- Risk assessment provides an essential summation of the best (and most protective) estimates that science can provide regarding the possible health hazards associated with an environmental exposure.