



SCHOLAR COACH

Boutique Academic Coaching & Tutoring

AP ENVIRONMENTAL SCIENCE · COURSE REVIEW AND PRACTICE

# AP Environmental Science **Mastery.**

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Every unit on the exam: concise concept review, worked examples, exam-style writing, practice problems with full explanations, a mixed practice test, and a reference section.

## INSIDE

Words in Context · Inferences · Command of Evidence · Central Ideas and Details · Function of a Sentence · Algebra · Advanced Math · Problem-Solving and Data Analysis · Geometry and Trigonometry · Three Full-Length Practice Exams with Explanations



# Table of Contents.

Course review, practice, and a mixed test.

## Contents

Start with the exam overview, work the units in order or jump to the one you need, then take the mixed practice test and finish with the reference pages. Click any entry to jump to that page.

### PART 1: START HERE

|                                                          |   |
|----------------------------------------------------------|---|
| <b>Start Here: The Exam, Your Plan, and Your Tools</b>   | 4 |
| <b>F</b> Start Here: The Exam, Your Plan, and Your Tools | 4 |
| Answers and Explanations                                 | 6 |

### PART 2: THE UNITS

|                                                        |    |
|--------------------------------------------------------|----|
| <b>Unit 1: The Living World: Ecosystems</b>            | 7  |
| <b>1</b> Concept review, worked examples, and practice | 7  |
| Unit 1: Answers and Explanations                       | 14 |
| <b>Unit 2: The Living World: Biodiversity</b>          | 16 |
| <b>2</b> Concept review, worked examples, and practice | 16 |
| Unit 2: Answers and Explanations                       | 22 |
| <b>Unit 3: Populations</b>                             | 24 |
| <b>3</b> Concept review, worked examples, and practice | 24 |
| Unit 3: Answers and Explanations                       | 30 |
| <b>Unit 4: Earth Systems and Resources</b>             | 31 |
| <b>4</b> Concept review, worked examples, and practice | 31 |
| Unit 4: Answers and Explanations                       | 39 |
| <b>Unit 5: Land and Water Use</b>                      | 40 |
| <b>5</b> Concept review, worked examples, and practice | 40 |
| Unit 5: Answers and Explanations                       | 46 |
| <b>Unit 6: Energy Resources and Consumption</b>        | 48 |
| <b>6</b> Concept review, worked examples, and practice | 48 |
| Unit 6: Answers and Explanations                       | 54 |
| <b>Unit 7: Atmospheric Pollution</b>                   | 55 |
| <b>7</b> Concept review, worked examples, and practice | 55 |
| Unit 7: Answers and Explanations                       | 61 |
| <b>Unit 8: Aquatic and Terrestrial Pollution</b>       | 62 |
| <b>8</b> Concept review, worked examples, and practice | 62 |
| Unit 8: Answers and Explanations                       | 68 |
| <b>Unit 9: Global Change</b>                           | 69 |
| <b>9</b> Concept review, worked examples, and practice | 69 |
| Unit 9: Answers and Explanations                       | 75 |

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PART 3: PRACTICE

Mixed Practice Test

T

Mixed Practice Test

Mixed Practice Test: Answers, Explanations, and Scoring

Free-Response Clinic

X

Free-Response Clinic

Free-Response Clinic: Scoring Guides and Model Responses

77

77

78

80

80

81

PART 4: REFERENCE

Reference: Formulas, Skills Checklist, and Glossary

R1

Equations, Constants and Skills Reference

R2

Skills Checklist and Glossary

83

83

84

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# Start Here: The Exam, Your Plan, and Your Tools

How the AP Environmental Science exam is built, how points are earned, and how to use this book.

## F Start Here: The Exam, Your Plan, and Your Tools

How AP Environmental Science is structured and scored, what each free-response type rewards, how to plan your weeks, and the math habits that earn points.

### Why This Matters

Knowing how the exam is built before you study saves weeks. This chapter covers the format, the unit weights, the seven practices, how free-response points are earned, two study plans, and the math habits that protect points on every question.

### The 2027 Exam

The exam is on **Thursday, May 13, 2027 (Session 2)**. It is fully digital, taken in Bluebook. Section I has **80 multiple-choice questions** in 90 minutes and counts for 60%. Section II has **3 free-response questions** in 70 minutes and counts for 40%. The free-response questions are: (1) design an investigation, (2) analyze and interpret quantitative data, (3) analyze an environmental problem using calculations. A calculator is permitted and reference information is available in Bluebook; check AP Central for current policy, and practice setting up arithmetic by hand with units.

| Unit | Title                             | Share of multiple choice |
|------|-----------------------------------|--------------------------|
| 1    | The Living World: Ecosystems      | 6-8%                     |
| 2    | The Living World: Biodiversity    | 6-8%                     |
| 3    | Populations                       | 10-15%                   |
| 4    | Earth Systems and Resources       | 10-15%                   |
| 5    | Land and Water Use                | 10-15%                   |
| 6    | Energy Resources and Consumption  | 10-15%                   |
| 7    | Atmospheric Pollution             | 7-10%                    |
| 8    | Aquatic and Terrestrial Pollution | 7-10%                    |
| 9    | Global Change                     | 15-20%                   |

The course has four big ideas: energy transfer, interactions between Earth systems, interactions between species and the environment, and sustainability. Questions mix units, so a graph of a food web might ask about pollution. Units 3 to 6 and 9 together carry most of the multiple-choice weight.

### Seven Science Practices

| Practice               | What it looks like                   | MC share | FRQ share    |
|------------------------|--------------------------------------|----------|--------------|
| Concept Explanation    | Define and explain processes         | 30-38%   | 13-20%       |
| Visual Representations | Read and draw models, maps, diagrams | 12-19%   | 6-10%        |
| Text Analysis          | Read a passage and extract claims    | 6-8%     | not assessed |

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| Practice                | What it looks like                 | MC share | FRQ share |
|-------------------------|------------------------------------|----------|-----------|
| Scientific Experiments  | Design and evaluate investigations | 2-4%     | 10-14%    |
| Data Analysis           | Interpret tables and graphs        | 12-19%   | 6-10%     |
| Mathematical Routines   | Calculate with units               | 6-9%     | 20%       |
| Environmental Solutions | Propose and justify solutions      | 17-23%   | 26-34%    |

Explanation and solutions dominate both sections, and math is about 20% of free-response points, so every unit in this book includes calculation practice.

## How Free-Response Points Are Earned

| Question | Type                                                      | What earns points                                                                                                                           |
|----------|-----------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| 1        | Design an investigation (scenario with a model or visual) | A testable hypothesis naming the independent and dependent variables; a procedure with a control and constants; a prediction with reasoning |
| 2        | Analyze and interpret quantitative data                   | Cite specific values and trends; describe direction of change; justify a realistic solution                                                 |
| 3        | Analyze an environmental problem using calculations       | Setup with units, then the answer; explain results and propose solutions                                                                    |

In the most recent scoring guidelines each question was worth 10 points, so Section II is 30 raw points, and most parts are worth 1 point each. In one recent calculation, each calculation earned 2 points: one for setup and one for the answer. Confirm any point change on AP Central.

### Patterns that earn points

Name the item, then give the mechanism with 'because'. State the direction of change (increase or decrease) and the reason. Give a realistic, specific solution and a valid added benefit. Show unit cancellation and scientific notation. Do not repeat the prompt without adding new content.

## Study Plans

| Week | 4-week plan                                          | 8-week plan                                          |
|------|------------------------------------------------------|------------------------------------------------------|
| 1    | Start Here, Units 1, 2, 3                            | Start Here, Units 1 and 2                            |
| 2    | Units 4, 5, 6                                        | Unit 3                                               |
| 3    | Units 7, 8, 9                                        | Unit 4                                               |
| 4    | Practice test, Free-Response Clinic, reference pages | Unit 5                                               |
| 5    |                                                      | Unit 6                                               |
| 6    |                                                      | Units 7 and 8                                        |
| 7    |                                                      | Unit 9                                               |
| 8    |                                                      | Practice test, Free-Response Clinic, reference pages |

Within each unit, read Core Ideas, try every Worked Example before reading the solution, then write your own version of the Write It Like a 5 response. Review mistakes in a notebook, grouped by cause: concept, math setup, or wording.

## How to Use This Book

- ◆ Each unit chapter has: Why This Matters, Core Ideas, Worked Examples, Write It Like a 5, Coach's Playbook and 10 practice items with explanations.
- ◆ The Mixed Practice Test has 12 multiple-choice and 3 free-response questions; take it timed.
- ◆ The Free-Response Clinic drills the three question types with scoring guides.
- ◆ The two reference pages summarize equations, skills and vocabulary.

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## Key Math Habits

### Calculations you must be able to set up

Percent change =  $(\text{new} - \text{old})/\text{old} \times 100$ . Use parentheses and state 'increase' or 'decrease'.

Rate of natural increase (%) =  $(\text{CBR} - \text{CDR})/10$ . Doubling time =  $70/(\text{percent growth rate})$ ; add it to the start year if asked for a year.

Trophic transfer: multiply by 0.10 for each step up. Unit conversion: write each factor as a fraction and cancel units; for area use squared factors.

Always write the equation, substitute with units, cancel them, and finish with a labeled answer. Use scientific notation for very large or small values: add exponents when multiplying and subtract when dividing. Check that the answer is reasonable.

## Practice

### PRACTICE Start Here Check

Show your work. Justify conclusions.

1. A lake's fish population falls from 250 to 200. What is the percent change?  
 (A) 25% decrease (B) 20% increase (C) 20% decrease  
 (D) 50% decrease
2. A reserve covers 4.5 km<sup>2</sup>. What is its area in square meters?  
 (A)  $4.5 \times 10^3 \text{ m}^2$  (B)  $4.5 \times 10^6 \text{ m}^2$  (C)  $4.5 \times 10^9 \text{ m}^2$   
 (D)  $4.5 \times 10^5 \text{ m}^2$
3. A student asks, 'Does fertilizer affect algae?'  
 (a) Rewrite this as a testable hypothesis.  
 (b) Identify the independent and dependent variables.  
 (c) Give one variable to hold constant.
4. A town has a CBR of 22 and a CDR of 8 per 1,000 per year, with no net migration, in 2027.  
 (a) Calculate the rate of natural increase.  
 (b) Calculate the doubling time.  
 (c) In what year will the population double?

## Answers and Explanations

### F Start Here: The Exam, Your Plan, and Your Tools

#### PRACTICE · START HERE CHECK

1. C.  $(200 - 250)/250 \times 100 = -20\%$ , a 20% decrease. Choice A divides by the new value instead of the old.
2. B. 1 km = 1,000 m, so  $1 \text{ km}^2 = 10^6 \text{ m}^2$  and  $4.5 \text{ km}^2 = 4.5 \times 10^6 \text{ m}^2$ . Choice A uses the factor for length rather than area.
3. (a) If more fertilizer is added to pond water, then algal growth will be greater. (b) Independent: amount of fertilizer; dependent: algal growth (for example, chlorophyll or cell count). (c) Light, temperature, water volume, or starting algae.
4. (a)  $(22 - 8)/10 = 1.4\%$  per year. (b)  $70/1.4 = 50$  years. (c)  $2027 + 50 = 2077$ .

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# Unit 1: The Living World: Ecosystems

Exam weighting: about 6-8% of the multiple-choice section. Concept review, worked examples, exam-style writing, and 10 practice items, all with full explanations.

## 1 The Living World: Ecosystems

Energy flows through ecosystems while matter cycles. Master the biomes, the nutrient cycles, productivity and the 10 percent rule, plus the math that goes with them.

### Why This Matters

Unit 1 is 6-8% of the multiple-choice section, but its ideas reappear everywhere: energy flow, nutrient cycles and producers versus consumers are the language of every later unit. Students lose points by drawing food-web arrows backward, mixing up detritivores and decomposers, and dropping units.

### Core Ideas

#### 1.1 Introduction to Ecosystems

An **ecosystem** is the living (biotic) and nonliving (abiotic) parts of an area and their interactions. **Producers** (autotrophs) make food using sunlight (photosynthesis) or, in vents, chemical energy (chemosynthesis). **Consumers** (heterotrophs) eat other organisms: herbivores, carnivores and omnivores. **Detritivores** (earthworms, dung beetles) eat dead material; **decomposers** (fungi, bacteria) break it down chemically and release nutrients. Energy flows one way (sun, organisms, heat); matter cycles. Producers photosynthesize ( $\text{CO}_2 + \text{water} + \text{light} \rightarrow \text{glucose} + \text{O}_2$ ); all organisms respire ( $\text{glucose} + \text{O}_2 \rightarrow \text{CO}_2 + \text{water} + \text{ATP and heat}$ ).

#### 1.2 Terrestrial Biomes

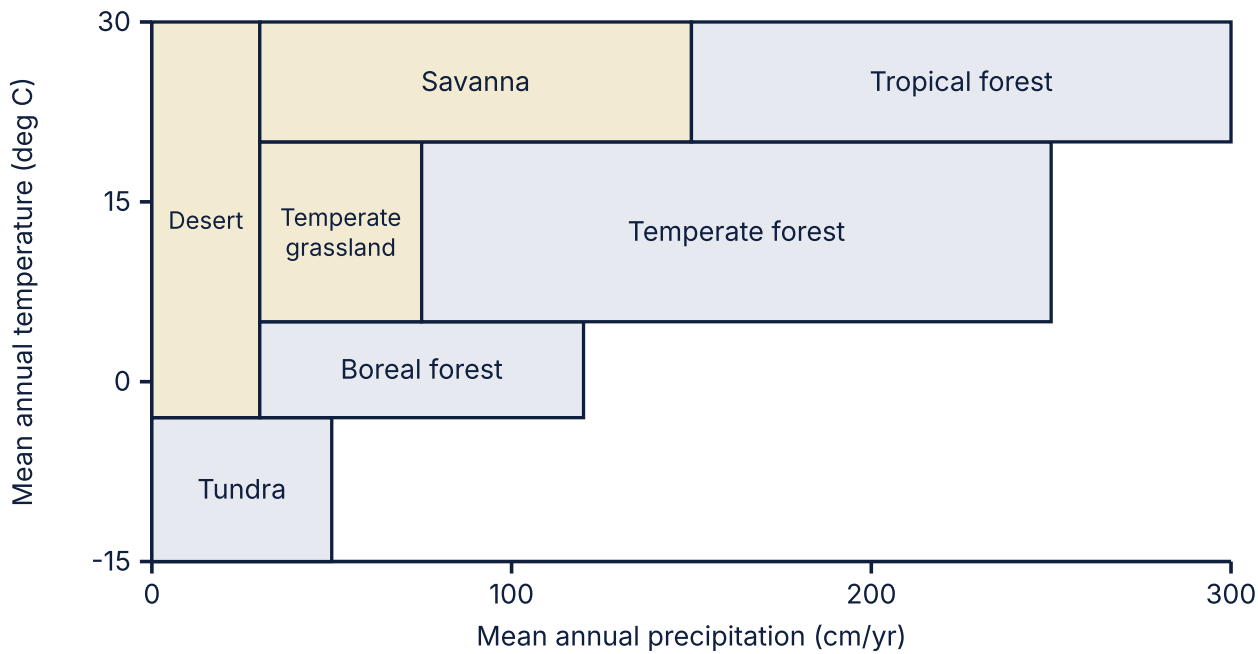
A **biome** is a large region defined by its climate and dominant vegetation. Temperature and precipitation, including their seasonal pattern, predict the biome.

| Biome                      | Climate                                          | Vegetation and soil                                                          |
|----------------------------|--------------------------------------------------|------------------------------------------------------------------------------|
| Tropical rainforest        | Warm all year, very wet                          | Tallest canopy, greatest richness; nutrients held in biomass, thin poor soil |
| Savanna                    | Warm; wet season and dry season                  | Grasses with scattered trees; fire and grazers are common                    |
| Desert                     | Dry (under about 25 cm/yr); big day-night swings | Sparse plants such as succulents; low organic matter                         |
| Chaparral                  | Hot dry summers, mild wet winters                | Dense, fire-adapted shrubs                                                   |
| Temperate grassland        | Cold winters, hot summers, moderate rain         | Deep, fertile soil; few trees; often converted to farmland                   |
| Temperate deciduous forest | Four seasons, moderate to high rain              | Broadleaf trees drop leaves; fertile soil                                    |
| Boreal forest (taiga)      | Long cold winters, short summers                 | Conifers; acidic, nutrient-poor soil; slow decomposition                     |
| Tundra                     | Very cold, low precipitation                     | Permafrost, low plants and moss; thaw releases stored carbon                 |

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Approximate climate sketch of major terrestrial biomes. Real boundaries overlap, and seasonality and soil also matter.

### 1.3 Aquatic Biomes

- ◆ **Freshwater** (under about 0.5 ppt salt): streams and rivers, lakes and ponds (littoral, limnetic, profundal and benthic zones) and wetlands that filter water and absorb floods.
- ◆ **Transitional:** estuaries (river meets sea, brackish, nutrient-rich nurseries), salt marshes and mangroves (shoreline buffers against storms and erosion).
- ◆ **Marine** (about 35 ppt): coral reefs (warm, clear, shallow; very high richness; sensitive to heat and acidity), intertidal zones, and the open ocean, where light and nutrients limit productivity.

### 1.4 The Carbon Cycle

Carbon moves among the atmosphere ( $\text{CO}_2$ ), living things, oceans, soils and rock. Photosynthesis moves carbon into organisms; respiration, decomposition and combustion return it. Oceans absorb and release  $\text{CO}_2$ , and burial of dead organisms over millions of years forms sedimentary rock and fossil fuels. Burning fossil fuels moves stored carbon to the atmosphere in decades, and deforestation removes a carbon sink.

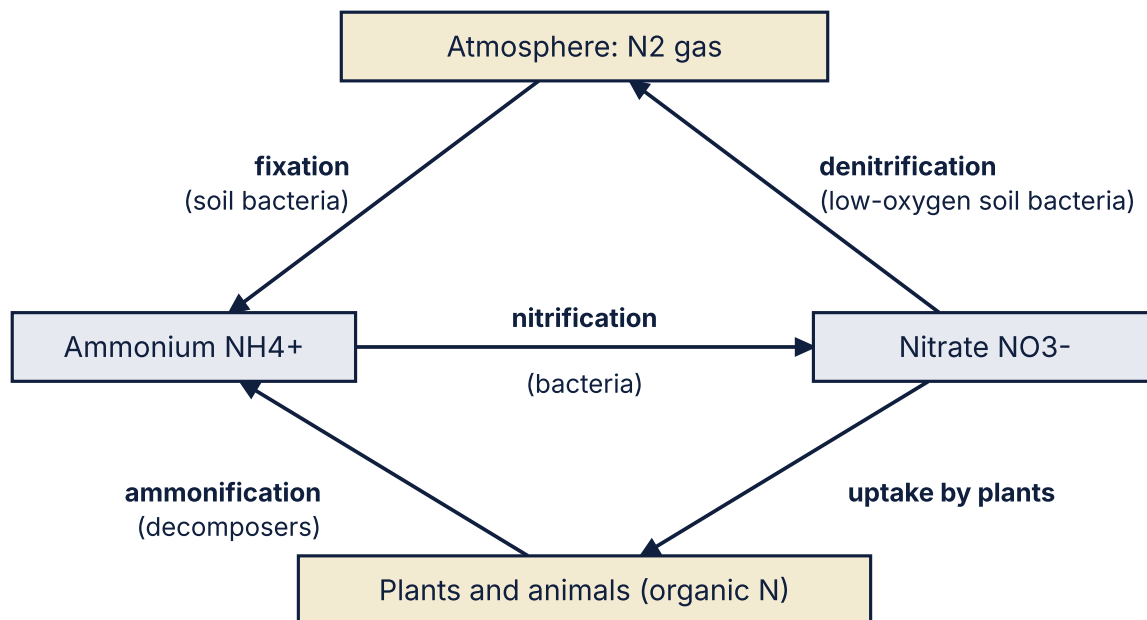
### 1.5 The Nitrogen Cycle

The atmosphere is the largest nitrogen reservoir ( $\text{N}_2$ , about 78% of air), but most organisms cannot use it. Soil bacteria (and bacteria in legume root nodules) perform **fixation**, converting  $\text{N}_2$  to ammonium ( $\text{NH}_4^+$ ); lightning also fixes some. Fixation is slow, so nitrogen often limits plant growth.

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Nitrogen cycle. Fixation turns N<sub>2</sub> into ammonium; nitrification makes nitrate; denitrification returns N<sub>2</sub> to the air.

### Nitrogen cycle vocabulary

**Fixation:** N<sub>2</sub> to NH<sub>4</sub><sup>+</sup>. **Nitrification:** NH<sub>4</sub><sup>+</sup> to NO<sub>2</sub><sup>-</sup> to NO<sub>3</sub><sup>-</sup>.

**Assimilation:** plants take up NH<sub>4</sub><sup>+</sup> or NO<sub>3</sub><sup>-</sup> and build organic nitrogen. **Ammonification:** decomposers return organic nitrogen to NH<sub>4</sub><sup>+</sup>.

**Denitrification:** bacteria in low-oxygen soil turn NO<sub>3</sub><sup>-</sup> back into N<sub>2</sub>. Humans add nitrogen through synthetic fertilizer and fossil-fuel combustion.

## 1.6 The Phosphorus Cycle

Phosphorus has **no significant atmospheric component**. Its reservoirs are rock and ocean sediment; slow weathering releases phosphate (PO<sub>4</sub><sup>3-</sup>) that plants absorb, animals obtain by eating, and decomposers return to soil. Because weathering is slow, phosphorus is scarce and is often the limiting nutrient in fresh water. Fertilizer and sewage runoff add phosphate and fuel eutrophication.

## 1.7 The Hydrologic (Water) Cycle

Solar energy drives **evaporation**, **transpiration** (water vapor from plants) and **sublimation**; vapor **condenses** and falls as **precipitation**, then moves by **runoff** or **infiltration** and **percolation** into groundwater and aquifers. Oceans hold about 97% of Earth's water, and most fresh water is locked in ice. Paving and pumping shift the balance toward runoff and depletion.

## 1.8 Primary Productivity

### Productivity

NPP = GPP – *R*, where GPP is total energy captured by photosynthesis and *R* is the energy producers use in respiration.

NPP is the energy left to build biomass, so it is what consumers can eat. Units: kcal/m<sup>2</sup>/yr or g/m<sup>2</sup>/yr.

NPP per square meter is highest in tropical rainforests, estuaries, swamps and reefs, and lowest in deserts and open ocean. The open ocean still contributes a large share of Earth's NPP because it covers so much area. Light, temperature, water and nutrients limit NPP.

## 1.9 Trophic Levels

Producers are level 1, primary consumers (herbivores) level 2, secondary consumers level 3 and tertiary consumers level 4. Omnivores occupy more than one level, and decomposers and detritivores act on every level.

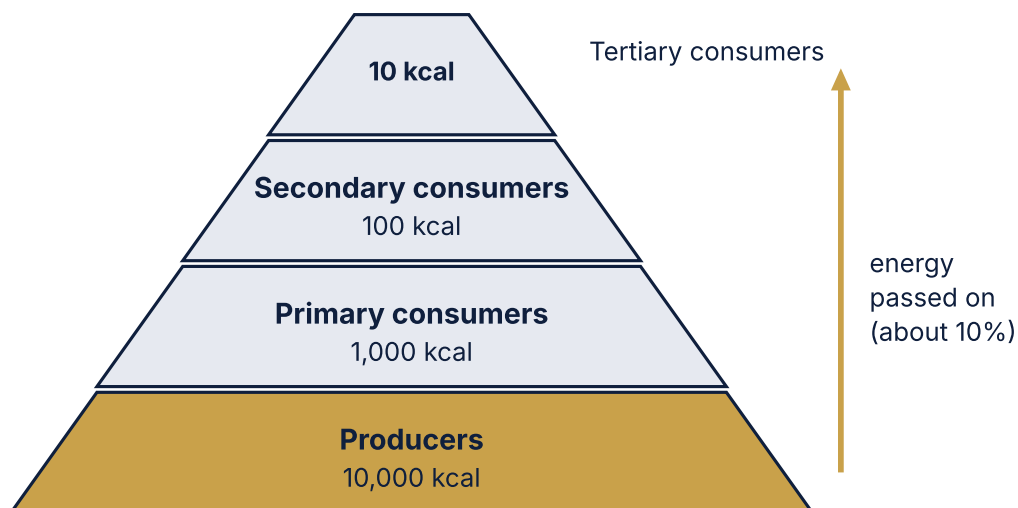
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## 1.10 Energy Flow and the 10% Rule

Only about **10%** of the energy at one trophic level is available to the next. The rest is lost as heat in respiration, left in waste, or stays in uneaten parts. So food chains rarely exceed four or five levels.



About 90% of the energy at each level is lost as heat, respiration, waste and uneaten parts.

Energy pyramid with 10,000 kcal fixed by producers (illustrative values, shapes not to scale).

### 10% rule calculation

Energy at level  $n = (\text{energy at level 1}) \times (0.10)^{n-1}$ .

To work upward from a consumer: divide by 0.10 for every step you go down. Show the units.

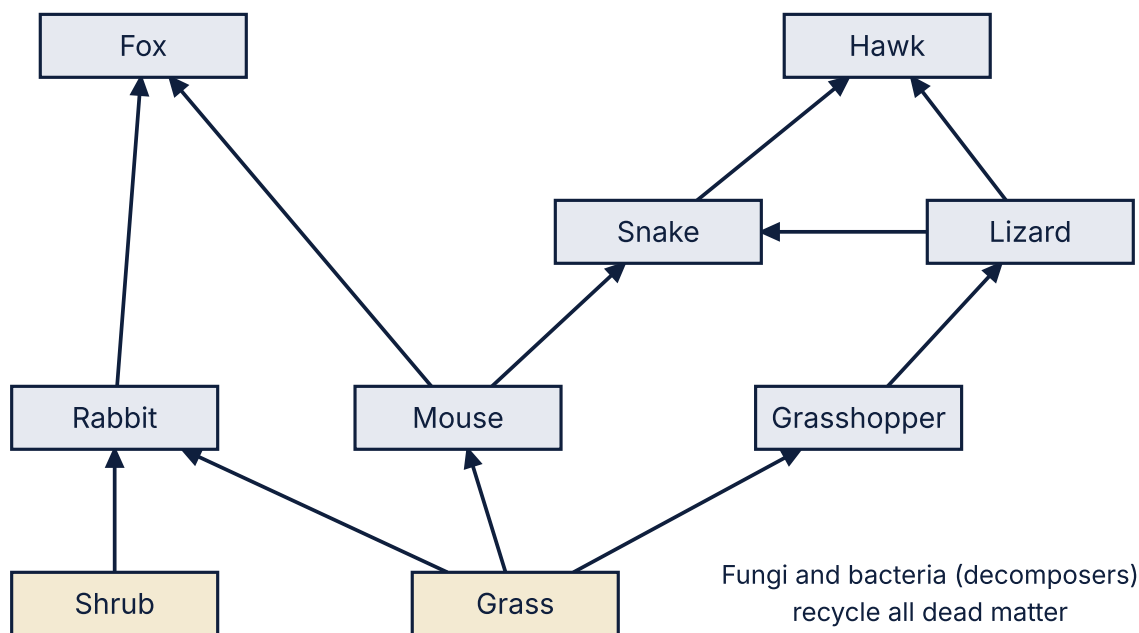
## 1.11 Food Chains and Food Webs

A food chain is one path of energy; a **food web** is many interlocking chains. Arrows point from the food to the eater, in the direction of energy flow. A **keystone species** has an effect on its community far larger than its abundance suggests, so removing it can trigger a trophic cascade.

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Arrows point from the organism eaten to the organism that eats it.

Terrestrial food web. Producers are shaded gold. The longest chain is Grass, Grasshopper, Lizard, Snake, Hawk.

## Worked Examples

### EXAMPLE 1: CONVERSIONS AND PERCENT CHANGE

A reserve covers  $3.2 \text{ km}^2$  and has an NPP of  $850 \text{ g carbon per m}^2 \text{ per year}$ . (a) Find the total NPP in metric tons of carbon per year ( $1 \text{ metric ton} = 1,000,000 \text{ g}$ ). (b) After a fire, NPP is  $612 \text{ g/m}^2/\text{yr}$ . Find the percent change.

#### SOLUTION

(a) Area:  $3.2 \text{ km}^2 \times (1000 \text{ m}/1 \text{ km})^2 = 3.2 \times 10^6 \text{ m}^2$ .

Total:  $3.2 \times 10^6 \text{ m}^2 \times 850 \text{ g C/m}^2/\text{yr} = 2.72 \times 10^9 \text{ g C/yr}$ .

Convert:  $2.72 \times 10^9 \text{ g} \times (1 \text{ t}/10^6 \text{ g}) = 2.72 \times 10^3 \text{ metric tons C per year (2,720 t/yr)}$ .

(b) Percent change =  $(\text{new} - \text{old})/\text{old} \times 100 = (612 - 850)/850 \times 100 = -28\%$ . NPP decreased by 28%.

### EXAMPLE 2: THE 10% RULE

Producers in a meadow plot capture  $80,000 \text{ kcal}$  per year. Grasshoppers eat the grass, frogs eat grasshoppers and herons eat frogs. (a) How much energy reaches each level? (b) How many kcal of producer energy are needed to deliver  $60 \text{ kcal}$  to herons?

| Trophic level | Organism     | Energy (kcal/yr) |
|---------------|--------------|------------------|
| 1             | Grass        | 80,000           |
| 2             | Grasshoppers | ?                |
| 3             | Frogs        | ?                |
| 4             | Herons       | ?                |

#### SOLUTION

(a) Each step multiplies by 0.10: grass 80,000; grasshoppers 8,000; frogs 800; herons 80 kcal per year.

(b) Herons are level 4, which is three transfers above producers. Needed =  $60 / (0.10)^3 = 60 / 0.001 = 60,000 \text{ kcal}$  of producer energy.

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**EXAMPLE 3: READING THE FOOD WEB**

Use the food web in 1.11. (a) Give the longest chain. (b) Predict two effects of removing all lizards. (c) If grass NPP along that chain is 100,000 kcal, how much energy reaches the hawk?

**SOLUTION**

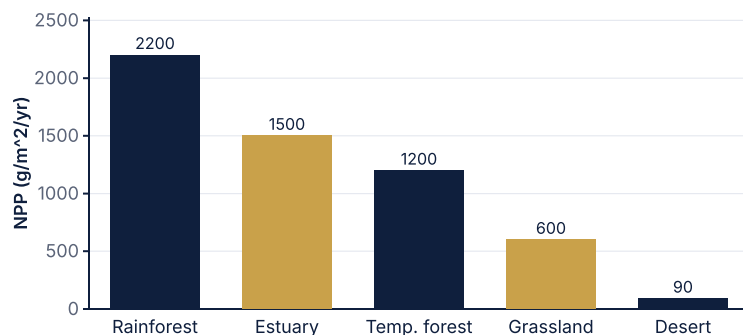
(a) Grass, Grasshopper, Lizard, Snake, Hawk (four transfers).

(b) Grasshoppers lose a predator, so their numbers rise and they eat more grass. Snakes lose a food source and eat more mice, so mouse numbers fall.

(c)  $100,000 \times (0.10)^4 = 10$  kcal reaches the hawk.

**EXAMPLE 4: COMPARING PRODUCTIVITY**

Net primary productivity (g dry biomass per m<sup>2</sup> per year): rainforest 2,200; estuary 1,500; temperate forest 1,200; grassland 600; desert 90. (a) By what percent does rainforest NPP exceed temperate forest NPP? (b) What mass of NPP does a 40,000 m<sup>2</sup> grassland produce per year, in metric tons?



Fictional NPP values for five ecosystems.

**SOLUTION**

(a)  $(2,200 - 1,200) / 1,200 \times 100 = 83.3\%$  higher.

(b)  $600 \text{ g/m}^2/\text{yr} \times 40,000 \text{ m}^2 = 2.4 \times 10^7 \text{ g/yr}$ ; divide by  $10^6 \text{ g/t} = 24$  metric tons per year.

**Write It Like a 5****Model Response**

Prompt: Nitrogen limits plant growth in a farm field. Describe how nitrogen becomes available to plants, and explain one human action that disrupts the nitrogen cycle and its consequence. Nitrogen-fixing bacteria in the soil convert atmospheric N<sub>2</sub> into ammonium (NH<sub>4</sub><sup>+</sup>). Nitrifying bacteria then convert ammonium to nitrate (NO<sub>3</sub><sup>-</sup>), which plant roots absorb. Because fixation is slow, available nitrogen often limits plant growth. Applying excess synthetic fertilizer adds nitrate faster than plants can use it. Runoff carries the surplus to streams, causing eutrophication: algae bloom and die, and decomposers use up dissolved oxygen, so fish die.

**What the grader looks for**

(1) Names fixation (or nitrification) with the correct form of nitrogen. (2) Gives the mechanism, not just the name. (3) Identifies a specific human action (fertilizer, fossil-fuel combustion). (4) States the consequence with the full chain: runoff, nutrient enrichment, algal bloom, oxygen depletion. Do not say that pesticides cause eutrophication.

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## Coach's Playbook

- ◆ Draw food-web arrows from food to eater and label trophic levels first.
- ◆ For every calculation write the setup, cancel units line by line, and finish with a unit and a direction (increase or decrease).
- ◆ For each cycle, name the reservoirs first, then the processes that move matter between them.

### Common traps

1) Reversing food-web arrows, or calling a decomposer a trophic level 5 consumer. 2) Saying savanna has no rain; it has a long dry season and a wet season. 3) Claiming phosphorus has a gas phase or that fixation converts  $N_2$  to nitrate. 4) Forgetting parentheses or the factor of 100 in percent change, and dropping squared units when converting  $km^2$  to  $m^2$ .

### Quick Check

Q: What is NPP in terms of GPP? A:  $NPP = GPP - \text{respiration}$ . Q: 5,000 kcal of producers supports how much energy in secondary consumers? A: 50 kcal. Q: Which cycle has no atmospheric reservoir? A: Phosphorus.

### Challenge Corner

Pond algae have GPP of  $5,000 \text{ kcal}/m^2/yr$  and respire  $2,000 \text{ kcal}/m^2/yr$ . Zooplankton eat the algae, small fish eat zooplankton, and bass eat the small fish. How much bass energy does a 2.0 hectare pond hold per year ( $1 \text{ ha} = 10,000 m^2$ )?  $NPP = 5,000 - 2,000 = 3,000 \text{ kcal}/m^2/yr$ . Zooplankton: 300; small fish: 30; bass: 3  $\text{kcal}/m^2/yr$ . Area =  $2.0 \times 10,000 = 20,000 m^2$ . Bass energy =  $3 \times 20,000 = 60,000 \text{ kcal}/yr$ .

## Practice

### PRACTICE Unit 1 Practice

Show your work. A calculator is allowed. Justify conclusions.

- In a food web diagram, an arrow drawn from a mouse to a snake means that
  - (A) the mouse eats the snake
  - (B) energy and matter move from the mouse to the snake, which eats it
  - (C) the snake is a producer for the mouse
  - (D) the mouse is a decomposer of the snake
- Which process converts atmospheric nitrogen gas into ammonium that plants can use?
  - (A) Nitrification
  - (B) Denitrification
  - (C) Nitrogen fixation
  - (D) Ammonification
- Producers in a lake fix 40,000 kcal per year. About how much energy is available to tertiary consumers?
  - (A) 40 kcal
  - (B) 400 kcal
  - (C) 4,000 kcal
  - (D) 4 kcal
- Which statement about the phosphorus cycle is correct?
  - (A) Bacteria fix phosphorus gas from the air.
  - (B) The atmosphere is the largest phosphorus reservoir.
  - (C) Phosphorus returns from ocean sediment to land within months.
  - (D) It has no significant atmospheric reservoir, and slow rock weathering often makes it limiting in fresh water.
- A biome has a mean annual temperature near 25 degrees C and about 110 cm of rain, falling mostly in a six-month wet season. It is covered by grasses with scattered trees and has frequent fires. This is most likely
  - (A) tropical rainforest
  - (B) savanna
  - (C) temperate grassland
  - (D) desert

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6. The table gives GPP and respiration by producers. Which ecosystem has the greatest NPP?

| Ecosystem  | GPP (kcal/m <sup>2</sup> /yr) | R (kcal/m <sup>2</sup> /yr) |
|------------|-------------------------------|-----------------------------|
| Forest     | 9,000                         | 5,200                       |
| Cropland   | 4,000                         | 1,200                       |
| Salt marsh | 8,000                         | 3,500                       |
| Open ocean | 1,500                         | 1,000                       |

- (A) Forest (B) Cropland (C) Salt marsh  
(D) Open ocean
7. A student suspects nitrogen limits algae growth in a pond.  
(a) Write a testable hypothesis naming the independent and dependent variables.  
(b) Describe an investigation using 12 identical containers of pond water, including treatments, a control, and two variables held constant.  
(c) Predict the result and justify it.  
(d) Identify one human source of nitrate and one consequence for fish if it reaches the pond.
8. A 12 hectare meadow has producers with an NPP of 2,000 kcal/m<sup>2</sup>/yr (1 ha = 10,000 m<sup>2</sup>).  
(a) Calculate the total NPP in kcal per year in scientific notation.  
(b) Using the 10% rule, calculate the energy available to secondary consumers.  
(c) A fox needs 2,500 kcal per day. How many whole foxes could this energy support for a year (365 days)?
9. Atmospheric carbon dioxide rose from 315 ppm to 420 ppm over 60 years.  
(a) Calculate the percent change and the average percent change per year.  
(b) Identify two processes that remove carbon from the atmosphere and two that add it.  
(c) Explain why burning fossil fuels raises atmospheric carbon dioxide more than the respiration of living organisms does.
10. Sea otters eat sea urchins, and sea urchins eat kelp.  
(a) Write the food chain with arrows in the correct direction and name the trophic level of each organism.  
(b) Predict what happens to urchins and kelp if otters are removed, and explain.  
(c) Define keystone species and state why otters qualify.

## Answers Unit 1: Answers and Explanations

Read every explanation, including the ones for problems you answered correctly.

### 1 The Living World: Ecosystems

#### PRACTICE · UNIT 1 PRACTICE

- B. An arrow shows the direction of energy and matter flow, from the organism eaten to the one that eats it. Choice A reverses the arrow, which is the most common mistake.
- C. Nitrogen fixation by soil bacteria converts N<sub>2</sub> to ammonium. Nitrification (A) changes ammonium to nitrate, and ammonification (D) returns organic nitrogen to ammonium, so neither starts from N<sub>2</sub>.
- A. Each transfer keeps about 10%: 40,000 to 4,000 (primary) to 400 (secondary) to 40 kcal (tertiary). Choice B counts one transfer too few.
- D. Phosphorus has no significant atmospheric reservoir; rock and sediment are its reservoirs and weathering is slow, so it often limits freshwater plants. Choice B confuses it with nitrogen.
- B. Warm year-round with distinct wet and dry seasons, grass with scattered trees and fire describe savanna. Tropical rainforest (A) is wet all year; temperate grassland (C) has cold winters.
- C. NPP = GPP - R: forest 3,800; cropland 2,800; salt marsh 4,500; open ocean 500 kcal/m<sup>2</sup>/yr. Forest (A) has the largest GPP, the tempting choice, but much is used in respiration.
- (a) Hypothesis: If nitrate is added to pond water, then algal density (DV, such as chlorophyll or cell count) will be higher than in water without added nitrate (IV: nitrate added). (b) Four containers each get no nitrate (control), low nitrate, medium, and high, with 3 replicates each. Keep light, temperature, water volume and starting algae constant. (c) Algae increase with nitrate if nitrogen is limiting, because algae can then grow until another factor limits them; the control stays low. (d) Fertilizer runoff or sewage supplies nitrate. Algae bloom and die, decomposers use up dissolved oxygen, and fish suffocate.
- (a) Area = 12 × 10,000 = 1.2 × 10<sup>5</sup> m<sup>2</sup>. NPP = 2,000 kcal/m<sup>2</sup>/yr × 1.2 × 10<sup>5</sup> m<sup>2</sup> = 2.4 × 10<sup>8</sup> kcal/yr. (b) Secondary consumers are two transfers up: 2.4 × 10<sup>8</sup> × 0.1 × 0.1 = 2.4 × 10<sup>6</sup> kcal/yr. (c) One fox needs 2,500 × 365 = 912,500 kcal/yr. 2.4 × 10<sup>6</sup> / 912,500 = 2.63, so 2 foxes. (d)

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9. (a) Percent change =  $(420 - 315)/315 \times 100 = 33.3\%$  increase. Per year:  $33.3/60 = 0.56\%$  per year. (b) Remove: photosynthesis and ocean absorption. Add: respiration, decomposition, combustion, or deforestation. (c) Respiration returns recently captured carbon, so it is roughly balanced; fossil fuels hold carbon stored for millions of years, so burning adds new carbon to the active cycle.
10. (a) Kelp (producer, level 1) to urchins (primary consumer, level 2) to otters (secondary consumer, level 3). (b) Urchins increase because their predator is gone, and they overgraze kelp, so kelp decreases (a trophic cascade). (c) A keystone species has a disproportionately large effect on community structure relative to its abundance; otters control urchins, which protects kelp habitat for many species.

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# Unit 2: The Living World: Biodiversity

Exam weighting: about 6-8% of the multiple-choice section. Concept review, worked examples, exam-style writing, and 10 practice items, all with full explanations.

## 2 The Living World: Biodiversity

Biodiversity has genetic, species and ecosystem levels. Learn ecosystem services, island biogeography, tolerance, adaptation and succession, and use diversity math correctly.

### Why This Matters

Unit 2 is 6-8% of the multiple-choice section, and its ideas show up in many free-response questions. Students lose points by confusing species richness with the number of individuals, describing adaptation as something an individual does during its life, and naming ecosystem services without the mechanism. Read graphs at the right place, and always say what the dependent variable is, such as the number of species.

### Core Ideas

#### 2.1 Introduction to Biodiversity

**Biodiversity** has three levels. **Genetic diversity** is variation in alleles within a species; it lets populations adapt to disease and change. **Species diversity** combines **richness** (the number of different species) and **evenness** (how similar their abundances are). **Ecosystem diversity** is the variety of habitats in a region. Richness counts species, not individuals: a field of 500 dandelions has a richness of 1.

##### Simpson diversity index (one common form)

$D = 1 - \sum(n/N)^2$ , where  $n$  is the number of individuals of one species and  $N$  is the total number of individuals.

$D$  runs from 0 (one species dominates completely) to nearly 1 (many species, evenly spread). A larger  $D$  means greater diversity. State which form of the index you use.

#### 2.2 Ecosystem Services

| Type         | What it is                        | Example                                                                    |
|--------------|-----------------------------------|----------------------------------------------------------------------------|
| Provisioning | Goods people harvest              | Timber, fish, crops, fresh water                                           |
| Regulating   | Natural control of conditions     | Wetland water purification, flood control, pollination, climate regulation |
| Cultural     | Non-material benefits             | Recreation, beauty, spiritual value                                        |
| Supporting   | Processes that sustain the others | Nutrient cycling, soil formation, primary production                       |

Losing a service often forces people to pay for a replacement. Draining a wetland removes free flood storage and water filtration, so a town may have to build levees and treatment plants. Name the service, then give the mechanism.

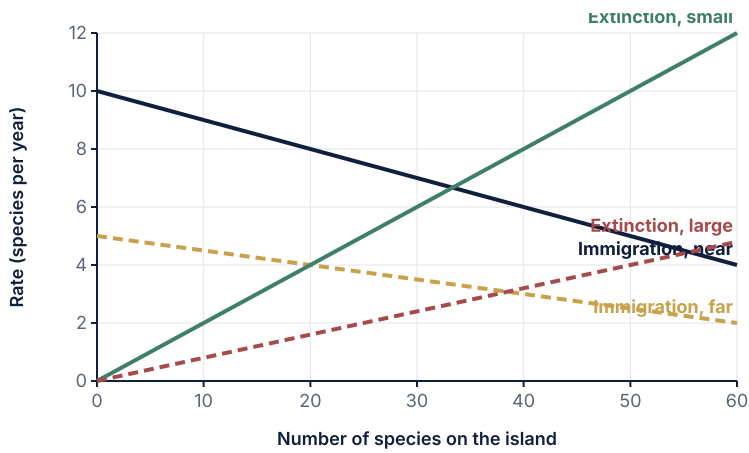
#### 2.3 Island Biogeography

The island biogeography model explains how many species live on an island, or on any habitat island such as a park, a lake or an isolated forest fragment. The number of species settles at an **equilibrium** where the rate of new species arriving (immigration) equals the rate of species disappearing (extinction).

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Equilibrium richness is where an immigration line crosses an extinction line. Near-large islands settle highest (about 56 species); far-small islands settle lowest (about 20). Straight lines are a simplification.

### Island biogeography rules

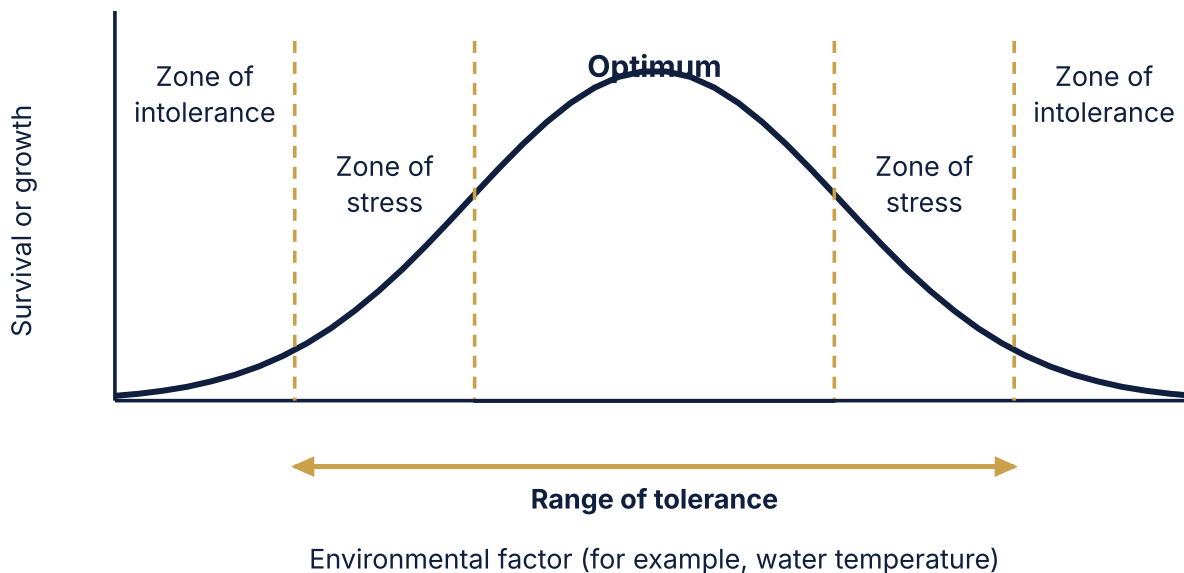
**Larger island:** more habitats and bigger populations, so lower extinction and more species.

**Closer to the mainland:** more immigrants arrive, so higher richness. Large and near gives the most species; small and far gives the fewest.

Fragmenting habitat creates smaller, more isolated islands, so richness falls. Wildlife corridors and large reserves slow the loss.

## 2.4 Ecological Tolerance

Every species has a **range of tolerance** for each abiotic factor, such as temperature, salinity, pH or dissolved oxygen. Performance peaks at the optimum and declines through zones of stress to the limits, beyond which individuals die. A **limiting factor** is the one closest to a species' limit. Species with a narrow range (specialists) are useful **indicator species**, because their presence or absence signals conditions such as clean, cold, well-oxygenated water.



Tolerance curve for one species. Outside the range of tolerance, no individuals survive. A narrow range marks a specialist.

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## 2.5 Natural Disruptions to Ecosystems

Fires, floods, hurricanes, volcanic eruptions, earthquakes, tsunamis, droughts, landslides and disease outbreaks can change habitats quickly and reset succession. Effects depend on frequency, intensity and area. Not all are purely harmful: periodic fire clears litter, releases nutrients, and opens cones of some pines. Human actions can change the outcome; decades of fire suppression build up fuel and make later fires larger.

## 2.6 Adaptations

An **adaptation** is a heritable trait (structural, physiological or behavioral) that improves survival or reproduction. Populations respond to change through **natural selection**, producing gradual genetic change over many generations.

### Natural selection in four statements

Individuals vary, and some of the variation is heritable.

More offspring are born than can survive.

Individuals with advantageous traits survive and reproduce more.

Over generations, the proportion of the trait in the population increases.

Individuals do not change their genes because they need to; the population changes. If the environment shifts faster than variation allows, or variation is lacking, the population may decline, move, or go extinct.

## 2.7 Ecological Succession

**Primary succession** starts where there is no soil (new lava, bare rock, a retreating glacier). **Pioneer species** such as lichens and mosses break down rock and build soil, and the process takes centuries. **Secondary succession** follows a disturbance (fire, abandoned farm field) that leaves soil, so it is faster. Fast-growing, sun-loving species are replaced by slower, shade-tolerant ones, ending in a relatively stable **climax community** that is still subject to disturbance. Biomass and soil depth increase through succession, and early species tend to be r-selected while late species tend to be K-selected.

Primary succession begins here



Secondary succession begins here (soil already present)

Time: decades (secondary) to centuries (primary)

Soil deepens; biomass and shade increase; fast-growing species give way to slow-growing species

Stages of succession (idealized).

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## Worked Examples

### EXAMPLE 1: RICHNESS, EVENNESS AND SIMPSON'S INDEX

Two plots each hold 4 beetle species and 100 beetles. Plot A counts: 40, 30, 20, 10. Plot B counts: 91, 3, 3, 3. Compare richness, evenness and diversity.

| Plot | Species 1 | Species 2 | Species 3 | Species 4 |
|------|-----------|-----------|-----------|-----------|
| A    | 40        | 30        | 20        | 10        |
| B    | 91        | 3         | 3         | 3         |

#### SOLUTION

Richness: both plots have 4 species, so richness is equal.

Plot A:  $D = 1 - (0.4^2 + 0.3^2 + 0.2^2 + 0.1^2) = 1 - 0.30 = 0.70$ .

Plot B:  $D = 1 - (0.91^2 + 3 \times 0.03^2) = 1 - (0.8281 + 0.0027) = 0.17$ .

Evenness is much higher in A, so A is more diverse even though richness is equal. Plot B is dominated by one species.

### EXAMPLE 2: HABITAT FRAGMENTS

A 4.0 km<sup>2</sup> forest is split by roads and its bird richness falls from 120 species to 90. A corridor 15 m wide and 2.4 km long is proposed. (a) Express the corridor area in hectares and as a percent of the forest (1 ha = 10,000 m<sup>2</sup>). (b) Find the percent change in richness. (c) Explain the loss and the corridor's value.

#### SOLUTION

(a) Forest:  $4.0 \text{ km}^2 \times 100 \text{ ha/km}^2 = 400 \text{ ha}$ . Corridor:  $15 \text{ m} \times 2400 \text{ m} = 36,000 \text{ m}^2 \times (1 \text{ ha}/10,000 \text{ m}^2) = 3.6 \text{ ha}$ . Percent =  $3.6/400 \times 100 = 0.9\%$ .

(b)  $(90 - 120)/120 \times 100 = -25\%$ , a 25% decrease.

(c) Smaller, isolated fragments support smaller populations, which have higher extinction rates and fewer arrivals. A corridor raises immigration between fragments, helping slow extinction.

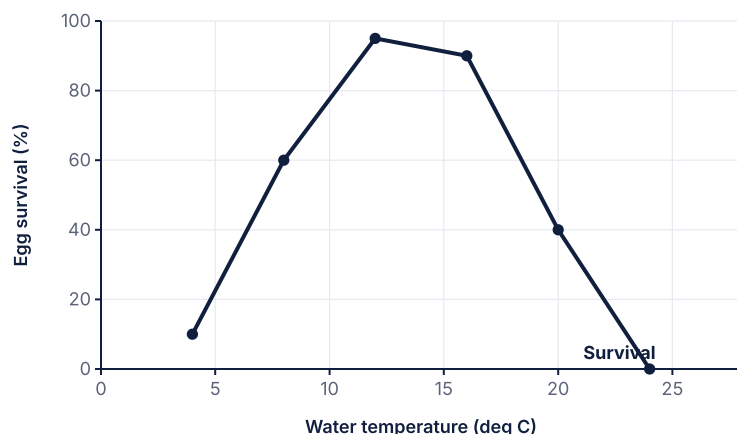
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**EXAMPLE 3: READING A TOLERANCE CURVE**

Egg survival of a fish at different water temperatures is plotted. (a) At which temperatures is survival at least 90%? (b) What does the data show about the upper limit? (c) A power plant warms a river from 14 to 22 degrees C. Estimate survival at each temperature by linear interpolation and the percent change.



Fictional egg survival data.

**SOLUTION**

(a) 12 and 16 degrees C (95% and 90%), so the optimum lies in about 12-16 degrees C.

(b) Survival is 0% at 24 degrees C, so the upper limit is at or below 24; the lower limit is not shown because 10% survive at 4 degrees C.

(c) At 14: midway between 95 and 90, so 92.5%. At 22: midway between 40 and 0, so 20%. Percent change =  $(20 - 92.5)/92.5 \times 100 = -78.4\%$ , a decrease of about 78%.

**EXAMPLE 4: SELECTION IN A BEETLE POPULATION**

A beetle population of 1,000 starts with 2% pesticide-resistant individuals. A spray kills 95% of non-resistant beetles and 10% of resistant beetles. Survivors breed and the population returns to 1,000. Find the percent resistant after one spray, and after a second spray.

**SOLUTION**

Start: 20 resistant, 980 non-resistant. Survivors: resistant  $20 \times 0.90 = 18$ ; non-resistant  $980 \times 0.05 = 49$ . Total 67; resistant =  $18/67 = 26.9\%$ .

Regrowth to 1,000 gives 269 resistant and 731 non-resistant (resistance is heritable). Second spray survivors:  $269 \times 0.90 = 242$  and  $731 \times 0.05 = 37$ . Resistant =  $242/279 = 86.9\%$ .

No beetle became resistant on purpose; the spray selected among existing variation, so the proportion rose over generations.

**Write It Like a 5****Model Response**

Prompt: A wildfire burns a forest but leaves the soil intact. Identify the type of succession and describe how the plant community changes over the next 50 years. This is secondary succession, because the soil and its seed bank survived. In the first years, fast-growing, sun-loving grasses and wildflowers colonize. Over the next decades shrubs and fast-growing trees such as aspen or pine establish and shade the ground. Slower-growing, shade-tolerant trees then replace them. As succession proceeds, soil organic matter, biomass and habitat structure increase, so species richness generally rises until the community nears a stable climax.

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### What the grader looks for

(1) Correct type with its reason (soil present). (2) Ordered stages with specific plant types. (3) A reason for the replacement, such as shading. (4) A direction of change in a measurable property (biomass, soil, richness). Naming primary succession for a burned forest with soil loses the first point.

### Coach's Playbook

- ◆ Write the dependent variable exactly: 'number of ant species', not 'ants'.
- ◆ For adaptation answers use the pattern: variation, selection pressure, differential survival, change in the population over generations.
- ◆ For tolerance graphs, read the region the question asks about (below a threshold or inside the optimum) and cite values.
- ◆ For island questions, state both size and distance, then link them to extinction and immigration.

### Common traps

1) Counting individuals when the question asks for richness. 2) Saying an organism 'adapted' during its lifetime, or evolved 'because it needed to'. 3) Calling a burned forest with intact soil primary succession. 4) Listing an ecosystem service without explaining how the ecosystem provides it.

### Quick Check

Q: Name the three levels of biodiversity. A: Genetic, species, ecosystem. Q: Which island holds more species, large-near or small-far? A: Large-near. Q: What starts primary but not secondary succession? A: Bare surface with no soil.

### Challenge Corner

A model for habitat islands is  $S = c \times A^z$ , where  $S$  is species,  $A$  is area and  $z$  is about 0.30. If 90% of a habitat is destroyed, what percent of species are expected to be lost eventually? Remaining area is 10% of the original, so  $S_2/S_1 = (0.10)^{0.30} = 0.501$ . About 50% of species remain, so about 49.9% (roughly half) are lost. The model is a guide, not a requirement of the exam.

### Practice

#### PRACTICE Unit 2 Practice

Show your work. A calculator is allowed. Justify conclusions.

- Two meadows each contain four plant species and 100 stems. Meadow 1 has 25 stems of each species. Meadow 2 has 91 stems of one species and 3 stems of each of the others. Which statement is correct?
  - (A) Richness is equal, but meadow 1 has higher evenness and higher Simpson diversity.
  - (B) Meadow 1 has higher richness than meadow 2.
  - (C) Meadow 2 has higher richness because one species is very abundant.
  - (D) The meadows have equal evenness and equal diversity.
- A mangrove forest traps sediment and reduces storm-surge damage to a town. This is best classified as which type of ecosystem service?
  - (A) Provisioning
  - (B) Cultural
  - (C) Regulating
  - (D) Supporting
- According to island biogeography, which island should have the greatest equilibrium species richness?
  - (A) A small island 5 km from the mainland
  - (B) A small island 200 km from the mainland
  - (C) A large island 200 km from the mainland
  - (D) A large island 5 km from the mainland

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4. A stonefly larva survives only in cold, well-oxygenated stream water. It disappears after a warm-water discharge. This species is best described as
- (A) a generalist with a wide tolerance range
  - (B) an indicator species with a narrow tolerance range
  - (C) an r-selected species adapting to heat
  - (D) a pioneer species in primary succession
5. Soot darkens tree bark, and over many generations a moth population becomes mostly dark. Which statement best explains this?
- (A) Dark moths survived and reproduced more, and the trait is heritable, so its frequency rose.
  - (B) Each moth darkened during its lifetime to match the bark and passed on the change.
  - (C) The moths needed to be dark, so mutations occurred to meet that need.
  - (D) Light moths changed color when they moved to dark trees.
6. Which observation best indicates primary succession rather than secondary succession?
- (A) Grasses and wildflowers appear in an abandoned farm field.
  - (B) Aspen seedlings grow in the ground of a burned forest.
  - (C) Shrubs replace weeds in a cleared lot.
  - (D) Lichens colonize newly cooled lava that has no soil.
7. A student wants to know whether forest-patch size affects the number of ant species.
- (a) State a testable hypothesis with the independent and dependent variables.
  - (b) Describe a method using 10 patches of different sizes, including sampling effort and two constants.
  - (c) Describe the graph you would make and the trend predicted by island biogeography.
  - (d) Explain why counting ants would not answer the question.
8. Bird counts in a wetland before drainage: 30, 25, 20, 15, 10 (five species). After drainage: 70, 15, 10, 5 (four species).
- (a) Calculate Simpson's index before and after.
  - (b) Calculate the percent change in richness and in Simpson's index.
  - (c) Identify one regulating ecosystem service the wetland provided and explain how losing it affects people.
9. Juvenile clam survival (%) at salinities (ppt, parts per thousand): 5 ppt, 5%; 10 ppt, 35%; 15 ppt, 80%; 20 ppt, 95%; 25 ppt, 90%; 30 ppt, 55%; 35 ppt, 10%.
- (a) Identify the salinities of optimum survival.
  - (b) Why can the full range of tolerance not be stated from the data?
  - (c) Heavy rain lowers salinity from 24 to 12 ppt. Estimate survival at each by interpolation and the percent change.
  - (d) Is the clam a generalist or specialist for salinity? Justify.
10. A hurricane strikes an island lizard population; those with larger toe pads cling to branches and survive at higher rates.
- (a) Explain how the population will change over generations.
  - (b) Explain why saying that individual lizards adapted to the hurricane is incorrect.
  - (c) Identify one condition that would prevent adaptation.
  - (d) Describe one benefit of a natural disruption such as fire to an ecosystem.

## Answers Unit 2: Answers and Explanations

Read every explanation, including the ones for problems you answered correctly.

### 2 The Living World: Biodiversity

#### PRACTICE · UNIT 2 PRACTICE

1. A. Both meadows contain four species, so richness is equal. Meadow 1 is perfectly even ( $D = 0.75$ ), while meadow 2 is dominated by one species ( $D = 0.17$ ). Choice C confuses abundance with richness.
2. C. Trapping sediment and buffering storms regulate physical conditions, so it is a regulating service. Supporting (D) is the tempting choice, but it covers processes like nutrient cycling and soil formation.
3. D. Large islands have lower extinction rates and near islands have higher immigration rates, so large-near gives the most species. Choice C ignores distance.
4. B. A species that disappears when conditions shift outside a narrow range indicates the change in water quality. Choice A reverses the idea: a generalist tolerates wide ranges.
5. A. Selection acts on existing heritable variation: dark moths left more offspring. Choice B describes individual change, which is the Lamarckian error; need does not cause mutations (C).
6. D. No soil means primary succession, started by pioneers such as lichens. All other choices begin on soil, which is secondary succession.

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7. (a) If patch area increases, then the number of ant species per patch increases. IV: patch area; DV: number of ant species. (b) Sample each patch with the same number of pitfall traps for the same days, in the same season and habitat type; identify species in the catch. Constants: trap number, sampling time, season. (c) Scatterplot of species number (y) against area (x); predict a positive trend, because larger patches have lower extinction and more habitat types. (d) A count of ants measures abundance; one common species could give a large count with few species.
8. (a) Before:  $1 - (0.09 + 0.0625 + 0.04 + 0.0225 + 0.01) = 1 - 0.225 = 0.775$ . After:  $1 - (0.49 + 0.0225 + 0.01 + 0.0025) = 0.475$ . (b) Richness:  $(4 - 5)/5 \times 100 = -20\%$ . Simpson:  $(0.475 - 0.775)/0.775 \times 100 = -38.7\%$ . (c) Flood control: wetlands store storm water; losing the wetland means more runoff, flooding of nearby homes and costly infrastructure. Water purification is also acceptable.
9. (a) Survival is highest at about 20-25 ppt (95% and 90%). (b) Survival is still above 0 at both ends (5% at 5 ppt and 10% at 35 ppt), so the limits lie beyond the measured salinities. (c) At 12:  $35 + (2/5)(45) = 53\%$ . At 24:  $95 - (4/5)(5) = 91\%$ . Percent change =  $(53 - 91)/91 \times 100 = -41.8\%$ . (d) Specialist for salinity: survival falls quickly within 10 ppt of the optimum, so its tolerance range is narrow.
10. (a) Large-toed lizards survive and reproduce more, and the trait is heritable, so its frequency increases over generations. (b) Individuals do not change their genes during life. The population changes because of differential survival. (c) No heritable variation, a very small population, or environmental change faster than reproduction. (d) Fire clears dead litter, releases nutrients to soil and opens habitat for fire-adapted species.

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# Unit 3: Populations

Exam weighting: about 10-15% of the multiple-choice section. Concept review, worked examples, exam-style writing, and 10 practice items, all with full explanations.

## 3 Populations

Learn how populations are classified, counted and modeled: r and K strategies, survivorship, growth curves, age structures and the human demographic math the exam asks for.

### Why This Matters

Populations carry 10-15% of the multiple-choice section and appear in nearly every free-response set, often as a calculation. Students lose points by mixing up Type I, II and III survivorship, treating r-selected traits as 'weak', ignoring migration when a question includes it, and forgetting to add the doubling time to the start year.

### Core Ideas

#### 3.1 Generalist and Specialist Species

**Generalists** (raccoons, rats, cockroaches, coyotes) eat many foods and tolerate many habitats, so they thrive in disturbed or changing environments and are often invasive. **Specialists** (pandas on bamboo, koalas on eucalyptus) have narrow diets or habitats; they face less competition in stable conditions but are vulnerable when the habitat changes.

#### 3.2 K-Selected and r-Selected Species

| Trait           | r-selected                        | K-selected                      |
|-----------------|-----------------------------------|---------------------------------|
| Offspring       | Many, small                       | Few, large                      |
| Parental care   | Little or none                    | Extensive                       |
| Age at maturity | Early                             | Late                            |
| Life span       | Short                             | Long                            |
| Population size | Fluctuates; often far below K     | Stable near K                   |
| Habitat         | Disturbed, unstable               | Stable                          |
| Survivorship    | Usually Type III                  | Usually Type I (or II)          |
| Examples        | Insects, weeds, bacteria, oysters | Elephants, whales, humans, oaks |

These are two ends of a spectrum, not two boxes. K-selected species are more vulnerable to extinction when habitat or adults are lost, because they recover slowly. Invasive species are typically generalist and r-selected; a lack of predators is a feature of their new habitat, not a trait of the species.

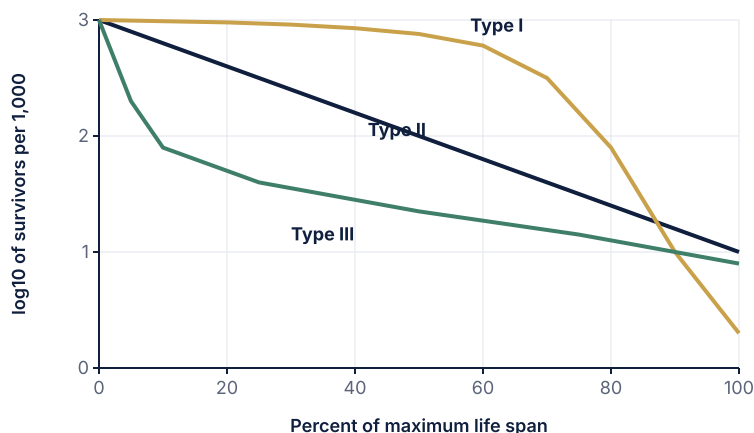
#### 3.3 Survivorship Curves

A **survivorship curve** shows how many individuals of a cohort survive to each age. It describes the pattern of mortality, not the animal's size.

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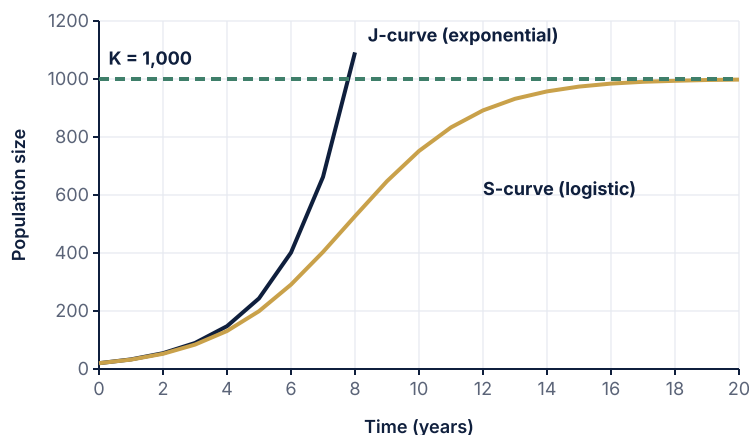
Survivorship curves on a log scale (0 = 1 survivor, 3 = 1,000). Type II is a straight line because the same percent die in each interval.

- ◆ **Type I:** most survive to old age, then mortality rises (humans, elephants; few offspring, high parental care).
- ◆ **Type II:** a constant chance of dying at every age (many songbirds, small mammals, some lizards).
- ◆ **Type III:** very high mortality of the young and few survivors (oysters, sea turtles, most insects and trees; many offspring, no care).

### 3.4 Carrying Capacity

**Carrying capacity (K)** is the maximum population an environment can sustain indefinitely with its resources (food, water, space). It changes when resources change. **Density-dependent** factors, such as competition, predation, parasitism and disease, act more strongly as the population gets denser. **Density-independent** factors, such as fire, floods, storms and freezes, act regardless of density. A population that overshoots K usually crashes, then oscillates around K.

### 3.5 Population Growth and Resource Availability



Exponential (J) growth is unlimited; logistic (S) growth levels off at carrying capacity K.

With unlimited resources, populations grow exponentially (a J-shaped curve) at their **biotic potential**. Real populations meet **environmental resistance** and grow **logistically**: growth is slow at first, fastest at the middle of the curve (about half of K), then levels off at K.

#### Growth curves

Exponential:  $\Delta N / \Delta t = rN$ . Logistic:  $\Delta N / \Delta t = rN(1 - N/K)$ .

On a logistic graph, K is the plateau and the steepest part of the curve is where the population adds the most individuals per year.

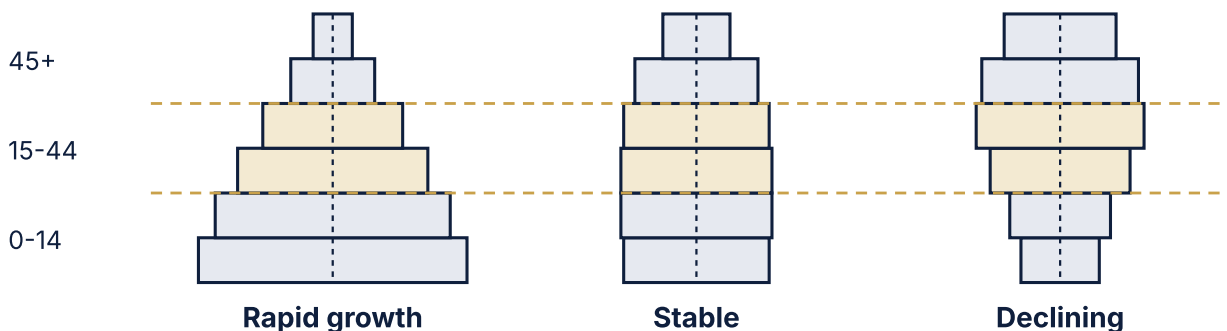
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### 3.6 Age Structure Diagrams

Age group (years); males left, females right



Idealized age structure diagrams. A wide base means rapid growth; a narrow base means decline.

Age structure diagrams show the share of a population in pre-reproductive (0-14), reproductive (15-44) and post-reproductive (45+) groups. A wide base predicts rapid growth. Even after fertility falls to replacement, a large young cohort keeps growing for decades: **population momentum**.

### 3.7 Total Fertility Rate

**Total fertility rate (TFR)** is the average number of children a woman would have in her lifetime at current birth rates. Replacement-level fertility is about 2.1 in countries with low infant mortality, and higher where many children die young. TFR falls with more education and job opportunities for women, access to family planning, lower infant mortality, urbanization, later marriage and a higher cost of raising children.

### 3.8 Human Population Dynamics

#### Human population math

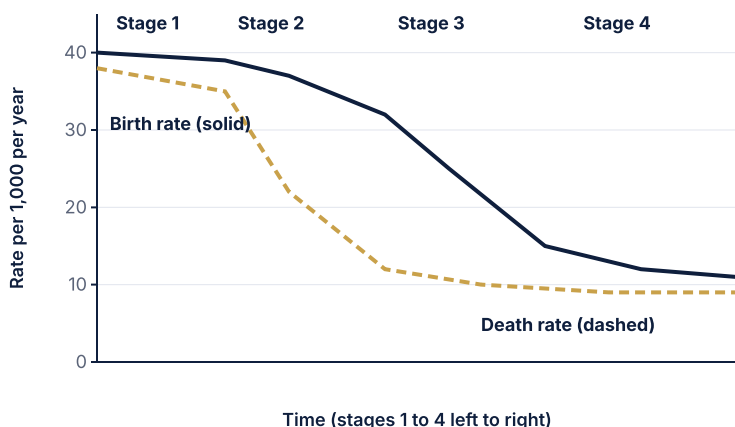
CBR and CDR are births and deaths per 1,000 people per year. Rate of natural increase (percent per year) =  $(\text{CBR} - \text{CDR})/10$ .

With migration: growth rate (%) =  $[(\text{CBR} + \text{immigration}) - (\text{CDR} + \text{emigration})]/10$ .

Rule of 70: doubling time (years) =  $70/(\text{percent growth rate})$ . For a target year, add the doubling time to the start year.

Other indicators include infant mortality (deaths under age one per 1,000 live births) and life expectancy. Falling death rates came from sanitation, medicine and more reliable food; world population passed 8 billion in 2022.

### 3.9 Demographic Transition



Idealized demographic transition. Growth is fastest where the gap between the birth rate and the death rate is widest (stage 2).

**Stage 1:** high birth and death rates, slow growth. **Stage 2:** death rates fall (sanitation, medicine, food) while birth rates stay high, so growth is rapid. **Stage 3:** birth rates fall (education, family planning, urbanization), so growth slows. **Stage 4:** low birth and death rates and slow or zero growth. Some models add a fifth stage in which deaths exceed births.

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## Worked Examples

### EXAMPLE 1: NATURAL INCREASE AND DOUBLING

A country has a CBR of 27 and a CDR of 9 per 1,000 per year, and 5.0 million people in 2027. (a) Find the rate of natural increase. (b) Estimate the doubling time and the year the population reaches 10 million. (c) Now include immigration of 2 and emigration of 5 per 1,000 and recalculate the doubling time.

#### SOLUTION

(a)  $(27 - 9)/10 = 1.8\%$  per year.

(b)  $70/1.8 = 38.9$  years;  $2027 + 38.9 = 2065.9$ , so about 2066.

(c) Growth rate =  $[(27 + 2) - (9 + 5)]/10 = 15/10 = 1.5\%$  per year. Doubling time =  $70/1.5 = 46.7$  years, longer because net emigration reduces growth.

### EXAMPLE 2: IDENTIFYING SURVIVORSHIP

Survivors per 1,000 at equal fractions of the life span. Classify each species.

| Fraction of life span | 0    | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 |
|-----------------------|------|-----|-----|-----|-----|-----|
| Species P             | 1000 | 400 | 160 | 64  | 26  | 10  |
| Species Q             | 1000 | 120 | 80  | 60  | 45  | 30  |
| Species R             | 1000 | 980 | 950 | 850 | 500 | 50  |

#### SOLUTION

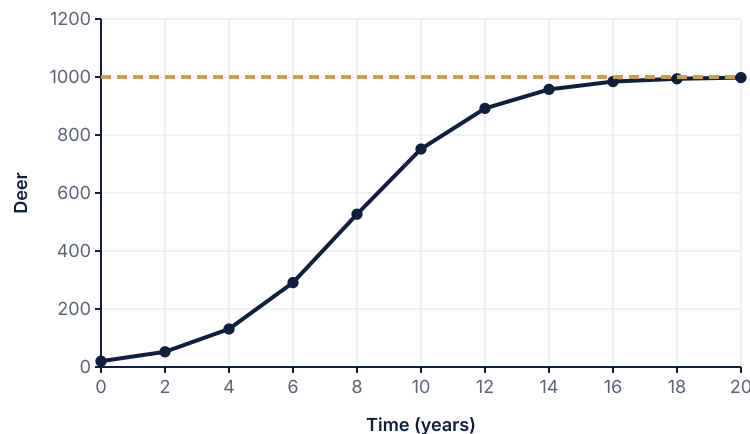
Compute percent dying in each interval. Species P: 60, 60, 60, 59, 62 percent. Constant percent mortality is Type II (a straight line on a log scale).

Species Q: 88, 33, 25, 25, 33 percent. Most die in the first interval, then few: Type III.

Species R: 2, 3, 11, 41, 90 percent. Low early mortality that rises late: Type I.

### EXAMPLE 3: READING A LOGISTIC CURVE

The graph shows a deer population on an island. (a) Estimate K. (b) At about what time is growth fastest, and what is the population then? (c) Predict the effect if a drought halves the food supply.



Fictional logistic growth, K shown dashed.

#### SOLUTION

(a) The curve levels off at  $K = 1,000$  deer.

(b) The steepest part is near  $t = 8$  years, where  $N$  is about 500, half of  $K$ . Algebra check: 20 deer growing with  $r = 0.5$  reach 500 when  $e^{-0.5t} = 1/49$ , so  $t = 7.8$  years.

(c) Carrying capacity falls (less food). Numbers above the new  $K$  will decline through starvation and disease, and the population may drop below it.

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**EXAMPLE 4: COMPARING TWO COUNTRIES**

Country A: CBR 36, CDR 12, infant mortality 60 per 1,000. Country B: CBR 10, CDR 11, immigration 3 and emigration 1 per 1,000. (a) Calculate each growth rate. (b) Find A's doubling time. (c) Assign demographic transition stages and predict each age structure.

| Country | CBR | CDR | Immigration | Emigration |
|---------|-----|-----|-------------|------------|
| A       | 36  | 12  | 0           | 0          |
| B       | 10  | 11  | 3           | 1          |

**SOLUTION**

(a) A:  $(36 - 12)/10 = 2.4\%$ . B: natural increase  $(10 - 11)/10 = -0.1\%$ ; with migration  $[(10 + 3) - (11 + 1)]/10 = +0.1\%$ , so B grows only through immigration.

(b)  $70/2.4 = 29.2$  years.

(c) A is stage 2: rapid growth, high infant mortality and a wide-based age structure. B is stage 4 or later: low birth and death rates and a narrow base with a large older population.

**Write It Like a 5****Model Response**

Prompt: A country has a wide-based age structure diagram and a total fertility rate of 4.2. Predict its population trend and explain why the population would keep growing even if the TFR dropped to replacement level. The wide base means a large share of the population is under 15, so many people will enter the reproductive years and have children; the population will grow rapidly. Even if TFR fell to the replacement level of about 2.1, this large cohort of young people would still reach childbearing age, so births would exceed deaths for decades. This is population momentum. Education for girls and access to family planning would lower TFR and slow later growth.

**What the grader looks for**

(1) Predicts growth and ties it to the wide base. (2) Names population momentum (or describes a large pre-reproductive cohort). (3) Explains with births exceeding deaths. (4) Gives a specific, realistic factor lowering fertility. Saying growth stops immediately at replacement TFR loses the key point.

**Coach's Playbook**

- ◆ For growth-rate questions, write the formula, substitute with units, divide by 10, then apply  $70/\text{rate}$ ; add to the start year if asked for a year.
- ◆ Check whether the problem includes migration. Natural increase never includes it.
- ◆ For survivorship, compare the percent dying in each interval; the steepest early drop is Type III.
- ◆ For curves, label K, the lag, the steep middle and the plateau.

**Common traps**

1) Forgetting to divide the CBR minus CDR by 10, giving 18% instead of 1.8%. 2) Giving the doubling time (39 years) when the question asks for the year. 3) Calling Type I the 'large animal' curve; it is the pattern of high early survival. 4) Calling a density-independent factor (fire, flood) density-dependent, or saying K never changes.

**Quick Check**

Q: A population grows 2.0% per year. Doubling time? A:  $70/2.0 = 35$  years. Q: Which survivorship type has the most deaths at young ages? A: Type III. Q: Is disease density-dependent or density-independent? A: Density-dependent.

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### Challenge Corner

For logistic growth with  $r = 0.5$  per year and  $K = 1,000$ , compute the population increase per year at  $N = 250, 500$  and  $900$  using  $rN(1 - N/K)$ , and explain the pattern.  $N = 250: 0.5 \times 250 \times 0.75 = 93.75$ .  $N = 500: 0.5 \times 500 \times 0.5 = 125$ .  $N = 900: 0.5 \times 900 \times 0.1 = 45$ . Growth is greatest at  $K/2 = 500$ . Near  $K$  the factor  $(1 - N/K)$  approaches zero, so growth slows: this is environmental resistance. (The exam does not require this formula.)

## Practice

### PRACTICE Unit 3 Practice

Show your work. A calculator is allowed. Justify conclusions.

- Oysters release millions of larvae, most of which die within days, but those that settle and grow often live for many years. This pattern is best described as  
 (A) Type I survivorship and K-selected  
 (B) Type II survivorship and K-selected  
 (C) Type III survivorship and r-selected  
 (D) Type I survivorship and r-selected
- Which set of traits best describes a K-selected species?  
 (A) Few offspring, extensive parental care, late maturity, long life  
 (B) Many offspring, little care, early maturity, short life  
 (C) Many offspring, extensive care, late maturity, short life  
 (D) Few offspring, no care, early maturity, population far below  $K$
- A country has a CBR of 18 and a CDR of 8 per 1,000 and no net migration. What is its growth rate and approximate doubling time?  
 (A) 10% and 7 years  
 (B) 0.1% and 700 years  
 (C) 2.6% and 27 years  
 (D) 1.0% and 70 years

- Which is a density-dependent limiting factor on a deer herd?  
 (A) A wildfire  
 (B) Disease that spreads faster as the herd becomes crowded  
 (C) An unusually early frost  
 (D) A flood

- The table shows age structure and TFR for three countries. If there is no migration, which country is most likely to see its population shrink soonest?

| Country | Under 15 | 15-44 | 45 and over | TFR |
|---------|----------|-------|-------------|-----|
| P       | 40%      | 40%   | 20%         | 4.1 |
| Q       | 22%      | 38%   | 40%         | 2.0 |
| R       | 15%      | 36%   | 49%         | 1.3 |

- Country P  
 (A) Country P  
 (B) Country Q  
 (C) Country R  
 (D) All three, because TFR values are low
- In the demographic transition, population growth is fastest in stage 2 because  
 (A) death rates fall while birth rates remain high  
 (B) birth rates fall while death rates remain high  
 (C) both rates are low  
 (D) death rates exceed birth rates
- A student suspects that crowding lowers the survival of seedlings.  
 (a) State a hypothesis with the independent and dependent variables.  
 (b) Describe an experiment with five plant densities and replicates, including a control and two constants.  
 (c) Predict the result and justify using density-dependent factors.  
 (d) Identify a density-independent factor that could confound the study if it affected only some plots.

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8. A country has 24 million people, a CBR of 31, a CDR of 7, immigration of 2 and emigration of 6 per 1,000 people per year.
  - (a) Calculate the rate of natural increase.
  - (b) Calculate the overall growth rate including migration.
  - (c) Using the overall growth rate, calculate the doubling time and the year the population reaches 48 million, if the starting year is 2027.
  - (d) How many people does the country add in the first year at the overall rate?
9. Survivors per 1,000 hatched or born. Species M at ages 0, 1, 2, 5, 10, 15 years: 1000, 50, 38, 28, 18, 8. Species N at the same ages: 1000, 970, 950, 900, 700, 250.
  - (a) Identify the survivorship type of each.
  - (b) Calculate the percent mortality in the first year for each.
  - (c) Which species is more likely K-selected? Give two supporting traits.
  - (d) Explain why the loss of adults hurts species N's population more.
10. Deer were introduced to an island. Population by year (0, 5, 10, 15, 20, 25, 30, 35, 40): 20, 60, 190, 520, 880, 1010, 960, 1000, 990.
  - (a) Estimate the carrying capacity.
  - (b) During which 5-year period did the population increase most, and by how much?
  - (c) Calculate the percent change in population from year 0 to year 10.
  - (d) Explain why growth slowed after year 20 and identify one density-dependent and one density-independent factor.

## Answers Unit 3: Answers and Explanations

Read every explanation, including the ones for problems you answered correctly.

### 3 Populations

#### PRACTICE · UNIT 3 PRACTICE

1. C. Very high early mortality with few survivors that then live long is a Type III curve, associated with r-selected species with many offspring. Choice A is the tempting one because long adult life sounds K-selected.
2. A. K-selected species have few offspring with extensive care, mature late and live long. Choice B describes r-selected species, and C and D mix the two sets.
3. D.  $(18 - 8)/10 = 1.0\%$  per year and  $70/1.0 = 70$  years. Choice A forgets to divide by 10. Choice C adds the rates instead of subtracting.
4. B. Disease transmission rises with crowding, so it is density-dependent. Fire, early frost and flood (A, C, D) act regardless of density.
5. C. Country R has the fewest children, so the fewest future parents, and a TFR of 1.3 is far below replacement. Country P has high TFR and a wide base, and Q is near replacement.
6. A. In stage 2 sanitation, medicine and food supply cut death rates while cultural change in birth rates lags, so the gap is largest. Choice B describes the pattern in stage 3.
7. (a) If seedling density increases, then the percent of seedlings surviving 8 weeks decreases. IV: density; DV: percent survival. (b) Plant five densities (such as 5, 10, 20, 40, 80 per plot) with 4 replicate plots each; the lowest density serves as the baseline. Keep soil type, water, light and plot size constant. (c) Survival declines as density rises, because crowded seedlings compete for light, water and nutrients and disease spreads more easily; these effects intensify with density. (d) A frost, flood or fire that hit only some plots would be density-independent and would confound the results.
8. (a)  $(31 - 7)/10 = 2.4\%$  per year. (b)  $[(31 + 2) - (7 + 6)]/10 = 20/10 = 2.0\%$  per year. (c)  $70/2.0 = 35$  years;  $2027 + 35 = 2062$ . (d)  $24,000,000 \times 0.020 = 480,000$  people.
9. (a) M: Type III (95% die in year 1, then few die). N: Type I (high survival until old age). (b) M:  $(1000 - 50)/1000 \times 100 = 95\%$ . N:  $(1000 - 970)/1000 \times 100 = 3\%$ . (c) Species N: few offspring that receive care and long adult life (late-life mortality). (d) N invests in few young and has slow reproduction, so removing adults reduces reproduction that cannot be quickly replaced; M compensates with many offspring.
10. (a) K is about 1,000 deer (the plateau). (b) Increases per 5 years: 40, 130, 330, 360, 130. The greatest increase was years 15-20, +360 deer. (c)  $(190 - 20)/20 \times 100 = 850\%$  increase. (d) Environmental resistance increased as the herd neared K (less food per deer). Density-dependent: competition for food, disease. Density-independent: a storm, drought or fire.

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# Unit 4: Earth Systems and Resources

Exam weighting: about 10-15% of the multiple-choice section. Concept review, worked examples, exam-style writing, and 10 practice items, all with full explanations.

## 4 Earth Systems and Resources

Plate tectonics, soil, atmosphere, winds, watersheds, seasons, climate, and ENSO: the physical systems behind every environmental problem.

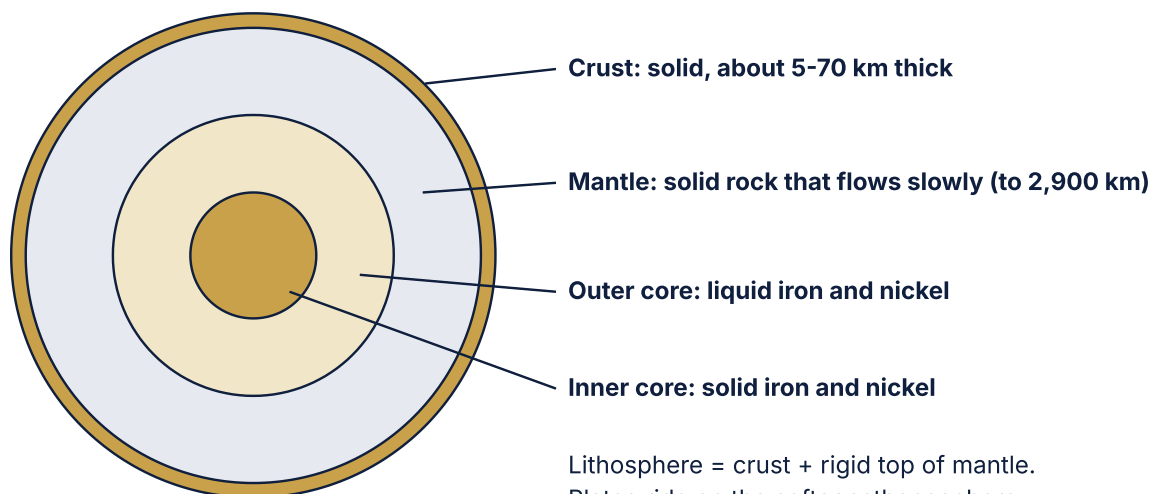
### Why This Matters

Unit 4 carries about 10-15% of the multiple-choice score and supplies the physical background for nearly every other unit: soil decides what farms can do, winds and ocean patterns decide where rain falls, and plate tectonics decides where hazards sit. Points are lost on look-alike vocabulary (weathering versus erosion, El Nino versus La Nina) and on facts stated without a mechanism.

### Core Ideas

#### Plate Tectonics

Earth has a solid **crust**, a slowly flowing **mantle**, a liquid **outer core**, and a solid **inner core**. The rigid **lithosphere** (crust plus uppermost mantle) is broken into plates that move a few centimeters per year on the softer **asthenosphere**, driven by heat from the interior. Most earthquakes and volcanoes occur along plate boundaries, such as the Pacific Ring of Fire. Hot spots (Hawaii) lie in plate interiors and leave an island chain as the plate moves over a fixed plume.

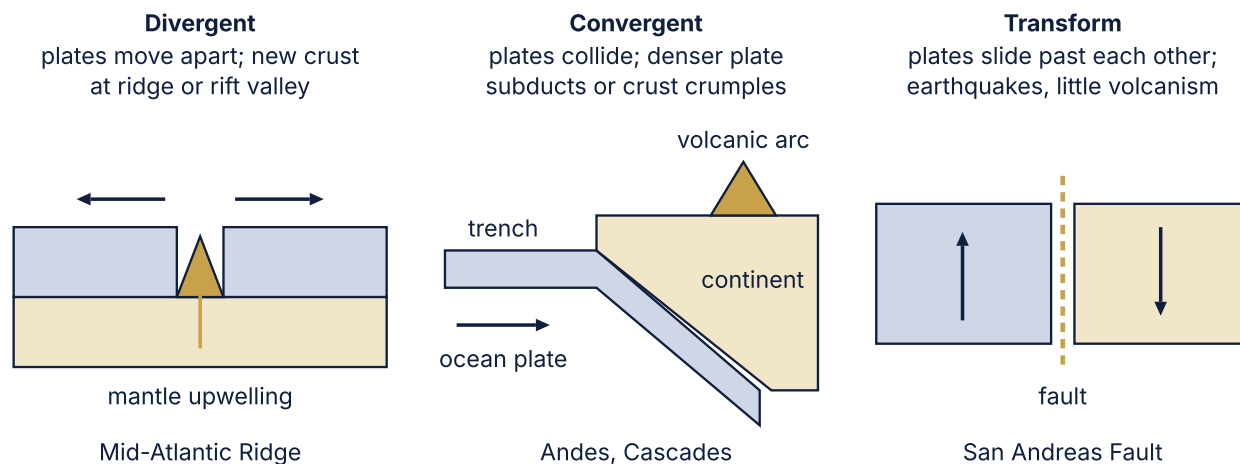


Earth's layers (crust drawn thicker than true scale).

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Three boundary types (side views for divergent and convergent, top view for transform).

### Boundary Types

**Divergent:** plates separate, magma rises, new crust forms (mid-ocean ridge, rift valley).

**Convergent:** ocean-continent makes a trench and volcanic arc; ocean-ocean makes an island arc; continent-continent makes folded mountains with no subduction volcanoes (Himalayas).

**Transform:** plates slide sideways; strong earthquakes, no new crust (San Andreas).

### Soil Formation and Erosion

Soil forms when **weathering** (physical, chemical, biological) breaks **parent material** into particles and organisms add organic matter. A few centimeters can take hundreds of years. **Erosion** is the transport of soil by wind or water; weathering breaks material down but does not move it. Vegetation roots and cover slow erosion; tilling, overgrazing, and clearing speed it. Soil conservation uses cover crops, windbreaks, terracing, contour plowing, and no-till planting.

|          |                                                      |
|----------|------------------------------------------------------|
| <b>O</b> | Organic litter, partly decomposed                    |
| <b>A</b> | Topsoil: humus plus minerals, most roots and life    |
| <b>E</b> | Leached layer (eluviation); pale, not always present |
| <b>B</b> | Subsoil: clay and minerals accumulate (illuviation)  |
| <b>C</b> | Weathered parent material, little life               |
| <b>R</b> | Bedrock                                              |

Soil profile (horizon thickness varies; E is often missing).

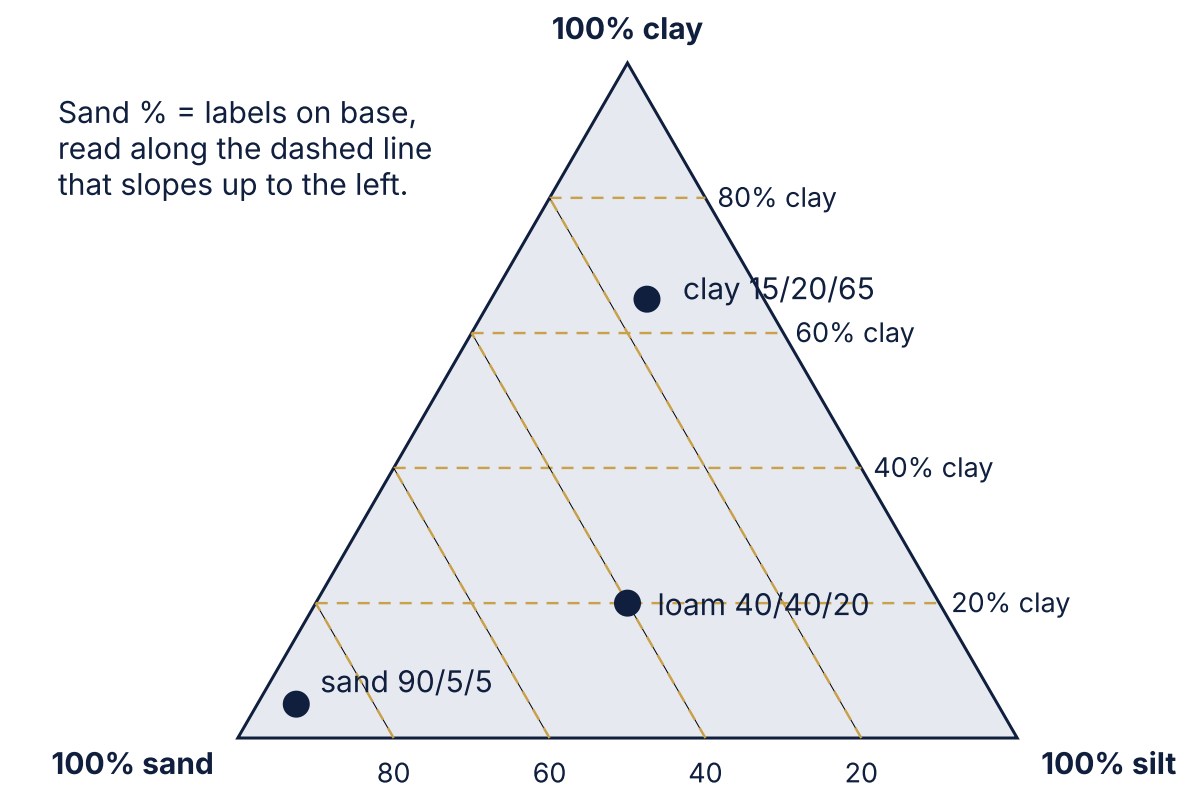
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Soil Composition and Properties

Mineral particles are **sand** (0.05-2 mm), **silt** (0.002-0.05 mm), and **clay** (under 0.002 mm). **Texture** is the percent of each, read on the soil texture triangle; **loam** is a blend of the three, favored for many crops. Soil also holds organic matter (humus), water, and air. Texture controls pore size, which controls **permeability** (how fast water moves through) and **water-holding capacity**.



Texture triangle idea: any mix of sand, silt, and clay (percent, sums to 100) is one point; labels read sand/silt/clay.

| Property                   | Sandy soil | Clayey soil  | Loam     |
|----------------------------|------------|--------------|----------|
| Pore size                  | Large      | Very small   | Mixed    |
| Infiltration and drainage  | Fast       | Slow         | Moderate |
| Water and nutrient holding | Low        | High         | Good     |
| Aeration                   | High       | Low when wet | Good     |

Earth's Atmosphere

Dry air is about 78% nitrogen, 21% oxygen, 0.9% argon, and about 0.04% carbon dioxide, plus variable water vapor (up to about 4%).

| Layer        | Approx. altitude | Key features                                          |
|--------------|------------------|-------------------------------------------------------|
| Troposphere  | 0-12 km          | Weather; temperature falls with height; most air mass |
| Stratosphere | 12-50 km         | Ozone layer absorbs UV; temperature rises with height |
| Mesosphere   | 50-85 km         | Temperature falls; meteors burn up                    |
| Thermosphere | above 85 km      | Very thin; temperature rises; auroras                 |

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## Global Wind Patterns

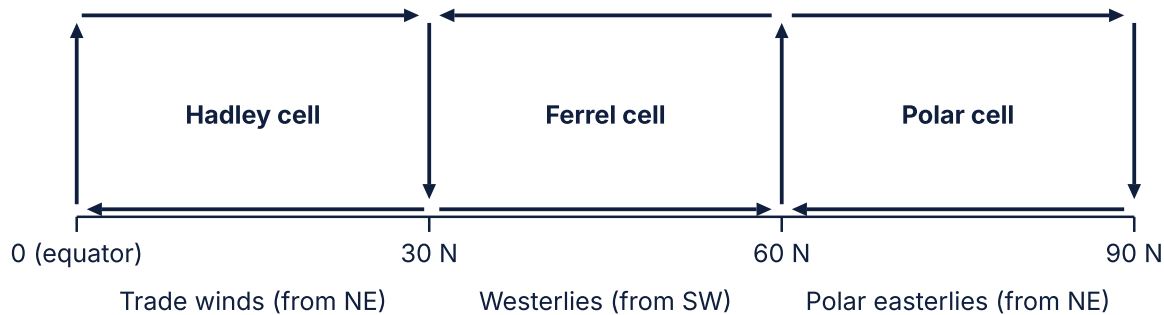
### Northern Hemisphere, side view of the troposphere

ITCZ: rising air,  
heavy rain

sinking dry air:  
deserts

rising air:  
rain

sinking cold air  
(polar desert)



Three circulation cells; surface winds are named for the direction they come FROM (Coriolis deflects them right in the north).

Solar heating is strongest at the equator, so warm moist air rises at the **ITCZ**, cools, and drops heavy rain (tropical rainforests). The dry air sinks near 30 degrees latitude, forming deserts. The **Coriolis effect**, caused by Earth's rotation, bends moving air to the right in the Northern Hemisphere and to the left in the Southern, producing the trade winds, westerlies, and polar easterlies. Wind-driven **upwelling** brings cold, nutrient-rich water to the surface.

## Watersheds

A **watershed** is all the land that drains to one outlet; **divides** (ridges) separate neighboring watersheds. Whatever happens upslope (fertilizer, paving, logging) reaches the stream. Impermeable surfaces cut infiltration, so runoff rises, peaks arrive sooner, and flooding increases.

## Solar Radiation and Earth's Seasons

### Why We Have Seasons

Earth's axis is tilted **23.5 degrees**. The hemisphere tilted toward the sun gets more direct rays and longer days, so it is summer there.

Distance to the sun is **not** the cause; Earth is slightly nearest the sun in early January.

At the equinoxes the sun is directly over the equator and day equals night everywhere; at solstices it is over 23.5 degrees N or S.

Insolation is greatest at the equator: sunlight arrives nearly perpendicular, crosses less atmosphere, and is not spread over a large area. **Albedo** (reflectivity) is high for ice and snow, low for dark ocean and forest.

## Earth's Geography and Climate

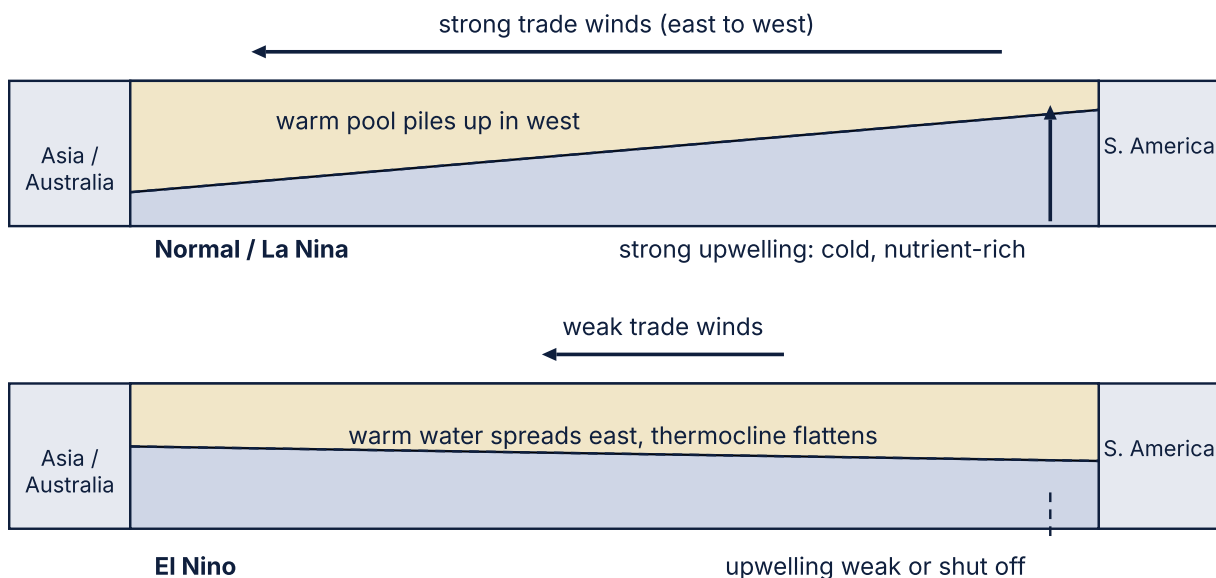
- ◆ **Latitude:** sets insolation and the belts above.
- ◆ **Altitude:** air cools about 6.5 degrees C per km of elevation.
- ◆ **Rain shadow:** moist wind rises over mountains (orographic lift), cools, and rains on the windward side; the leeward side is dry (Nevada).
- ◆ **Ocean currents and proximity to water:** water changes temperature slowly, so coasts have milder climates than continental interiors; warm and cold currents shift coastal climates.

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## El Nino and La Nina



Equatorial Pacific cross-section. La Nina is a stronger version of the normal pattern; El Nino weakens it.

**El Nino-Southern Oscillation (ENSO)** is a shift in Pacific conditions every 2-7 years. In El Nino the trade winds weaken, warm water spreads east, and upwelling off South America drops, so nutrient supply and anchovy catches fall; Indonesia and Australia tend toward drought, and Peru and the southern United States toward heavy rain. La Nina brings stronger trade winds, cooler eastern Pacific surface water, strong upwelling, and the opposite rainfall shifts. La Nina means cooler-than-average water, not El Nino.

## Worked Examples

### EXAMPLE 1: PLATE MOTION

Two coastlines now 3,000 km apart separate at a combined 2.5 cm per year. When were they in contact?

#### SOLUTION

Convert:  $3,000 \text{ km} \times 10^5 \text{ cm/km} = 3 \times 10^8 \text{ cm}$ .

Time =  $\frac{3 \times 10^8 \text{ cm}}{2.5 \text{ cm/yr}} = 1.2 \times 10^8 \text{ years}$ .

They were joined about 120 million years ago (constant rate assumed).

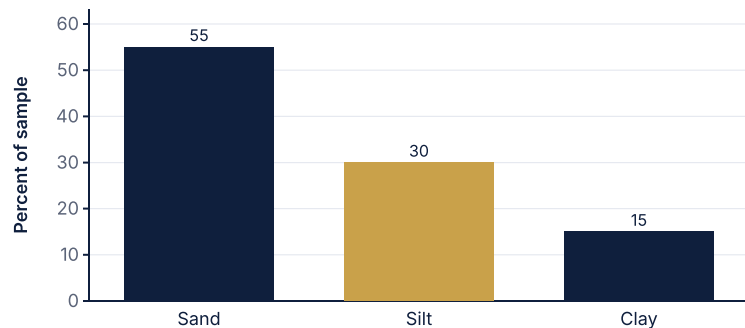
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**EXAMPLE 2: SOIL TEXTURE**

An 80 g dried soil sample separated into 44 g sand, 24 g silt, and 12 g clay. Find the percents, classify the soil on the triangle, and predict drainage compared with loam.



Texture composition

**SOLUTION**

Sand  $44/80 = 55\%$ , silt  $24/80 = 30\%$ , clay  $12/80 = 15\%$ ; sum 100%.

With clay under 20% and sand above 52%, the texture is **sandy loam**.

Prediction: more sand means larger pores, so faster drainage and less water held than loam.

**EXAMPLE 3: WATERSHED RUNOFF**

A storm drops 18 mm of rain on a  $25 \text{ km}^2$  watershed. Before development 30% of rain runs off. After development 45% runs off. Find the runoff volume before and after, and the percent increase.

**SOLUTION**

Rain volume =  $0.018 \text{ m} \times 25 \times 10^6 \text{ m}^2 = 4.5 \times 10^5 \text{ m}^3$ .

Before:  $0.30 \times 4.5 \times 10^5 = 1.35 \times 10^5 \text{ m}^3$ . After:  $0.45 \times 4.5 \times 10^5 = 2.0 \times 10^5 \text{ m}^3$  (202,500).

Percent increase =  $\frac{(202,500 - 135,000)}{135,000} \times 100 = 50\%$  increase, because less water infiltrates impermeable surfaces.

**EXAMPLE 4: READING ENSO DATA**

Use the table. (a) Classify each year. (b) Find the percent change in catch from year 1 to year 3.

| Year | East Pacific temp. anomaly (C) | Anchovy catch (million t) |
|------|--------------------------------|---------------------------|
| 1    | +0.1                           | 9.0                       |
| 2    | -1.2                           | 10.4                      |
| 3    | +1.8                           | 6.3                       |

**SOLUTION**

(a) Year 1: anomaly +0.1 is near neutral. Year 2: -1.2 means cooler than average, La Nina. Year 3: +1.8 means warmer, El Nino.

(b)  $\frac{(6.3 - 9.0)}{9.0} \times 100 = -30\%$ , a 30% decrease.

Reason: weaker upwelling means fewer nutrients, so lower productivity.

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## Write It Like a 5

### Model Response

Prompt: A coastal city sits where a plate boundary runs offshore, with a mountain range 60 km inland. Identify the boundary and explain two consequences. Response: The pattern is a convergent boundary where a denser oceanic plate subducts beneath the continental plate. Subduction creates an offshore trench and, as the sinking plate melts, magma rises to build a line of volcanoes inland, which explains the range. Stress along the boundary releases as strong earthquakes and tsunamis, so the city could enforce seismic building codes and restrict low-lying coastal construction.

### What the grader looks for

Correct boundary type with the direction of motion; the mechanism (density, subduction, melting); two distinct consequences stated with because; a realistic policy solution rather than stopping the hazard.

## Coach's Playbook

- 1 **Name the process.** Weathering, erosion, deposition, and infiltration are different steps.
- 2 **Add the mechanism.** Say what changes, then the result.
- 3 **Show direction.** State increase or decrease, with units.
- 4 **Do the setup.** Write the unit conversion before the arithmetic.

### Common traps

1) Writing that seasons come from distance to the sun. 2) Calling El Nino the cool phase. 3) Saying clay drains fast because it is fine; small pores mean slow drainage. 4) Describing wind direction by where it blows to rather than from.

### Quick Check

Q: Which soil horizon holds most humus? A: The A horizon (topsoil). Q: Which boundary produces the Himalayas? A: Convergent, continent-continent. Q: What drives upwelling off Peru? A: Trade winds pushing surface water west.

### Challenge Corner

Island X sits on an active hot spot; chain island Y is 450 km away on the same plate and is 6.0 million years old. (a) Find the plate speed in cm per year. (b) Predict the age of island Z, 750 km from X. Solution: (a)  $450 \text{ km} = 4.5 \times 10^7 \text{ cm}$ ;  $4.5 \times 10^7 / 6.0 \times 10^6 = 7.5 \text{ cm/yr}$ . (b)  $7.5 \times 10^7 \text{ cm} / 7.5 = 1.0 \times 10^7 \text{ years}$ , 10 million years old.

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## Practice

### PRACTICE Unit 4 Practice

Show your work. A calculator is allowed. Justify conclusions.

- Two continental plates collide along a boundary. Which description is correct?
  - New crust forms as the plates move apart, with a rift valley
  - Folded mountains form and subduction volcanoes are rare
  - The plates slide sideways and create no mountains
  - A deep ocean trench and a volcanic arc form
- Use the table. Rain falls at 30 mm per hour for 2 hours. Which soil produces the most surface runoff?

| Soil | Texture | Infiltration (mm/h) |
|------|---------|---------------------|
| X    | Sand    | 150                 |
| Y    | Loam    | 25                  |
| Z    | Clay    | 2                   |

- Sand, because its large pores fill quickly
  - Loam, because it has mixed particle sizes
  - Sand and loam equally, because both are coarse
  - Clay, because infiltration is far slower than the rainfall rate
- Which statement best explains why the Northern Hemisphere has summer in June?
    - It is tilted toward the sun, so it receives more direct light and longer days
    - Earth is closest to the sun in June
    - The sun gives off more energy in June
    - Earth's rotation speeds up in June
  - Why are many large deserts near 30 degrees latitude?
    - Warm air rises there and cools, dropping heavy rain
    - Trade winds carry all moisture to the poles
    - Air that sinks there warms and is already dry from losing moisture near the equator
    - Mountains block all rain at that latitude
  - A map shows cooler-than-average surface water in the eastern equatorial Pacific and strong trade winds. Which is expected?
    - El Nino, with reduced upwelling off South America
    - La Nina, with strong upwelling and productive fisheries off South America
    - La Nina, with warm water piling up near Peru
    - El Nino, with stronger trade winds
  - A parking lot replaces forest in a watershed. What is the most likely effect on the stream?
    - Higher, earlier flood peaks and less groundwater recharge
    - Lower peak flow because water spreads out
    - No change, since the total rainfall is the same
    - Slower runoff because pavement is smooth
  - Design an investigation of how soil texture affects the amount of water a soil holds.
    - State a testable hypothesis naming the independent and dependent variables.
    - Describe the procedure and list three variables you would control.
    - Explain how you would make the results reliable.
  - A hillside field loses soil at 12 t per hectare per year. Soil bulk density is 1.3 t per cubic meter and 1 ha = 10,000 square meters.
    - Calculate the depth lost per year in mm.
    - How many years until 5 cm of topsoil is gone?
    - Contour plowing and cover crops cut the loss to 4.2 t/ha/yr. Calculate the percent decrease and the total soil saved on an 80 ha farm per year.

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9. Use the data: El Nino years had Peruvian anchovy catches of 4.1, 3.6 and 5.0 million t; neutral years averaged 9.0 million t.
  - (a) Calculate the percent change in the mean El Nino catch from the neutral mean.
  - (b) Explain the mechanism linking El Nino to the catch.
  - (c) Identify one weather effect of El Nino elsewhere.
10. A town lies 150 km inland of a deep ocean trench, below a chain of volcanoes.
  - (a) Identify the boundary type and explain why the volcanoes form.
  - (b) Name one hazard the town faces.
  - (c) Propose a local government action to reduce risk and give one added benefit.

## Answers Unit 4: Answers and Explanations

Read every explanation, including the ones for problems you answered correctly.

### 4 Earth Systems and Resources

#### PRACTICE · UNIT 4 PRACTICE

1. B. In continent-continent collision neither plate subducts easily, so crust folds into mountains and subduction volcanoes are rare. Choice D describes ocean-continent convergence, the tempting error.
2. D. Rain at 30 mm/h exceeds clay's 2 mm/h infiltration by 28 mm/h, so about 56 mm of the 60 mm runs off over 2 hours. Loam would shed only 10 mm and sand none, and the idea that fine particles drain well is a mistake.
3. A. The tilt of Earth's axis aims the northern half toward the sun in June, giving higher sun angle and longer days. Choice B is the common error; Earth is nearest the sun in January.
4. C. Air rising at the equator loses moisture as rain, then sinks near 30 degrees, warming by compression so humidity falls. Choice A confuses the sinking cell with the rising one at the ITCZ.
5. B. Cooler water in the east and strong trades are La Nina, which strengthens upwelling and nutrient supply. Choice A names the warm phase, the typical mix-up.
6. A. Impermeable surfaces reduce infiltration, so more runoff reaches the stream faster, raising peaks and cutting recharge. Choice D wrongly focuses on smoothness rather than lost infiltration.
7. (a) Hypothesis: If soil has a higher percent clay, then it will hold more water per kg of dry soil. IV: soil texture (percent sand/silt/clay). DV: mass or volume of water retained.  
 (b) Dry equal masses of sand, loam, and clay in identical funnels with filters; pour the same volume of water at the same temperature; collect drainage for a set time; water held = poured minus drained. Controlled: soil mass, water volume, funnel size, time, packing, temperature.  
 (c) Repeat each soil with at least 3 trials and average, use the same measuring tool, and compare to a no-soil control.
8. (a) Volume =  $12/1.3 = 9.23$  m<sup>3</sup> per ha; depth =  $9.23/10,000 = 9.2 \times 10^{-4}$  m = 0.92 mm/yr.  
 (b)  $50 \text{ mm}/0.923 \text{ mm/yr} \approx 54$  yr (about 54 years).  
 (c) Percent decrease =  $\frac{12-4.2}{12} \times 100 = 65\%$  decrease. Saved:  $(12 - 4.2) \times 80 = 624$  t per year.
9. (a) Mean =  $(4.1 + 3.6 + 5.0)/3 = 4.23$  million t. Change =  $\frac{4.23-9.0}{9.0} \times 100 = -53\%$  (a 53% decrease).  
 (b) Weakened trade winds reduce upwelling, so less cold nutrient-rich water reaches the surface; phytoplankton fall and anchovy lose their food.  
 (c) Heavy rain and flooding in Peru or the southern United States, or drought in Indonesia and Australia.
10. (a) Convergent boundary: a denser oceanic plate subducts beneath the continent; the sinking plate releases water and melts, and the magma rises to form a volcanic arc.  
 (b) Earthquake or volcanic eruption (ash, lahars).  
 (c) Adopt seismic building codes and zone out construction in lahar valleys; benefit: fewer deaths and lower repair costs, or an evacuation plan that also helps with floods.

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# Unit 5: Land and Water Use

Exam weighting: about 10-15% of the multiple-choice section. Concept review, worked examples, exam-style writing, and 10 practice items, all with full explanations.

## 5 Land and Water Use

Commons, forests, farming, irrigation, pests, meat, fish, mining, cities, footprints, and the practices that make each more sustainable.

### Why This Matters

Unit 5 carries about 10-15% of the multiple-choice score and feeds the solution parts of the free-response questions: you are often asked to name a realistic practice, justify it, and add a benefit. Points are lost to vague answers ("use less water") and to confusing a practice with its impact.

### Core Ideas

#### The Tragedy of the Commons

When many users share an open-access resource (pasture, fishery, air, groundwater), each gains fully from using more but shares the cost of damage, so the resource is overused. Solutions are regulation (quotas, permits, fees), privatization or community management with enforced rules, and education.

#### Clearcutting

**Clearcutting** removes all trees. It is cheap and fast, and suits species that need full sun, but it increases erosion, stream sedimentation, nutrient loss, and flooding, destroys habitat, raises soil temperature, and releases stored carbon. Alternatives are selective cutting, shelterwood, and strip cutting.

#### The Green Revolution

Beginning in the mid-1900s, high-yield varieties, synthetic fertilizer, pesticides, irrigation, and machinery greatly raised yields per hectare and cut hunger. Costs include fertilizer runoff and eutrophication, high water and fossil fuel use, soil degradation, pesticide resistance, loss of crop genetic diversity, and expensive inputs that small farmers struggle to afford.

#### Impacts of Agricultural Practices

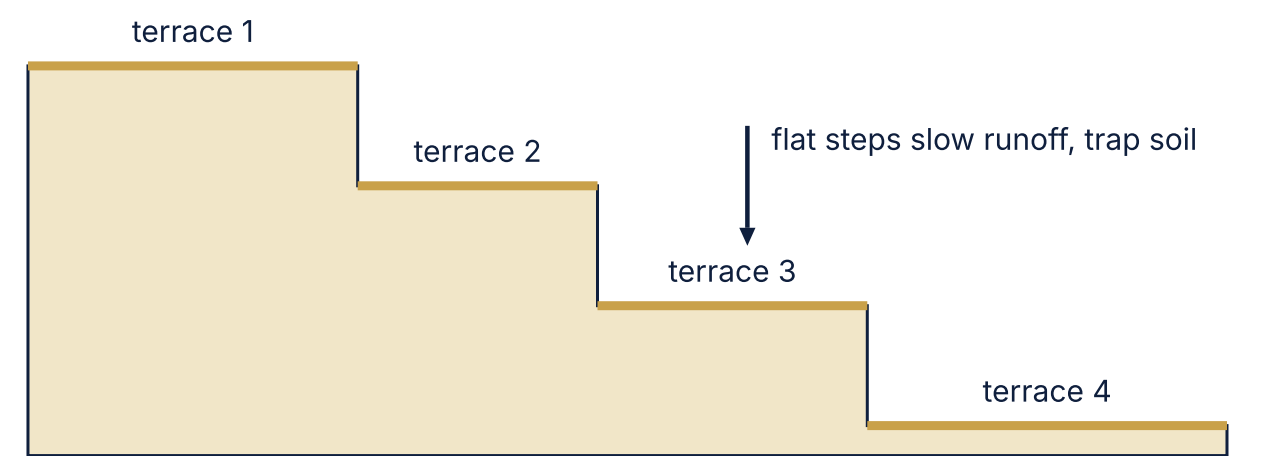
**Tilling** breaks soil and speeds erosion and loss of soil carbon. **Slash-and-burn** clears land quickly but exposes soil and releases CO<sub>2</sub>. **Monocultures** raise pest risk. **Overgrazing** removes cover. **Fertilizer** and **manure** cause nutrient runoff. Soil conservation counters these:

- ◆ **Conservation (no-till) tillage:** leaves residue, cuts erosion, keeps soil carbon.
- ◆ **Contour plowing and terracing:** rows or steps along elevation lines slow runoff.
- ◆ **Cover crops, crop rotation, strip cropping, windbreaks:** keep roots and cover on soil; legume rotation adds nitrogen.

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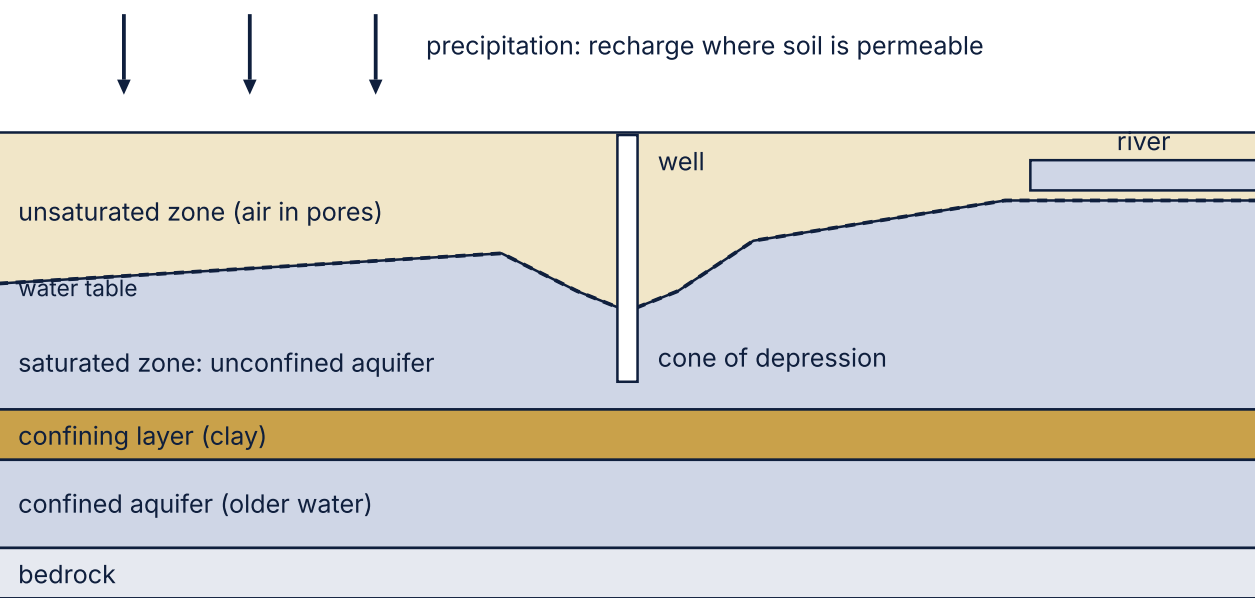
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Terracing converts a steep slope into level steps; contour plowing follows the same idea with rows along elevation lines.

Irrigation Methods

Agriculture uses about 70% of global freshwater consumption. Over-irrigation raises the water table (waterlogging) and leaves salts as water evaporates (**salinization**), which lowers yields. Heavy pumping of aquifers (see diagram) lowers water tables.



Aquifer cross-section. Pumping faster than recharge lowers the water table; over-pumping causes drying wells, land subsidence, and (on coasts) saltwater intrusion.

**Irrigation Math**

Volume = depth x area; 1 mm over 1 ha = 10 m³.

Water drawn =  $\frac{\text{water needed by crop}}{\text{efficiency (as a decimal)}}$ ; lower efficiency means more water drawn.

| Method               | Typical efficiency | Pros                                   | Cons                              |
|----------------------|--------------------|----------------------------------------|-----------------------------------|
| Flood / furrow       | about 60%          | Cheap, simple                          | Evaporation, runoff, salinization |
| Spray (center-pivot) | about 75%          | Even coverage, less labor              | Energy for pumping, wind drift    |
| Drip / micro         | about 90%          | Water goes to roots, less salt buildup | High cost, clogging               |

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## Pest Control Methods

| Type       | Example                    | Limit                                |
|------------|----------------------------|--------------------------------------|
| Chemical   | Synthetic pesticide        | Resistance, non-target kills, runoff |
| Biological | Ladybugs, Bt               | Slow; can become invasive            |
| Cultural   | Rotation, planting dates   | Needs planning                       |
| Physical   | Traps, row covers, tilling | Labor                                |

Repeated spraying selects for resistant pests, forcing stronger doses (the **pesticide treadmill**). Pesticides do not cause eutrophication; fertilizer does.

## Meat Production Methods

**Feedlots and CAFOs** crowd animals on grain, giving fast weight gain and low land use per animal but heavy feed demand, manure lagoons, antibiotics, methane, and water pollution. **Pasture-based** systems use less grain but need more land, and **overgrazing** removes cover, compacts soil, and can lead to desertification. Eating lower on the food chain needs less land and water, since about 10% of energy passes up each level.

## Impacts of Overfishing

Catching fish faster than stocks reproduce collapses populations. Drift nets, longlines, and bottom trawling cause **bycatch** and seafloor damage. Responses: quotas, size and gear limits, closed seasons, marine protected areas, and consumer certification.

## Impacts of Mining

**Surface mining** (strip, open-pit, mountaintop removal) strips vegetation and soil; **subsurface mining** is dangerous and can collapse. Both create tailings, dust, and **acid mine drainage**, where sulfide minerals form sulfuric acid that carries metals into streams. Reclamation regrades land and replants; laws require bonds for cleanup.

## Impacts of Urbanization

Cities replace soil with **impermeable surfaces**, so infiltration falls, runoff and flood peaks rise, and groundwater recharge declines. Dark surfaces cause the **urban heat island**. Sprawl fragments habitat and raises vehicle use.

## Ecological Footprints

### Ecological Footprint

The land and water area (global hectares) needed to supply a person's resources and absorb their waste.

**Overshoot ratio** =  $\frac{\text{footprint}}{\text{biocapacity}}$ . A value above 1 means demand exceeds regeneration (an ecological deficit).

## Introduction to Sustainability

**Sustainability** means meeting present needs without compromising future generations' ability to meet theirs, balancing environmental, economic, and social needs. Using a renewable resource at or below its **sustainable yield** keeps it available.

## Methods to Reduce Urban Runoff

Raise infiltration or hold water back: **permeable pavement**, **green roofs**, **rain gardens and bioswales**, **retention basins**, and vegetated buffers by streams. Each also filters pollutants; green roofs add insulation. Avoid unrealistic answers such as gravel roads.

## Integrated Pest Management

**IPM** combines monitoring, an action threshold, biological and cultural controls, resistant crops, and targeted, minimal pesticide. It lowers cost, resistance, and pollution.

## Sustainable Agriculture

Rotation, intercropping, cover crops, conservation tillage, agroforestry, perennial crops, drip irrigation, IPM, organic nutrients, and reducing food waste maintain soil, water, and yields.

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## Aquaculture

Fish farming eases pressure on wild stocks and uses feed efficiently, but pens release waste and antibiotics, spread disease, and allow escapees; coastal ponds can destroy mangroves, and carnivorous fish are fed wild-caught fish. Recirculating and integrated systems reduce these effects.

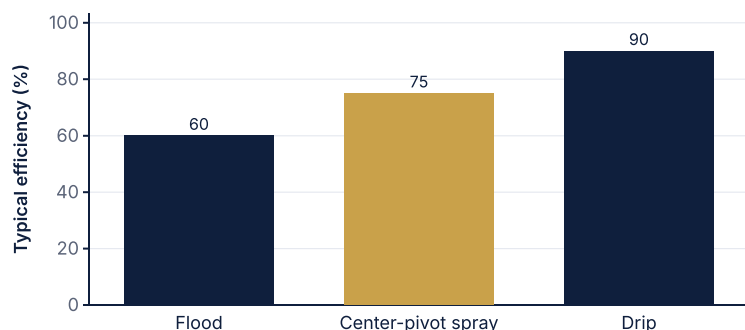
## Sustainable Forestry

Selective cutting, longer rotations, reduced-impact logging, replanting, protecting streamside buffers and old growth, and certified wood keep forests productive and limit erosion.

## Worked Examples

### EXAMPLE 1: IRRIGATION WATER

A 40 ha field needs 600 mm of water per season delivered to the roots. Compare water drawn using flood (60% efficient) and drip (90% efficient) irrigation.



Share of applied water that reaches crop roots (typical values)

#### SOLUTION

Needed volume =  $0.60 \text{ m} \times 40 \times 10^4 \text{ m}^2 = 2.4 \times 10^5 \text{ m}^3$ .

Flood:  $2.4 \times 10^5 / 0.60 = 4.0 \times 10^5 \text{ m}^3$ . Drip:  $2.4 \times 10^5 / 0.90 = 2.67 \times 10^5 \text{ m}^3$ .

Savings =  $1.33 \times 10^5 \text{ m}^3$ , which is  $\frac{133,333}{400,000} \times 100 = 33\%$  less water.

### EXAMPLE 2: TILLAGE AND EROSION

Conventional tillage loses 14 t of soil per hectare per year; no-till loses 3 t. Find the percent decrease and total soil saved on 120 ha.

#### SOLUTION

Percent decrease =  $\frac{(14-3)}{14} \times 100 = 78.6\%$  decrease.

Saved =  $(14 - 3) \text{ t/ha/yr} \times 120 \text{ ha} = 1,320 \text{ t per year}$ .

No-till works because residue covers soil and roots hold it.

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**EXAMPLE 3: ECOLOGICAL FOOTPRINT**

A country's footprint is 4.8 global hectares (gha) per person and its biocapacity is 2.4 gha per person. If every person on Earth lived this way, with 1.6 gha of biocapacity per person worldwide, how many Earths would be needed?

| Quantity            | Value (gha per person) |
|---------------------|------------------------|
| Country footprint   | 4.8                    |
| Country biocapacity | 2.4                    |
| World biocapacity   | 1.6                    |

**SOLUTION**

Overshoot ratio =  $4.8/2.4 = 2.0$ : the country uses twice what its land regenerates, relying on imports or depleting stocks.

Earths needed =  $4.8/1.6 = 3.0$  Earths.

The country is in ecological deficit; reducing meat and fossil fuel use lowers the footprint.

**EXAMPLE 4: AQUACULTURE FEED**

A salmon farm uses 1.3 kg of feed per kg of fish gained, and the feed is 25% wild-caught fish by mass. How much wild fish supports a harvest of 500 t?

**SOLUTION**

Feed =  $500 \text{ t} \times 1.3 = 650 \text{ t}$ .

Wild fish =  $650 \times 0.25 = 162.5 \text{ t}$ , or 0.325 kg wild fish per kg of salmon.

Farming still depends on wild stocks; using plant-based feed or farming herbivores lowers pressure.

**Write It Like a 5****Model Response**

Prompt: A town builds a large parking lot and the creek floods more often. Explain why and propose a solution.

Response: The asphalt is impermeable, so rain cannot infiltrate and instead runs off quickly into storm drains, which raises the creek's peak flow and reduces groundwater recharge. To reduce flooding the town could replace some asphalt with permeable pavement, which lets water soak into the soil below, and build a retention basin that stores storm flow and releases it slowly. A benefit is that infiltrating water is filtered, so less oil and sediment reaches the creek.

**What the grader looks for**

Names the cause (impermeable surface), the mechanism (less infiltration, more and faster runoff), a realistic solution (not 'gravel roads'), and a specific added benefit.

**Coach's Playbook**

- 1 Solve each calculation with units.** Write the conversion, then divide by efficiency to get the water drawn.
- 2 Pair every solution with a reason.** Say what the practice does and why it works.
- 3 Match the term to the problem.** Fertilizer causes eutrophication; pesticides do not.
- 4 Be specific.** Name the practice (drip irrigation, rotational grazing), not 'conserve'.

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**Common traps**

1) Saying pesticides cause eutrophication. 2) Suggesting an unrealistic runoff fix such as gravel roads. 3) Dividing by efficiency the wrong way (gross water is needed water divided by efficiency, so it is larger). 4) Forgetting to say a percent decrease is a decrease.

**Quick Check**

Q: What is a salt problem from over-irrigation called? A: Salinization. Q: What reduces both erosion and fuel use? A: No-till farming. Q: Overshoot ratio above 1 means what? A: Footprint exceeds biocapacity.

**Challenge Corner**

A mine yields 20,000 t of copper per year from ore that is 0.5% copper by mass. (a) Find the ore mined and the tailings produced. (b) If ore grade falls to 0.4% for the same output, find the percent increase in ore. Solution: (a)  $20,000/0.005 = 4.0 \times 10^6$  t ore; tailings =  $4,000,000 - 20,000 = 3.98 \times 10^6$  t. (b)  $20,000/0.004 = 5.0 \times 10^6$  t; increase =  $\frac{1.0}{4.0} \times 100 = 25\%$  increase, so lower grade means more waste and energy per tonne of metal.

**Practice****PRACTICE Unit 5 Practice**

Show your work. A calculator is allowed. Justify conclusions.

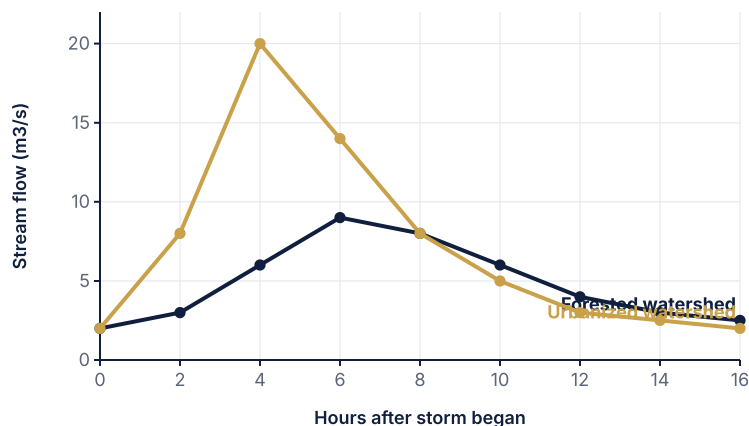
- Which situation is the best example of the tragedy of the commons?  
(A) A landowner logs a private forest slowly to keep income steady  
(B) A town sells bicycles at a loss  
(C) Ranchers who share open pasture each add cattle because the gain is private and the damage is shared  
(D) A company overfishes a pond that it alone owns
- A farmer replaces furrow irrigation with drip irrigation. Which result is most likely?  
(A) Less evaporation and runoff and lower salinization risk, at higher installation cost  
(B) Greater water loss because the lines leak  
(C) More salt buildup because less water is applied  
(D) No change in water use
- Which was an environmental consequence of the Green Revolution?  
(A) Lower yields per hectare  
(B) Reduced fertilizer demand  
(C) Greater genetic diversity among crops  
(D) Increased fertilizer and pesticide runoff and higher irrigation demand
- Compared with selective cutting, clearcutting a steep slope most directly causes  
(A) no change in sediment in nearby streams  
(B) more erosion and stream sedimentation because ground cover is removed  
(C) a cooler forest floor  
(D) faster regrowth of shade-tolerant species

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5. Use the graph. Which statement is supported?



Stream response to the same storm

- (A) The forested watershed has the higher peak flow  
 (B) Both watersheds peak at the same time  
 (C) The urbanized watershed peaks higher and earlier than the forested one  
 (D) The forested watershed returns to its pre-storm flow sooner
6. A city has a footprint of 6.0 gha per person and a biocapacity of 1.5 gha per person. What does this indicate?  
 (A) A biocapacity reserve of 4.5 gha  
 (B) The city is sustainable  
 (C) The footprint is 1.5 times the biocapacity  
 (D) It uses more than its land can regenerate, depending on resources from elsewhere
7. Design an investigation to test whether planting a cover crop reduces soil loss from sloped plots.  
 (a) State a testable hypothesis and the independent and dependent variables.  
 (b) Describe the procedure and three controlled variables.  
 (c) Predict the result and justify it.
8. A 25 ha corn field needs 700 mm of water delivered to the roots. Spray irrigation is 75% efficient, drip is 90% efficient, and water costs 0.12 dollars per cubic meter. Installing drip costs 30,000 dollars.  
 (a) Calculate the volume drawn with each method.  
 (b) Calculate the yearly water cost saved by drip.  
 (c) Calculate the payback time.
9. A fish stock index fell as catch rose. Data (year, catch in thousand t, catch per boat-day in t): 2015, 82, 8.0; 2017, 95, 7.1; 2019, 60, 4.6; 2021, 31, 2.2; 2023, 14, 1.1.  
 (a) Calculate the percent change in catch from 2017 to 2023.  
 (b) Explain what the catch per boat-day trend shows about the stock.  
 (c) Propose two realistic management actions with a reason for each.
10. A town plans a shopping center that will pave 12 ha of former pasture.  
 (a) Explain two effects on local water.  
 (b) Propose two designs to reduce runoff and give one added benefit of each.  
 (c) Identify one other effect of urbanization and explain its cause.

## Answers Unit 5: Answers and Explanations

Read every explanation, including the ones for problems you answered correctly.

### 5 Land and Water Use

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1. C. Open access means each rancher keeps the whole gain but shares the cost of degraded pasture. Choices A and D describe owners who bear the costs of their own use, so they are not commons problems.
2. A. Drip delivers water at the roots so less is lost to evaporation and runoff, and less water means less salt left behind; the cost is higher up front. Choice C reverses the salinization link.
3. D. Fertilizer, pesticide, and irrigation use rose with high-yield varieties, which also narrowed genetic diversity. Choices A and B contradict the yield gains and the growth in inputs.
4. B. Removing all trees leaves soil bare, so rain washes sediment into streams. Choice C is wrong because clearing raises soil temperature and sun exposure.
5. C. The urbanized curve peaks at 20 m<sup>3</sup>/s at 4 h, the forested curve at 9 m<sup>3</sup>/s at 6 h. Choice D is false: by hour 16 the urbanized stream is back to 2 m<sup>3</sup>/s but the forested stream is still at 2.5.
6. D. A ratio of  $6.0/1.5 = 4$  exceeds 1, an ecological deficit, so the city relies on imports or depletes stocks. Choice C quotes the inverse ratio, a common slip.
7. Hypothesis: If a cover crop is planted, then soil loss will be lower than on bare plots. IV: cover crop present or absent. DV: mass of sediment collected per plot after rain.
  - (b) Build several identical plots on the same slope and soil; plant cover crop on half and leave half bare; give all plots the same simulated rainfall; weigh dried sediment collected at the base of each plot. Controlled: slope, soil type, rainfall amount, plot size, time.
  - (c) Cover plots lose less soil because roots hold soil and leaves reduce raindrop impact; use at least 3 plots per treatment and average.
8. (a) Needed volume =  $0.70 \times 25 \times 10^4 = 1.75 \times 10^5 \text{ m}^3$ . Spray:  $1.75 \times 10^5 / 0.75 = 233,333 \text{ m}^3$ . Drip:  $1.75 \times 10^5 / 0.90 = 194,444 \text{ m}^3$ .
  - (b) Saved  $38,889 \text{ m}^3 \times 0.12 = 4,667$  dollars per year.
  - (c) Payback =  $30,000 / 4,667 = 6.4$  years.
9. (a)  $\frac{(14-95)}{95} \times 100 = -85.3\%$ , an 85% decrease.
  - (b) Catch per boat-day (effort-adjusted) fell 86% from 8.0 to 1.1 t even though boats kept fishing, so the stock itself is shrinking; fish are harder to find.
  - (c) Set catch quotas below the sustainable yield so fish can reproduce; create marine protected areas or closed seasons so spawners survive; require larger mesh to reduce juvenile bycatch.
10. (a) Impermeable pavement reduces infiltration, so runoff volume and flood peaks rise; groundwater recharge falls. Runoff also carries oil and sediment to streams.
  - (b) Permeable pavement lets water soak in and filters pollutants; a retention basin holds storm flow and settles sediment; a green roof absorbs rain and insulates the building.
  - (c) Urban heat island: dark pavement and buildings absorb sunlight and there is less vegetation for evapotranspiration, so the city is warmer.

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# Unit 6: Energy Resources and Consumption

Exam weighting: about 10-15% of the multiple-choice section. Concept review, worked examples, exam-style writing, and 10 practice items, all with full explanations.

## 6 Energy Resources and Consumption

Renewable and nonrenewable energy, power plants, efficiency math, and the trade-offs of every major energy source.

### Why This Matters

Unit 6 carries about 10-15% of the multiple-choice score, and calculation parts of the free-response questions often come from it: power times time, fuel mass from energy demand, efficiency, and payback. Points are lost for missing units, wrong conversions, and describing an energy source without its trade-off.

### Core Ideas

#### Renewable and Nonrenewable Resources

**Renewable** sources (solar, wind, hydro, geothermal, tidal, sustainably harvested biomass) replenish on human time scales.

**Nonrenewable** sources (coal, oil, natural gas, uranium) form over millions of years and are depleted by use. Renewable does not mean impact-free, and biomass is renewable only when regrown.

#### Global Energy Consumption

About 80% of global primary energy comes from fossil fuels. Energy use rises with population and wealth: wealthy countries use many times more energy per person, while many low-income households burn wood, charcoal, or dung (traditional biomass) for cooking. Renewables are growing quickly but still supply a minority of total energy.

#### Fuel Types and Uses

| Fuel                       | Notes                                                                                                        |
|----------------------------|--------------------------------------------------------------------------------------------------------------|
| Wood, charcoal, peat, dung | Local heating and cooking; peat is early-stage coal                                                          |
| Coal                       | Rank rises lignite, subbituminous, bituminous, anthracite; more carbon and energy per kg; mostly electricity |
| Crude oil                  | Refined by distillation into gasoline, diesel, jet fuel; transportation                                      |
| Natural gas                | Mostly methane; heating and electricity; lowest CO <sub>2</sub> per energy of the fossil fuels               |
| Ethanol, biodiesel         | Plant-based liquid fuels blended with or replacing gasoline and diesel                                       |

#### Distribution of Natural Energy Resources

Resources are unevenly spread. Major oil reserves lie in the Middle East; large coal reserves in the United States, Russia, China, Australia, and India. Geothermal is best near plate boundaries and hot spots, solar in sunny low-latitude deserts, wind on plains, coasts, and ridges, and hydropower where steep rivers or large flows exist. Uneven supply drives trade and conflict.

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## Energy Math

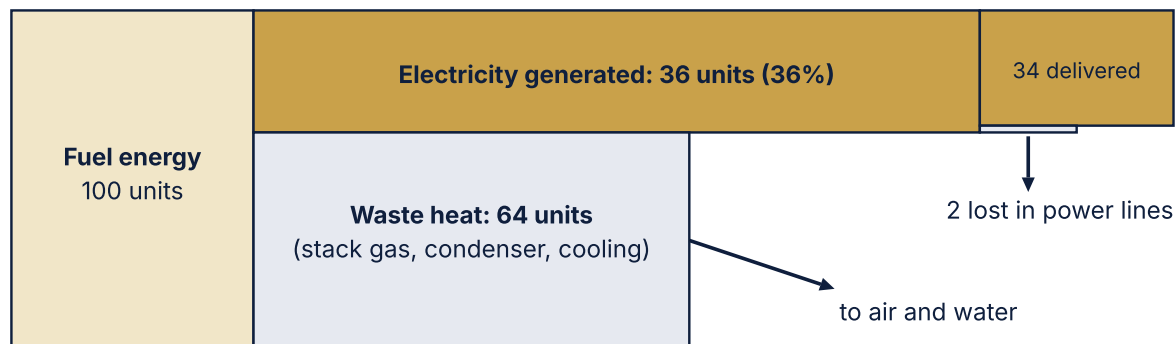
**Energy (kWh) = power (kW) x time (h).** Cost = kWh x price per kWh. A year has 8,760 hours; 1 kWh = 3.6 MJ.

**Efficiency** =  $\frac{\text{useful energy out}}{\text{energy in}} \times 100$ . **Capacity factor** =  $\frac{\text{actual output}}{\text{rated power} \times \text{hours}}$ .

**Payback (years)** =  $\frac{\text{up-front cost}}{\text{annual savings}}$ . **Fuel mass** =  $\frac{\text{energy needed}}{\text{energy per kg}}$ .

## Fossil Fuels

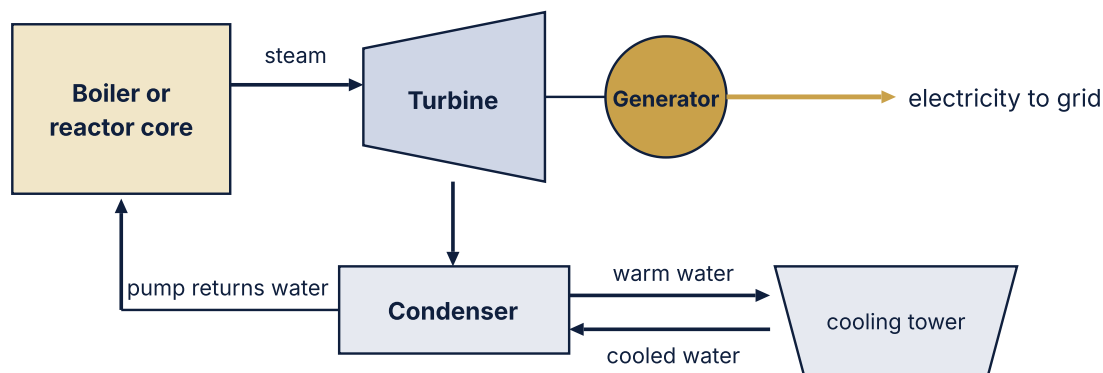
Fossil fuels formed from buried ancient organisms under heat and pressure: coal from swamp plants, oil and gas mostly from marine plankton. Burning them releases CO<sub>2</sub>, SO<sub>2</sub> and NO<sub>x</sub> (which form acid rain), particulates, and (for coal) mercury. **Hydraulic fracturing (fracking)** pumps fluid into shale to free gas and oil; it can contaminate groundwater, uses large volumes of water, and releases VOCs and methane. Oil (tar) sands need much energy and water and destroy habitat. **Cogeneration** captures waste heat, raising efficiency to as much as 60-80%.



Band width is proportional to energy. Typical thermal plant efficiency is about one-third.

Sankey-style energy flow for a fossil-fuel power plant (units per 100 units of fuel energy).

Heat makes steam; steam spins the turbine; the generator makes electricity.  
Coal, gas, biomass, and geothermal heat or a nuclear core all boil water this way.



Steam power plant schematic. Cooling water carries away about two-thirds of the fuel energy as waste heat.

## Nuclear Power

In **fission**, a neutron splits a uranium-235 nucleus, releasing heat and more neutrons (a chain reaction). Heat boils water to drive a turbine as above. Operation emits no CO<sub>2</sub> and plants produce reliable power, but mining has impacts, cooling water adds thermal pollution, and **spent fuel** stays dangerous for thousands of years (long half-lives), requiring secure storage. A loss of coolant can cause a meltdown (Chernobyl 1986, Fukushima 2011, Three Mile Island 1979).

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## Reactor Parts

**Fuel rods:** enriched uranium. **Control rods:** absorb neutrons to slow or stop the reaction. **Moderator:** slows neutrons (often water). **Coolant:** removes heat. **Containment:** thick shell around the core.

## Energy from Biomass

Burning wood or crop waste, or making ethanol (from fermented corn or sugarcane) and biodiesel, is called carbon-neutral because the  $\text{CO}_2$  was recently absorbed by plants. That holds only if the plants are regrown and little fossil energy is used for growing and processing. Land clearing, fertilizer, and competition with food crops reduce the benefit, and indoor cooking fires cause respiratory disease.

## Solar Energy

**Photovoltaic (PV)** cells convert sunlight directly to electricity; **concentrating solar** uses mirrors to boil fluid; **active** systems heat water, and **passive** design uses windows, thermal mass, and orientation. Operation is emission-free, but output is intermittent and needs storage, and manufacturing uses mined materials and land.

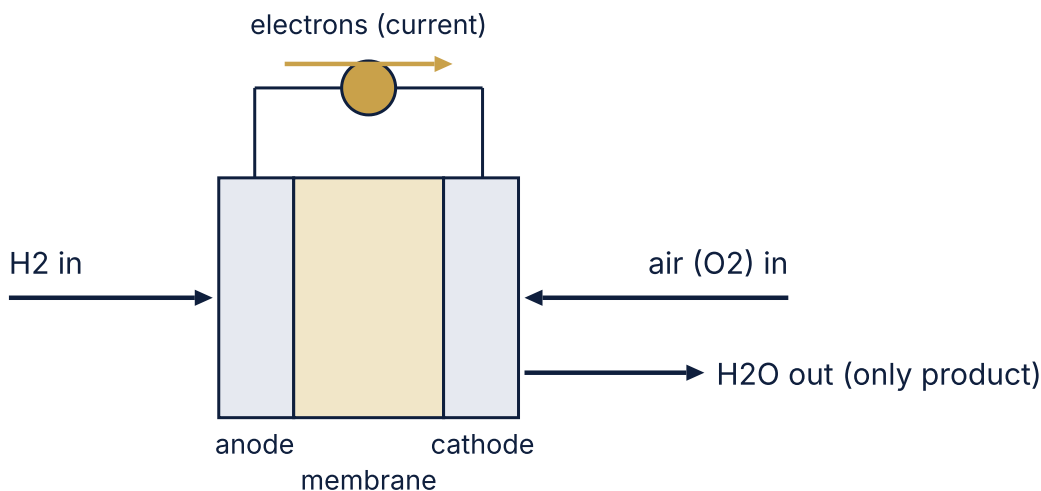
## Hydroelectric Power

Falling water spins turbines. Dams give flood control and steady power, but flood habitat and communities, trap sediment, block fish migration, alter river temperature and flow, and reservoirs can emit methane from decaying plants. Run-of-river, pumped storage, and tidal systems have smaller or different impacts.

## Geothermal Energy

Heat from Earth's interior produces steam for turbines near plate boundaries and hot spots, and **geothermal heat pumps** heat and cool buildings nearly anywhere. It runs continuously, but sites are limited, drilling is costly, and some release hydrogen sulfide.

## Hydrogen Fuel Cell



anode:  $\text{H}_2$  splits into  $\text{H}^+$  and  $\text{e}^-$

$\text{H}^+$  crosses the membrane;  $\text{e}^-$  take the circuit

cathode:  $\text{O}_2 + \text{H}^+ + \text{e}^-$  makes  $\text{H}_2\text{O}$

Hydrogen fuel cell: chemical energy becomes electricity directly, with water as the only exhaust.

A fuel cell combines hydrogen and oxygen to make electricity and water. Hydrogen is an **energy carrier, not a source**: it must be made, usually from natural gas (which emits  $\text{CO}_2$ ) or by electrolysis of water (clean only if the electricity is clean). Storage and distribution are challenges.

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## Wind Energy

Wind turns turbine blades that run a generator. It has no operating emissions and low water use, but wind is intermittent, turbines can kill birds and bats, and some people object to noise and appearance. Offshore wind is steadier but costs more. Power rises sharply with wind speed.

## Energy Conservation

Using less energy is often the cheapest option: LED lighting, insulation and sealing, efficient appliances, hybrid and electric vehicles, public transit, passive design, smart thermostats, and green building standards. Efficiency standards and tax credits are realistic policy tools.

## Worked Examples

### EXAMPLE 1: EFFICIENCY AND FUEL

A coal plant produces 100 MWh for one hour at 36% efficiency. Coal gives 24 MJ per kg. Find the coal burned and the waste heat.

#### SOLUTION

Electricity =  $100 \text{ MWh} \times 3600 \text{ MJ/MWh} = 3.6 \times 10^5 \text{ MJ}$ .

Energy in =  $3.6 \times 10^5 / 0.36 = 1.0 \times 10^6 \text{ MJ}$ . Coal =  $1.0 \times 10^6 \text{ MJ} / 24 \text{ MJ/kg} = 41,700 \text{ kg}$  (about 42 t).

Waste heat =  $1.0 \times 10^6 - 3.6 \times 10^5 = 6.4 \times 10^5 \text{ MJ}$ , matching the Sankey diagram's 64%.

### EXAMPLE 2: KWH AND COST

A home swaps 20 incandescent bulbs (60 W each) for 20 LEDs (9 W each). Each lamp runs 4 h per day for 365 days. Electricity costs 0.15 dollars per kWh. Find the yearly savings, and the payback if LEDs cost 3 dollars each.

| Bulb             | Power (W) | Energy per year (kWh) |
|------------------|-----------|-----------------------|
| Incandescent x20 | 1200      | 1752                  |
| LED x20          | 180       | 262.8                 |

#### SOLUTION

Old:  $20 \times 0.060 \text{ kW} \times 1460 \text{ h} = 1752 \text{ kWh}$ . New:  $20 \times 0.009 \times 1460 = 262.8 \text{ kWh}$ .

Saved = 1489.2 kWh, which at 0.15 dollars is  $1489.2 \times 0.15 = 223.38$  dollars per year.

Payback =  $\frac{60 \text{ dollars}}{223.38 \text{ dollars/yr}} = 0.27 \text{ yr}$ , about 3 months.

### EXAMPLE 3: CAPACITY FACTOR

A 3.0 MW wind turbine delivers 7,884 MWh in a year. Find the capacity factor and the number of homes served if a home uses 10,800 kWh per year.

#### SOLUTION

Maximum possible =  $3.0 \text{ MW} \times 8760 \text{ h} = 26,280 \text{ MWh}$ .

Capacity factor =  $7884 / 26,280 = 0.30 = 30\%$ , because wind is not always blowing at rated speed.

Homes =  $\frac{7,884,000 \text{ kWh}}{10,800 \text{ kWh/home}} = 730$  homes.

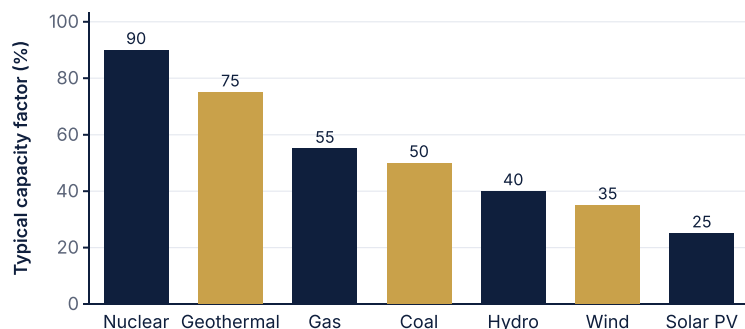
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**EXAMPLE 4: SOLAR PAYBACK**

A 6 kW rooftop array costs 14,000 dollars and has an 18% capacity factor. Electricity is worth 0.14 dollars per kWh. Find yearly output, savings, and payback.



Approximate, site dependent

**SOLUTION**

Output =  $6 \text{ kW} \times 8760 \text{ h} \times 0.18 = 9,461 \text{ kWh}$  per year.

Savings =  $9,461 \times 0.14 = 1,325$  dollars per year.

Payback =  $14,000 / 1,325 = 10.6$  years; subsidies or higher prices shorten it.

**Write It Like a 5****Model Response**

Prompt: A region with strong sun and a coal plant must add generation. Evaluate solar PV against coal. Response: Solar PV emits no  $\text{CO}_2$ ,  $\text{SO}_2$ , or particulates while operating, while coal burning releases all three and contributes to acid rain and climate change. However, solar output is intermittent, with a capacity factor near 25% compared with about 50–70% for coal, so the region needs storage such as batteries or backup. Therefore solar is the better choice for air quality and long-term cost, if paired with storage.

**What the grader looks for**

A named advantage with a specific pollutant or mechanism; a named limitation tied to a cause (intermittency); a comparison, not a list; a realistic fix for the limitation; a clear final choice.

**Coach's Playbook**

- 1 Convert first.** Put power in kW and time in hours before multiplying; use 8,760 h per year.
- 2 Track the direction.** Efficiency divides energy out by energy in, so input is larger than output.
- 3 Pair each source with a trade-off.** Every energy source has a benefit and an impact.
- 4 Show setup and units.** Credit is split between setup and answer.

**Common traps**

1) Calling hydrogen an energy source rather than a carrier. 2) Mixing up control rods (absorb neutrons) with moderators (slow neutrons) or coolant. 3) Using nameplate power instead of capacity factor when estimating real output. 4) Offering a technology when the question asks for a government policy.

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**Quick Check**

Q: Which fossil fuel emits least CO<sub>2</sub> per energy unit? A: Natural gas. Q: Why is wind capacity factor below 100%? A: Wind speed varies and turbines also stop for maintenance. Q: What unit is power x time? A: Energy, such as kWh.

**Challenge Corner**

Coal here is 75% carbon by mass. Each kg of carbon makes 44/12 kg of CO<sub>2</sub>. Using Example 1, find kg of CO<sub>2</sub> per kWh. Solution: per kg of coal, CO<sub>2</sub> =  $0.75 \times 44/12 = 2.75$  kg. Coal per kWh =  $41,667 \text{ kg}/100,000 \text{ kWh} = 0.417 \text{ kg/kWh}$ . CO<sub>2</sub> per kWh =  $0.417 \times 2.75 = 1.15 \text{ kg/kWh}$ .

**Practice****PRACTICE Unit 6 Practice**

Show your work. A calculator is allowed. Justify conclusions.

- Which energy source is nonrenewable and emits no CO<sub>2</sub> while generating electricity?  
 (A) Biomass (B) Natural gas (C) Hydroelectric power  
 (D) Nuclear fission
- Which is a documented concern of hydraulic fracturing?  
 (A) Increased coal ash disposal  
 (B) Possible groundwater contamination and release of methane and VOCs  
 (C) Flooding of river valleys  
 (D) Release of spent fuel rods
- In a nuclear reactor, the main job of control rods is to  
 (A) absorb neutrons to slow or stop the chain reaction  
 (B) remove heat from the core  
 (C) slow neutrons so they split uranium  
 (D) contain radiation inside the plant
- A 2 MW wind turbine generates 4,380 MWh in a year (8,760 h). What is its capacity factor?  
 (A) 50% (B) 12.5% (C) 25% (D) 200%
- Use the table. Replacing 1,000 MWh of coal electricity with natural gas electricity changes CO<sub>2</sub> emissions by about

| Source      | CO <sub>2</sub> (g per kWh, life cycle) |
|-------------|-----------------------------------------|
| Coal        | 820                                     |
| Natural gas | 490                                     |
| Solar PV    | 48                                      |
| Wind        | 11                                      |

- (A) an increase of 330 t (B) a decrease of 3.3 t (C) a decrease of 820 t  
 (D) a decrease of 330 t
- Burning wood pellets is often called carbon neutral. Which statement best criticizes that claim?  
 (A) Wood releases no CO<sub>2</sub> when burned  
 (B) CO<sub>2</sub> is offset only if trees are regrown, and harvesting and processing add emissions  
 (C) Wood has more energy per kg than coal  
 (D) Burning wood destroys the ozone layer
- Design an investigation to test whether the tilt angle of a solar panel affects its electrical output.
  - State a testable hypothesis and the independent and dependent variables.
  - Describe the procedure and three controlled variables.
  - Explain how you would ensure reliable results.

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8. A school replaces 200 fluorescent fixtures (80 W each) with LED fixtures (35 W each). They run 3,000 hours per year. Electricity costs 0.12 dollars per kWh and each LED fixture costs 45 dollars. The grid emits 0.4 kg CO<sub>2</sub> per kWh.
  - (a) Calculate the yearly energy saved in kWh.
  - (b) Calculate the yearly cost savings.
  - (c) Calculate the payback time.
  - (d) Calculate the CO<sub>2</sub> avoided per year.
9. Data for three plants (nameplate MW, annual MWh): A coal 500, 3,285,000; B wind 100, 262,800; C gas 300, 1,051,200.
  - (a) Calculate the capacity factor of each plant.
  - (b) How many 100 MW wind farms like B give the annual output of A?
  - (c) Explain why the wind farm's capacity factor is lower than the coal plant's, and propose one way to supply power when wind is weak.
10. A country must choose a new source of steady electricity.
  - (a) Identify one advantage and one disadvantage of nuclear power compared with coal.
  - (b) Explain why spent nuclear fuel is a long-term concern.
  - (c) Propose a local government policy that would increase use of rooftop solar and explain how it works.

## Answers Unit 6: Answers and Explanations

Read every explanation, including the ones for problems you answered correctly.

### 6 Energy Resources and Consumption

#### PRACTICE · UNIT 6 PRACTICE

1. D. Fission uses uranium, which is finite, and emits no CO<sub>2</sub> in operation. Hydroelectric power (choice C) is also low-emission but renewable; natural gas emits CO<sub>2</sub>.
2. B. Fracking fluid and wells can leak into groundwater, and methane and volatile organic compounds escape. Choice C describes dams and choice D describes nuclear waste, which are not fracking issues.
3. A. Control rods absorb neutrons, so inserting them lowers the number of fissions. Choice C describes the moderator, the common mix-up, and choice B describes coolant.
4. C. Capacity factor =  $4380 / (2 \times 8760) = 0.25$ . Choice A forgets to multiply the rated power by hours and compares only to 8,760.
5. D. Difference =  $820 - 490 = 330$  g per kWh, and 1,000 MWh is  $10^6$  kWh, so  $3.3 \times 10^8$  g = 330 t less CO<sub>2</sub>. Choice B slips by a factor of 100 in the conversion.
6. B. The claim holds only if replanted trees reabsorb the CO<sub>2</sub> released, and harvesting, drying, and transport add emissions. Choice A is false because burning wood always releases CO<sub>2</sub>.
7. (a) Hypothesis: If panel tilt angle changes, then electrical power output will change, with a maximum when the panel faces the sun most directly. IV: tilt angle. DV: power output (volts x amps) or energy over a set time.  
(b) Set identical panels at several angles (for example 0, 20, 40, 60 degrees) in the same place; record current and voltage with a meter at the same times. Controlled: panel type, direction faced, time of day, shading, panel temperature, load resistance.  
(c) Repeat each angle at least 3 times and average, and record light intensity to adjust for passing clouds.
8. (a)  $(80 - 35) \text{ W} \times 200 \times 3000 \text{ h} = 2.7 \times 10^7 \text{ Wh} = 27,000 \text{ kWh}$  per year.  
(b)  $27,000 \times 0.12 = 3,240$  dollars per year.  
(c) Cost =  $200 \times 45 = 9,000$  dollars; payback =  $9000 / 3,240 = 2.8$  years.  
(d)  $27,000 \times 0.4 = 10,800$  kg CO<sub>2</sub> (10.8 t) avoided.
9. (a) A:  $3,285,000 / (500 \times 8760) = 0.75$  (75%). B:  $262,800 / (100 \times 8760) = 0.30$  (30%). C:  $1,051,200 / (300 \times 8760) = 0.40$  (40%).  
(b)  $3,285,000 / 262,800 = 12.5$ , so 13 wind farms.  
(c) Wind blows at varying speeds and sometimes too weakly, whereas coal burns on demand; add battery storage, pumped hydro, or backup from a gas plant to supply power when wind is weak.
10. (a) Advantage: no CO<sub>2</sub>, SO<sub>2</sub>, or particulates in operation, with reliable output. Disadvantage: radioactive waste and high construction cost (or accident risk).  
(b) Fission products and actinides have long half-lives, so fuel remains radioactive for thousands of years and must be isolated from water and people.  
(c) Offer a rebate or property-tax break for rooftop solar, or require solar on new buildings; this lowers the up-front cost, shortens payback, and encourages installation.

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# Unit 7: Atmospheric Pollution

Exam weighting: about 7-10% of the multiple-choice section. Concept review, worked examples, exam-style writing, and 10 practice items, all with full explanations.

## 7 Atmospheric Pollution

Air pollutants, smog, inversions, indoor hazards, controls, acid rain and noise, with the calculations the exam asks for.

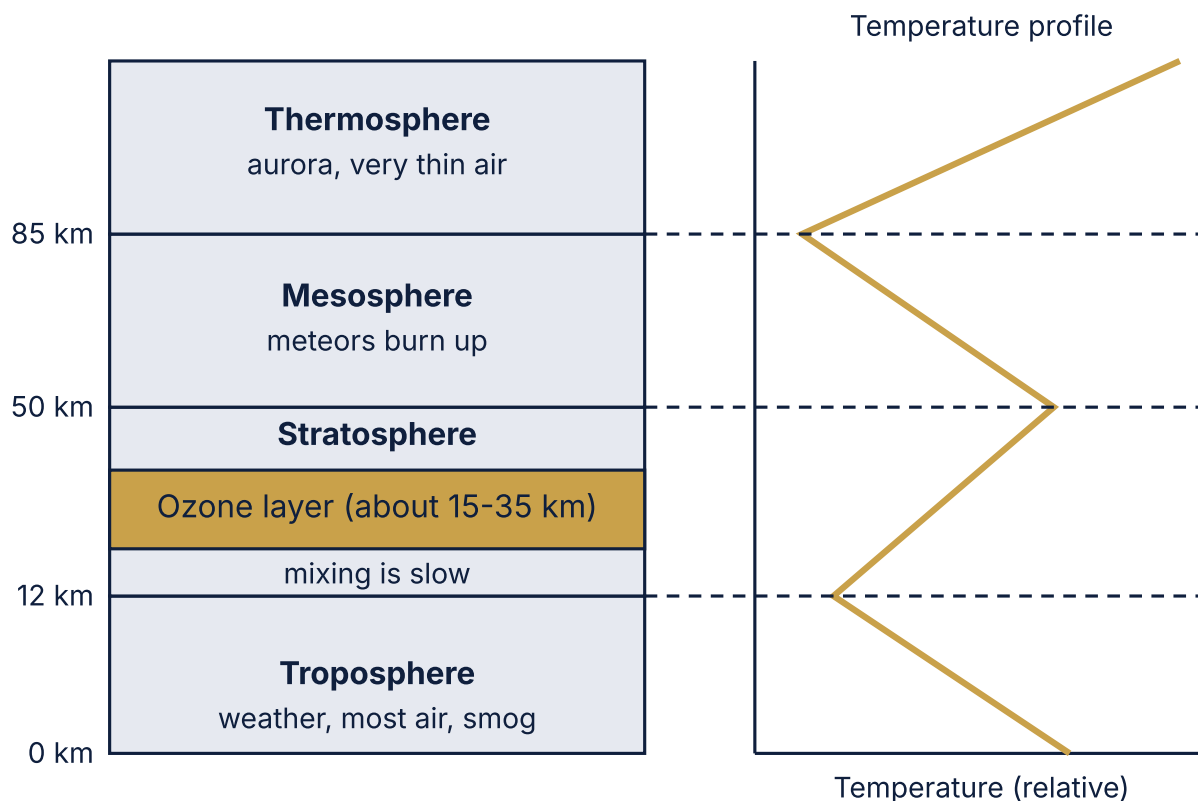
### Why This Matters

Unit 7 is about 7-10% of the multiple-choice section, and its ideas return in Units 6 and 9. Points are lost by mixing up primary and secondary pollutants, naming the wrong precursors of acid rain, and describing a control technology without saying what it captures.

### Core Ideas

#### 7.1 Introduction to Air Pollution

Earth's atmosphere is layered. The **troposphere** (surface to about 12 km) holds most of the air and all weather, and it is where ground-level pollution lives. The **stratosphere** above it holds the ozone layer, which absorbs most ultraviolet-B and UV-C radiation. Ozone is a problem near the ground but a shield high up.



Layers of the atmosphere (not to scale). Temperature falls with height in the troposphere and mesosphere and rises in the stratosphere (ozone absorbs UV) and thermosphere.

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A **primary pollutant** is emitted directly (soot, carbon monoxide, sulfur dioxide). A **secondary pollutant** forms in the air from reactions among primary pollutants (ground-level ozone, PAN, sulfuric and nitric acid). Sources are **stationary** (power plants, factories) or **mobile** (vehicles, ships). The Clean Air Act directs the EPA to set national air quality standards for six **criteria pollutants**.

### Criteria pollutants (Clean Air Act)

Carbon monoxide (CO): incomplete combustion; binds hemoglobin and cuts oxygen delivery.

Nitrogen dioxide (NO<sub>2</sub>): high-temperature combustion in engines and plants; smog and acid rain precursor.

Sulfur dioxide (SO<sub>2</sub>): burning coal and smelting; acid rain precursor, lung irritant.

Ground-level ozone (O<sub>3</sub>): secondary pollutant; damages lungs and plant tissue.

Particulate matter (PM<sub>10</sub>, PM<sub>2.5</sub>): soot, dust, smoke; PM<sub>2.5</sub> reaches deep into the lungs.

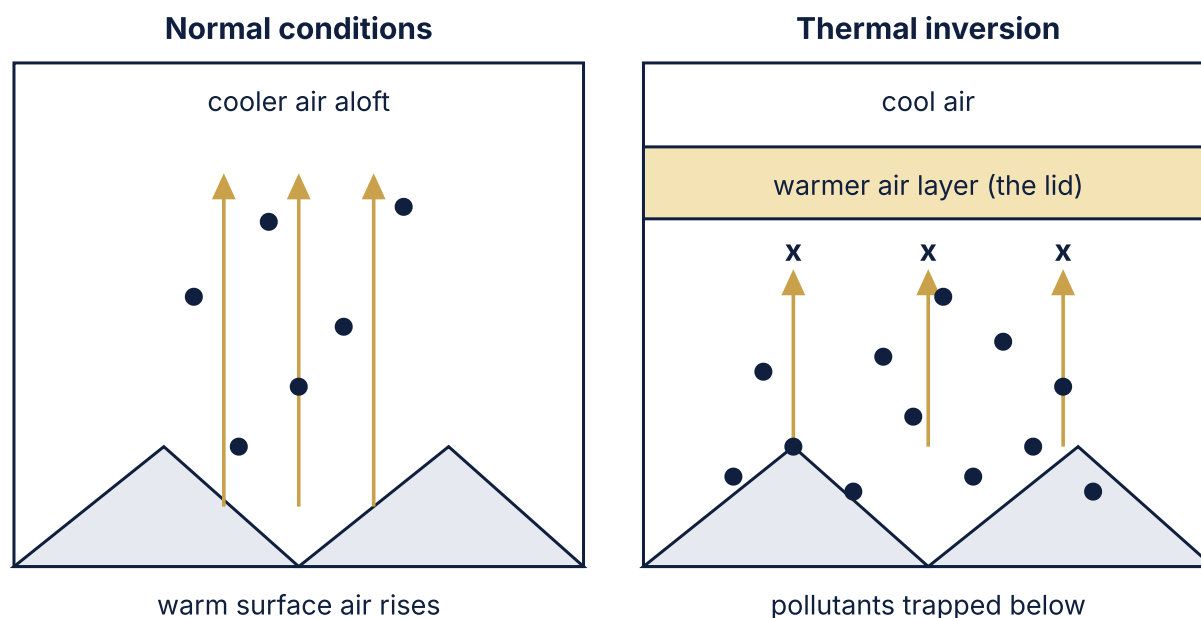
Lead (Pb): old paint, leaded fuel, smelters; damages the nervous system, especially in children.

## 7.2 Photochemical Smog

Smog forms when nitrogen oxides (NO<sub>x</sub>) and **volatile organic compounds** (VOCs, such as gasoline vapor and solvents) react in sunlight to make ozone, PAN and other irritants. Ozone peaks on sunny, warm afternoons, a few hours after the morning rush hour releases NO<sub>x</sub>. Smog triggers asthma and damages crops.

## 7.3 Thermal Inversion

Normally air is warmest at the surface and cools with height, so surface air rises and carries pollutants away. In a **thermal inversion** a layer of warm air lies over cooler air near the ground. The cool air is denser, cannot rise through the warm lid, and pollutants build up. Valleys ringed by mountains are prone to inversions, especially on calm, clear nights.



Normal air mixes upward. In an inversion a warm layer sits over cooler surface air, so the surface air cannot rise and pollutants accumulate.

## 7.4 Atmospheric CO<sub>2</sub> and Particulates

Burning fossil fuels, clearing forests and making cement raise atmospheric CO<sub>2</sub>, a greenhouse gas (Unit 9). Carbon dioxide is not one of the six criteria pollutants. **Particulate matter** is solid or liquid particles; PM<sub>10</sub> is 10 micrometers or less across and PM<sub>2.5</sub> is 2.5 micrometers or less. Smaller particles travel deeper into the lungs, so PM<sub>2.5</sub> links to asthma, heart disease and early death. Sulfate particles cool the climate; black carbon (soot) warms it.

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## 7.5 Indoor Air Pollutants

Indoor air is often more polluted than outdoor air. **Radon** is a radioactive gas from uranium decay in rock and soil that seeps through foundation cracks; it is a leading cause of lung cancer, and fixes include sealing and sub-slab venting. **Asbestos** fibers (old insulation) cause lung disease. Other hazards: mold, tobacco smoke, carbon monoxide, formaldehyde and other VOCs from furniture, and lead paint dust. In much of the developing world, cooking over open fires indoors is the largest source of indoor particulates and CO. Solutions: ventilation, chimneys, detectors, testing and removing sources.

## 7.6 Reduction of Air Pollutants

| Control                        | What it removes or prevents                                                                          | Where used               |
|--------------------------------|------------------------------------------------------------------------------------------------------|--------------------------|
| Wet scrubber                   | SO <sub>2</sub> and some particulates, by spraying water or a limestone slurry through exhaust       | Coal plant smokestack    |
| Electrostatic precipitator     | Charges particulates and collects them on plates                                                     | Power plants, factories  |
| Baghouse filter                | Particulates trapped in fabric bags                                                                  | Factories, cement plants |
| Catalytic converter            | Converts CO, NO <sub>x</sub> and unburned hydrocarbons to CO <sub>2</sub> , N <sub>2</sub> and water | Vehicle exhaust          |
| Vapor recovery nozzle          | Captures gasoline vapors (VOCs) during refueling, not tailpipe exhaust                               | Gas stations             |
| Cap and trade, low-sulfur fuel | Policy and fuel switching that lower SO <sub>2</sub> at the source                                   | Utilities                |

Prevention beats cleanup: switch fuels, raise fuel economy standards, expand transit. A local government can pass ordinances, build bus lanes or give incentives; a scrubber is a technology a company installs.

## 7.7 Acid Rain

Burning coal releases SO<sub>2</sub> and vehicles and plants release NO<sub>x</sub>. These react with water in the air to form sulfuric and nitric acids. Only NO<sub>x</sub> and SO<sub>x</sub> are acid rain precursors; VOCs and particulates are not. Clean rain is already slightly acidic (about pH 5.6) because of dissolved CO<sub>2</sub>, so acid rain is rain below 5.6. Effects: lake acidification (many fish die below about pH 5), release of toxic aluminum from soil, loss of calcium and magnesium from forest soils, and damage to marble and limestone. Lakes on limestone are **buffered** because carbonate neutralizes acid; lakes on granite are not. Winds carry acids far downwind.

## 7.8 Noise Pollution

Noise is unwanted sound, measured in decibels (dB) on a logarithmic scale: every 10 dB increase is a tenfold rise in sound intensity. Traffic, aircraft, construction and industry are the main sources. Long exposure above about 85 dB damages hearing; lower levels cause stress and sleep loss, and noise disrupts animals that communicate by sound. Controls: sound barriers, vegetation, zoning, limits on operating hours and hearing protection.

### Math tools for this unit

1 ppm = 1000 ppb; a gas at  $x$  ppm by volume is  $x \times 10^{-6}$  of the air volume.

Each pH unit is a 10-fold change in  $[H^+]$ ; a change of  $n$  units is  $10^n$ .

Percent change =  $\frac{\text{new} - \text{old}}{\text{old}} \times 100$ ; +10 dB is 10 times the sound intensity.

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## Worked Examples

### EXAMPLE 1: PPM AND PPB

An ozone monitor reads 0.082 ppm. (a) Convert to ppb. (b) A local limit is 70 ppb. By what percent does the reading exceed the limit?

| Unit | Parts per | Conversion        |
|------|-----------|-------------------|
| ppm  | million   | 1 ppm = 1,000 ppb |
| ppb  | billion   | 1 ppb = 0.001 ppm |

#### SOLUTION

(a) 1 ppm = 1,000 ppb, so  $0.082 \text{ ppm} \times 1000 = 82 \text{ ppb}$ .

(b) Percent change =  $\frac{82-70}{70} \times 100 = 17\%$  above the limit (17.1%).

### EXAMPLE 2: VOLUME OF A GAS IN A ROOM

A garage measures 6 m by 5 m with a 2.5 m ceiling. Carbon monoxide is 40 ppm by volume. How many liters of CO are in the garage?

#### SOLUTION

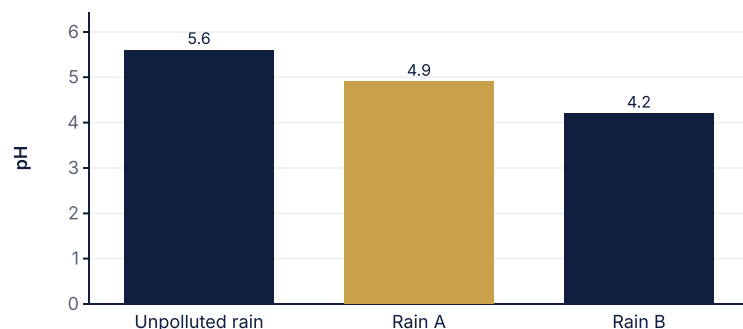
Room volume =  $6 \times 5 \times 2.5 = 75 \text{ m}^3 = 75,000 \text{ L}$ .

40 ppm =  $40 \times 10^{-6}$ , so CO volume =  $40 \times 10^{-6} \times 75,000 \text{ L} = 3.0 \text{ L}$ .

Units: L of CO cancel against L of air. Even 3 L is a dangerous dose for a closed space.

### EXAMPLE 3: ACID RAIN AND THE PH SCALE

Unpolluted rain has pH 5.6. Rain A is 4.9 and Rain B is 4.2. How many times more acidic is Rain B than clean rain, and than Rain A?



Measured rain pH. Lower pH means more acidic.

#### SOLUTION

Each pH unit is a factor of 10 in  $[\text{H}^+]$ .

Rain B vs clean rain:  $10^{5.6-4.2} = 10^{1.4} = 25$  times.

Rain B vs Rain A:  $10^{4.9-4.2} = 10^{0.7} = 5.0$  times.

Rain B is about 25 times more acidic than clean rain even though its pH is only 1.4 units lower.

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**EXAMPLE 4: SCRUBBER EFFICIENCY**

A coal plant burns 1.2 million tons of coal per year. The coal is 1.5% sulfur by mass. Burning converts each ton of sulfur to 2 tons of  $\text{SO}_2$  (64 g/mol vs 32 g/mol). A scrubber removes 95% of  $\text{SO}_2$ . How many tons of  $\text{SO}_2$  are emitted?

| Step                 | Quantity (tons/yr) |
|----------------------|--------------------|
| Sulfur in coal       | 18,000             |
| $\text{SO}_2$ formed | 36,000             |
| Removed by scrubber  | 34,200             |
| Emitted              | 1,800              |

**SOLUTION**

Sulfur burned:  $1,200,000 \times 0.015 = 18,000$  tons.

$\text{SO}_2$  produced:  $18,000 \times 2 = 36,000$  tons.

Emitted after scrubbing:  $36,000 \times (1 - 0.95) = 1,800$  tons per year, a 95% decrease from 36,000.

**Write It Like a 5****Model Response**

Prompt: Explain how a thermal inversion worsens photochemical smog over a valley city, and propose one local government action that reduces the problem. Response: In smog,  $\text{NO}_x$  from vehicles and VOCs from fuel and solvents react in sunlight to form ground-level ozone. In a thermal inversion, a layer of warm air sits above cooler surface air, so the cool dense air cannot rise and mix, and the ozone,  $\text{NO}_x$  and VOCs accumulate in the valley, increasing asthma and lung irritation. A city could build a dedicated bus lane and give commuters transit passes, which lowers the number of cars and therefore  $\text{NO}_x$  and VOC emissions, with the added benefit of less traffic noise.

**What the grader looks for**

Names both precursors ( $\text{NO}_x$  and VOCs) and sunlight; states that the warm layer blocks vertical mixing and that pollutant concentration increases; gives a realistic local action (ordinance, incentive or transit) rather than a smokestack technology; states a valid added benefit; uses direction words (increase, decrease) with a reason.

**Coach's Playbook**

- 1 Name the pollutant, then the source, then the effect, then the control. Use "because" to link each step.
- 2 For any control technology, say exactly what it captures: scrubbers catch  $\text{SO}_2$ , precipitators and baghouses catch particulates, converters treat tailpipe gases, vapor nozzles catch gasoline vapor.
- 3 Convert ppm to ppb first, then work in one unit. Write the units in every line.
- 4 If the prompt says "local government," answer with a policy, ordinance or incentive.

**Common traps**

1. Listing VOCs or particulates as acid rain precursors; only  $\text{NO}_x$  and  $\text{SO}_x$  count. 2. Saying a vapor recovery nozzle captures tailpipe emissions. 3. Offering a scrubber when the question asks for a local government action. 4. Treating  $\text{CO}_2$  as a criteria pollutant, or calling ground-level ozone and stratospheric ozone the same problem.

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**Quick Check**

Q1: What is the pH of unpolluted rain and why is it not 7? A: About 5.6, because dissolved  $\text{CO}_2$  forms carbonic acid.  
Q2: A sound goes from 55 dB to 85 dB. How many times more intense? A: 30 dB is three factors of 10, so  $10^3 = 1000$  times.  
Q3: Which pollutant binds hemoglobin? A: Carbon monoxide.

**Challenge Corner**

A school measures  $\text{PM}_{2.5}$  at 35 micrograms per cubic meter in a classroom of 9 m by 8 m by 3 m with no air purifier.  
(a) How many micrograms of  $\text{PM}_{2.5}$  are in the room? (b) A filter cuts the concentration by 60%. What is the new concentration and the mass remaining? Solution: (a) Volume =  $9 \times 8 \times 3 = 216 \text{ m}^3$ , so mass =  $35 \times 216 = 7,560 \mu\text{g}$ . (b) New concentration =  $35 \times 0.40 = 14 \mu\text{g}/\text{m}^3$ , mass =  $14 \times 216 = 3,024 \mu\text{g}$ .

**Practice****PRACTICE Unit 7 Practice**

Show your work. A calculator is allowed. Justify conclusions.

- Which of the following is a secondary pollutant?  
(A) Carbon monoxide from a tailpipe  
(B) Ground-level ozone formed from nitrogen oxides and VOCs in sunlight  
(C) Lead from old paint dust  
(D) Sulfur dioxide emitted directly from a smelter
- During a thermal inversion, pollutant concentrations near the ground rise because  
(A) warm surface air rises quickly and carries pollutants into the stratosphere  
(B) cool air above the surface presses warm air downward and creates more pollutants  
(C) ground temperatures fall below freezing, which produces more particulates  
(D) a layer of warmer air above cooler surface air prevents vertical mixing
- Which pair of pollutants are the main precursors of acid rain?  
(A) Nitrogen oxides and sulfur oxides  
(B) Volatile organic compounds and particulates  
(C) Carbon dioxide and methane  
(D) Chlorofluorocarbons and ozone
- A vapor recovery nozzle at a gas station reduces air pollution by  
(A) converting tailpipe CO to **CO<sub>2</sub>**  
(B) filtering particulates from engine exhaust  
(C) capturing gasoline vapors (VOCs) released during refueling  
(D) neutralizing acids in the fuel tank
- Which statement about radon is correct?  
(A) It is a VOC given off by new carpet and glue  
(B) It is a radioactive gas from rock and soil that can enter homes through foundation cracks  
(C) It is a particulate released by burning wood indoors  
(D) It is produced when mold grows in damp walls
- An air monitor reads 0.045 ppm of nitrogen dioxide. This equals  
(A) 0.045 ppb (B) 4.5 ppb (C) 450 ppb (D) 45 ppb
- A school sits 40 m from a busy road. Students think  $\text{PM}_{2.5}$  concentration falls with distance from the road.  
(a) Write a testable hypothesis that names the independent and dependent variables.  
(b) Describe a procedure that uses at least three distances and identify two variables to control.  
(c) Describe the data pattern that would support the hypothesis and explain why repeated measurements are needed.

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8. Six lakes in a region were surveyed.  
Lake / rain-fed pH / fish species: A 6.8 / 14; B 6.2 / 12; C 5.6 / 11; D 5.0 / 6; E 4.6 / 3; F 4.2 / 1.  
(a) Describe the relationship between pH and number of fish species.  
(b) Calculate the percent decrease in species from Lake A to Lake F.  
(c) Lake F is 2.6 pH units below Lake A. How many times higher is its hydrogen ion concentration?  
(d) Identify two precursors of acid rain and one human source for each.  
(e) Propose one action a county government could take to reduce the problem and give one added benefit.
9. A county has 150,000 vehicles. Each is refueled 52 times a year and each refueling releases 3.0 g of VOCs without a vapor recovery nozzle.  
(a) Calculate the total VOC emitted per year in metric tons (1 metric ton = 1,000,000 g).  
(b) Nozzles capture 95% of the vapors. Calculate the VOC still emitted per year.  
(c) Identify the secondary pollutant that VOCs help form and name one health effect.
10. A valley city has clear, calm winter days and a morning haze that lasts until evening.  
(a) Explain how a thermal inversion forms and why it traps pollution.  
(b) Describe how the pollutants nitrogen oxides and VOCs lead to ozone.  
(c) Identify one indoor air pollutant and a way to reduce exposure to it.

## Answers Unit 7: Answers and Explanations

Read every explanation, including the ones for problems you answered correctly.

### 7 Atmospheric Pollution

#### PRACTICE · UNIT 7 PRACTICE

1. B. Ozone is not emitted; it forms in the air from reactions of primary pollutants. Choice D is tempting because  $\text{SO}_2$  is a major pollutant, but a smelter releases it directly, so it is primary.
2. D. The warm layer acts as a lid and the cooler, denser air below cannot rise. Choice A describes normal conditions, the opposite of an inversion.
3. A. Only  $\text{NO}_x$  and  $\text{SO}_x$  react to form nitric and sulfuric acid. Choice C is tempting because  $\text{CO}_2$  makes rain slightly acidic, but it is not the cause of acid rain.
4. C. The nozzle seals the fill pipe and captures VOCs while fuel enters the tank. Choice A is the catalytic converter, which acts on tailpipe gases.
5. B. Radon comes from uranium decay in rock and soil and enters through cracks. Choice A is tempting because VOCs are indoor pollutants, but radon is radioactive and not a VOC.
6. D.  $1 \text{ ppm} = 1,000 \text{ ppb}$ , so  $0.045 \times 1000 = 45 \text{ ppb}$ . Choice A forgets to convert.
7. (a) Hypothesis:  $\text{PM}_{2.5}$  concentration (dependent variable) decreases as distance from the road (independent variable) increases. 1 point.  
(b) Measure at 10 m, 40 m and 100 m from the road with the same calibrated monitor, at the same times of day on days with similar wind, for the same duration. Controls: time of day, wind and weather, instrument and height. 2 points.  
(c) Concentrations should be highest near the road and fall with distance. Repeating measurements over several days averages out random changes in traffic and wind, so a pattern is not a one-time fluke. 1 point.  
Model: I predict  $\text{PM}_{2.5}$  in micrograms per cubic meter will decrease with distance because exhaust particles disperse and settle.
8. (a) As pH decreases, the number of fish species decreases; richness falls steeply below pH 5.6 (11 species at 5.6, 1 at 4.2). 1 point.  
(b)  $\frac{1-14}{14} \times 100 = -92.9\%$ , a 93% decrease. 2 points (setup and answer).  
(c)  $10^{2.6} = 398$  times higher, about 400 times. 1 point.  
(d)  $\text{SO}_2$  from burning coal at power plants;  $\text{NO}_x$  from vehicle engines. 2 points.  
(e) Example: build bus lanes and give transit incentives to cut vehicle  $\text{NO}_x$ ; added benefit is less congestion or less noise and lower  $\text{CO}_2$ . 2 points.
9. (a)  $150,000 \times 52 \times 3.0 \text{ g} = 23,400,000 \text{ g} = 23.4 \text{ metric tons per year}$ . 2 points.  
(b)  $23.4 \times (1 - 0.95) = 1.17 \text{ metric tons per year}$ . 2 points.  
(c) Ground-level ozone (or PAN) forms when VOCs and  $\text{NO}_x$  react in sunlight; it triggers asthma and lung irritation. 1 point.
10. (a) A warm air layer settles over cooler surface air (often cold ground on a clear calm night, in a valley). The cool air is denser and cannot rise through the warm layer, so no vertical mixing occurs and emissions concentrate. 2 points.  
(b)  $\text{NO}_x$  from combustion and VOCs from fuel vapor or solvents react in sunlight to make ground-level ozone, so levels build in the afternoon. 1 point.  
(c) Radon (test and seal cracks, add sub-slab venting) or carbon monoxide (install detectors, vent heaters) or mold (control moisture). 1 point.

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# Unit 8: Aquatic and Terrestrial Pollution

Exam weighting: about 7-10% of the multiple-choice section. Concept review, worked examples, exam-style writing, and 10 practice items, all with full explanations.

## 8 Aquatic and Terrestrial Pollution

Pollution sources, eutrophication, thermal pollution, toxics, waste, sewage, dose-response and pathogens, with calculations.

### Why This Matters

Unit 8 is about 7-10% of the multiple-choice section and feeds FRQs on water quality, toxics and waste. Points are lost by calling pesticides a cause of eutrophication, mixing up bioaccumulation with biomagnification, and writing a pollutant effect on the study instead of on the organisms.

### Core Ideas

#### 8.1 Sources of Pollution

**Point sources** come from one identifiable place, such as a factory pipe or sewage plant outfall; **nonpoint sources** are spread out, such as farm runoff, urban runoff and atmospheric deposition. Nonpoint pollution is harder to regulate. Main pollutants: nutrients, sediment, pathogens, heavy metals, pesticides, oil, plastics, heat. The **Clean Water Act** regulates discharges into surface water, the **Safe Drinking Water Act** sets standards for public supplies, **RCRA** controls hazardous waste from creation to disposal, and **CERCLA** (Superfund) pays for cleaning abandoned toxic sites by billing the responsible parties.

#### 8.2 Human Impacts on Ecosystems

Pollution and development alter habitat. Fragmentation isolates populations, sediment smothers streams, road salt harms freshwater life, and plastics and oil injure marine animals. Pollution tolerance can serve as a measure of water quality: mayfly, stonefly and caddisfly larvae need clean, oxygen-rich water and are **bioindicators**, while sludge worms tolerate pollution.

#### 8.3 Endocrine Disruptors

**Endocrine disruptors** are chemicals that mimic, block or alter hormones, even at very low doses. Examples are some pesticides (atrazine), PCBs, BPA and phthalates. Documented effects include altered sex characteristics in frogs and fish and reduced fertility. They affect development more than most toxics.

#### 8.4 Human Impacts on Wetlands and Mangroves

Wetlands and mangroves filter pollutants and sediment, store floodwater, buffer coasts from storm surge, serve as nurseries for fish and shrimp, and store large amounts of carbon. Draining for farms and housing, shrimp ponds, pollution and sea level rise destroy them. Their loss increases flooding, erosion and pollution, and reduces fisheries.

#### 8.5 Eutrophication

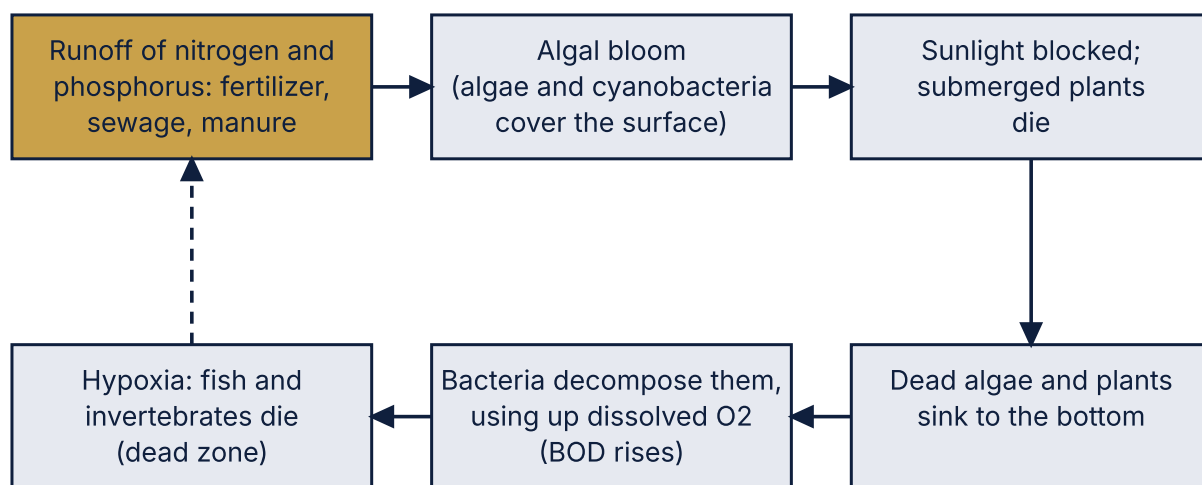
**Eutrophication** is the over-enrichment of water with nutrients, mainly phosphorus (limiting in most freshwater) and nitrogen (often limiting in salt water). Fertilizer, manure, sewage and some detergents wash in. Algae bloom, then die; decomposers use up dissolved oxygen and **biological oxygen demand (BOD)** rises. Low oxygen (**hypoxia**) kills fish and creates dead zones, such as the one at the mouth of the Mississippi River. Pesticides are not a nutrient and do not cause eutrophication. Solutions: less fertilizer, vegetated buffer strips, restored wetlands, phosphorus removal at sewage plants, and phosphate-free detergents.

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### Cultural eutrophication cycle



Dashed arrow: nutrients released from dead matter and sediment fuel new blooms

Eutrophication: excess nutrients lead to blooms, then oxygen depletion by decomposers.

#### Oxygen and water quality

**Dissolved oxygen (DO)** is measured in mg/L (= ppm). Most fish need DO above about 5 mg/L.

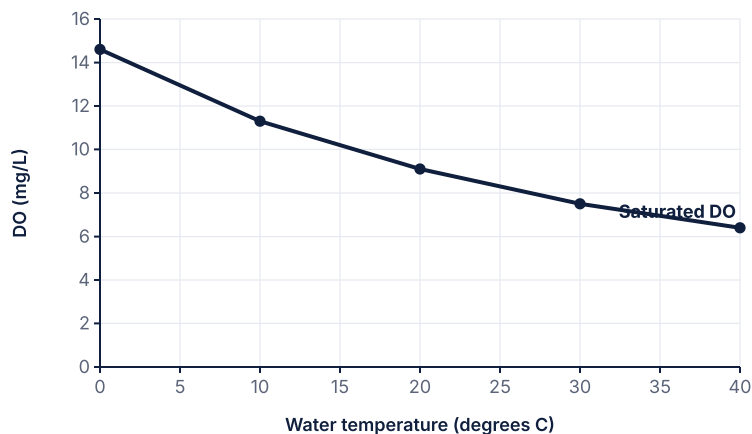
**BOD** = oxygen used by microbes decomposing organic matter. High BOD means low DO and heavy organic pollution.

5-day BOD =  $(DO_{\text{initial}} - DO_{\text{day 5}}) \times \text{dilution factor}$ ; dilution factor =  $\frac{\text{bottle volume}}{\text{sample volume}}$ .

Dilution:  $C_1V_1 = C_2V_2$ .

### 8.6 Thermal Pollution

Power plants and factories that use river water for cooling return it warmer. Warm water holds less dissolved oxygen, while the metabolism of fish rises, which together stress or kill organisms, and sudden changes cause thermal shock. Removal of shade and hot pavement runoff also warm streams. Cooling towers or cooling ponds, which release heat to the air before discharge, reduce the harm.



Warmer water holds less dissolved oxygen (freshwater at sea level).

### 8.7 Persistent Organic Pollutants (POPs)

**POPs** (DDT, PCBs, dioxins) resist breakdown, dissolve in fat, travel long distances by air and water, and are toxic. Because they persist, a single use can contaminate ecosystems for decades; many are banned under international agreements.

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## 8.8 Bioaccumulation and Biomagnification

**Bioaccumulation** is the buildup of a substance within one organism over time because it takes in the substance faster than it excretes it. **Biomagnification** is the increase in concentration at each higher trophic level, because predators eat many contaminated prey and retain the chemical in fat or tissue. Top consumers (eagles, ospreys, orcas, humans) carry the highest levels. Mercury in large fish and DDT in raptor eggshells are classic examples. Always mention both when a persistent pollutant reaches a top consumer.

## 8.9 Solid Waste Disposal

Municipal solid waste goes mostly to **sanitary landfills**: lined, with daily soil cover, leachate collection and methane capture. Risks include leachate contaminating groundwater, methane (a greenhouse gas) and land use. **Incineration** and waste-to-energy cut volume sharply and make electricity but emit air pollutants and leave toxic ash. Open dumps and ocean dumping are the worst options. E-waste holds lead, mercury and cadmium.

## 8.10 Waste Reduction Methods

The hierarchy is **reduce, reuse, recycle**, with reduction first. Other methods: composting food and yard waste, anaerobic digestion for biogas, deposits on bottles, pay-as-you-throw fees, and requiring producers to take back products. Recycling lowers extraction and energy use, but contamination and market prices limit its success.

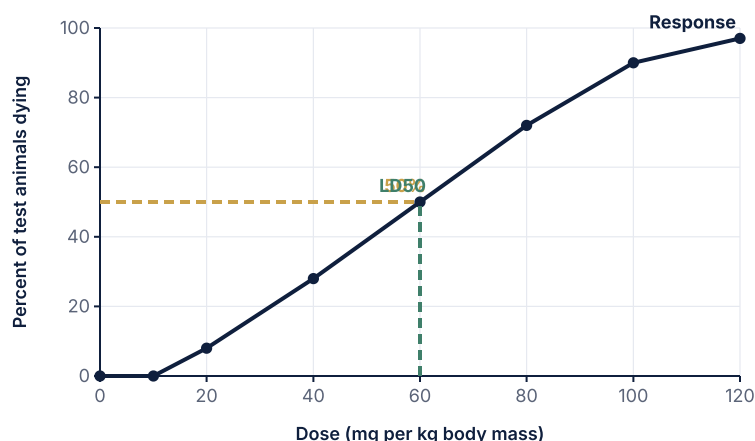
## 8.11 Sewage Treatment

| Stage     | Process                                                             | Removes                                    |
|-----------|---------------------------------------------------------------------|--------------------------------------------|
| Primary   | Screens, grit chamber, settling tank                                | Solids, grit, some BOD; produces sludge    |
| Secondary | Aeration with bacteria                                              | Most dissolved organic matter (lowers BOD) |
| Tertiary  | Chemical or biological nutrient removal, then chlorine, UV or ozone | Nitrogen, phosphorus, pathogens            |

Septic systems treat household wastewater in rural homes; a poorly maintained one leaks nutrients and pathogens.

## 8.12 Lethal Dose 50% (LD50) and 8.13 Dose Response Curve

The **LD50** is the dose that kills 50% of a test population, usually in mg of substance per kg of body mass; a lower LD50 means a more toxic substance. A **dose-response curve** plots the effect against dose. It is S-shaped, often with a **threshold** below which no effect appears. Acute exposure is short and high-dose; chronic exposure is long and low-dose. Doses scale with body mass: dose (mg) = LD50 (mg/kg) × mass (kg).



Dose-response curve: no response below a threshold of about 10 mg/kg; LD50 = 60 mg/kg.

### Toxicity and half-life tools

Dose (mg) = LD50 (mg/kg) × body mass (kg).

Remaining amount =  $N_0 \times (0.5)^{t/t_{1/2}}$ .

Magnification factor = concentration at the higher level ÷ concentration at the lower level.

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## 8.14 Pollution and Human Health

Lead damages the nervous system, especially in children; mercury harms brain development; arsenic and asbestos cause cancer; PCBs and DDT affect hormones and reproduction. Risk depends on dose, duration, and sensitivity. The **Delaney Clause** bars food additives shown to cause cancer. Poor communities often live closest to pollution sources, an environmental justice issue.

## 8.15 Pathogens and Infectious Diseases

Pathogens are bacteria, viruses, protozoa and parasites. **Waterborne** diseases (cholera, typhoid, giardiasis) spread through sewage-contaminated water; **vector-borne** diseases (malaria, dengue) spread by mosquitoes; others spread through air or animals. Fecal coliform bacteria signal sewage contamination. Prevention: sanitation, clean water, vaccination, vector control and surveillance. Warmer climates widen mosquito ranges.

## Worked Examples

### EXAMPLE 1: DILUTION

A stock solution of nitrate contains 500 mg/L. How many mL of stock are needed to prepare 200 mL of a 25 mg/L standard?

| Quantity         | Value    |
|------------------|----------|
| $C_1$ (stock)    | 500 mg/L |
| $C_2$ (standard) | 25 mg/L  |
| $V_2$            | 200 mL   |
| $V_1$            | 10 mL    |

### SOLUTION

$$C_1 V_1 = C_2 V_2, \text{ so } V_1 = \frac{25 \times 200}{500} = 10 \text{ mL.}$$

Add 10 mL of stock to enough water to make 200 mL total. Because 1 mg/L = 1 ppm in dilute water, the standard is 25 ppm.

### EXAMPLE 2: BIOLOGICAL OXYGEN DEMAND

A 20 mL wastewater sample is diluted to 300 mL. DO is 8.8 mg/L at the start and 3.1 mg/L after 5 days. Calculate the BOD of the wastewater.

| Measurement     | Value     |
|-----------------|-----------|
| Initial DO      | 8.8 mg/L  |
| DO at day 5     | 3.1 mg/L  |
| Dilution factor | 15        |
| BOD             | 85.5 mg/L |

### SOLUTION

$$\text{Dilution factor} = \frac{300}{20} = 15.$$

$$\text{DO used} = 8.8 - 3.1 = 5.7 \text{ mg/L.}$$

$$\text{BOD} = 5.7 \times 15 = 85.5 \text{ mg/L, which indicates heavy organic pollution.}$$

### EXAMPLE 3: HALF-LIFE

A pesticide with a half-life of 8 years is applied at 640 kg. (a) How much remains after 30 years? (b) How long until 5% remains?

### SOLUTION

$$\text{(a) } 640 \times (0.5)^{30/8} = 640 \times 0.0743 = 47.6 \text{ kg.}$$

$$\text{(b) } 0.05 = (0.5)^{t/8}, \text{ so } t = 8 \times \log_2(20) = 8 \times 4.32 = 34.6 \text{ years.}$$

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**EXAMPLE 4: BIOMAGNIFICATION**

Concentrations of a persistent pollutant are given. Find the factor of increase from plankton to osprey, and from water to osprey.

| Level      | Concentration (ppm) |
|------------|---------------------|
| Water      | 0.000002            |
| Plankton   | 0.04                |
| Small fish | 0.5                 |
| Large fish | 2.0                 |
| Osprey     | 25                  |

**SOLUTION**

Plankton to osprey:  $\frac{25}{0.04} = 625$  times.

Water to osprey:  $\frac{25}{0.000002} = 1.25 \times 10^7$  times (12.5 million).

The jump at each step is the effect of biomagnification, and the total shows that a trace amount in water becomes toxic in a top predator.

**Write It Like a 5****Model Response**

Prompt: A lake receives fertilizer runoff and develops a fish kill. Explain the cause and propose a solution. Response: Fertilizer adds nitrogen and phosphorus, which causes algae to bloom. When the algae die, bacteria decompose them and use up dissolved oxygen, so the BOD rises and DO falls below what fish need, leading to hypoxia and fish death. A farm could plant a vegetated buffer strip along the shoreline, which absorbs nutrients before they reach the lake and also reduces soil erosion.

**What the grader looks for**

Nutrients named (N and P, not pesticides); bloom, death and decomposition in order; oxygen consumed by decomposers; effect on organisms, not just the study; a realistic solution with a valid added benefit.

**Coach's Playbook**

- 1 Write each calculation as a ratio with units and cancel units on paper.
- 2 For food-chain pollutants, name the compound, the trophic path, and then the effect on the top consumer.
- 3 Describe the sequence in eutrophication in the correct order: nutrients, bloom, die-off, decomposition, low DO.
- 4 Match the treatment stage to the pollutant: solids (primary), organic matter (secondary), nutrients and pathogens (tertiary).

**Common traps**

1. Saying pesticides cause eutrophication. 2. Using bioaccumulation and biomagnification as synonyms. 3. Writing "lower LD50 is safer"; it is more toxic. 4. Forgetting the dilution factor in BOD.

**Quick Check**

Q1: Which pollutant limits growth in most freshwater? A: Phosphorus. Q2: Which treatment stage uses bacteria? A: Secondary. Q3: A compound has LD50 of 50 mg/kg. What dose kills half of 70 kg people, by this value? A:  $50 \times 70 = 3500$  mg (animal data are only a guide).

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**Challenge Corner**

A town of 40,000 people generates 2.0 kg of waste per person per day. Its landfill holds 500,000 metric tons. (a) How many years will it last? (b) A recycling program diverts 35% of the waste. How many years now? Solution: (a)  $40,000 \times 2.0 \times 365 = 29,200,000 \text{ kg} = 29,200 \text{ t}$  per year;  $500,000/29,200 = 17.1$  years. (b)  $29,200 \times 0.65 = 18,980 \text{ t}$  per year;  $500,000/18,980 = 26.3$  years, a 54% longer life.

**Practice****PRACTICE Unit 8 Practice**

Show your work. A calculator is allowed. Justify conclusions.

- Which is the main cause of cultural eutrophication in a lake?  
(A) Runoff of pesticides from farms  
(B) Warm water discharged by a power plant  
(C) Runoff of nitrogen and phosphorus from fertilizer and sewage  
(D) Acid rain lowering the pH
- Compared with cooler water, warm water discharged by a factory  
(A) holds less dissolved oxygen  
(B) holds more dissolved oxygen  
(C) causes algae to die  
(D) increases BOD directly
- Biomagnification refers to  
(A) accumulation of a chemical in one animal over its lifetime  
(B) breakdown of a chemical into harmless products  
(C) release of pollutants from sediment  
(D) increasing concentration of a persistent chemical at higher trophic levels
- Chemical X has an LD50 of 10 mg/kg and Chemical Y has an LD50 of 400 mg/kg. Which statement is correct?  
(A) Y is more toxic because its LD50 is higher  
(B) X is more toxic because a smaller dose kills half of the animals  
(C) Both are equally toxic at the same exposure time  
(D) X is less toxic because its LD50 is smaller
- Which stage of sewage treatment uses bacteria to break down dissolved organic matter?  
(A) Primary  
(B) Tertiary  
(C) Secondary  
(D) Grit removal
- A herbicide has a half-life of 5 years. If 200 g is applied, how much remains after 15 years?  
(A) 25 g  
(B) 100 g  
(C) 50 g  
(D) 12.5 g
- A researcher thinks that phosphorus runoff increases algal growth in a pond.  
(a) Write a testable hypothesis.  
(b) Describe an experiment using 12 identical outdoor tanks of pond water, with at least three treatments and a control; identify the dependent variable and two controlled variables.  
(c) Describe the expected result and explain how a negative result would affect your conclusion.
- Dissolved oxygen was measured downstream of a sewage outfall (km: DO in mg/L): 0: 8.4; 2: 5.1; 4: 3.2; 6: 4.4; 8: 6.3; 10: 7.5. Fish need at least 5 mg/L.  
(a) Describe the trend in DO.  
(b) Identify the approximate stretch of river where fish are at risk.  
(c) Explain the cause of the DO decline and the recovery downstream.  
(d) Propose one upgrade at the sewage plant and explain how it changes BOD.
- A town of 40,000 people produces 2.0 kg of solid waste per person per day. (1 metric ton = 1,000 kg.)  
(a) Calculate the town's annual waste in metric tons.  
(b) A recycling and composting program diverts 35% of the waste. Calculate the tons landfilled per year.  
(c) The landfill has 500,000 tons of capacity. Calculate how many years it lasts with the program, to one decimal.  
(d) Identify two risks of landfills.

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10. Osprey eggs in a region have thin shells. A persistent pesticide was sprayed on nearby fields years ago.
- Explain why the pesticide is found in highest concentrations in ospreys.
  - Distinguish bioaccumulation from biomagnification.
  - Identify two traits that make a compound a POP.
  - Describe one policy to reduce exposure to persistent toxics.

## Answers Unit 8: Answers and Explanations

Read every explanation, including the ones for problems you answered correctly.

### 8 Aquatic and Terrestrial Pollution

#### PRACTICE · UNIT 8 PRACTICE

- C. Nitrogen and phosphorus from fertilizer and sewage feed algal blooms. Choice A is a common error; pesticides are toxic but are not nutrients, so they do not fuel algae.
- A. Gas solubility falls as temperature rises. Choice B reverses the relationship; choice D confuses cause and effect, since BOD measures decomposition of organic matter.
- D. Biomagnification is about concentration rising up the food chain. Choice A is bioaccumulation within one organism, the tempting confusion.
- B. A smaller LD50 means a smaller dose is lethal, so X is more toxic. Choices A and D reverse that.
- C. Secondary treatment aerates the wastewater so microbes consume dissolved organic matter and BOD falls. Choice B (tertiary) removes nutrients and pathogens.
- A. 15 years is 3 half-lives, so  $200 \times (0.5)^3 = 25$  g. Choice B divides 200 by 2 only once.
- If phosphorus concentration (independent variable) in pond water increases, then algal growth (dependent variable) will increase. 1 point.
  - Treatments: 0 (control), low and high phosphorus, 4 replicate tanks each. DV: algal biomass (chlorophyll or cell count). Constants: light, temperature, nitrogen, water source. 3 points.
  - Algal biomass rises with phosphorus. If no change, another nutrient (such as nitrogen) or light may be limiting, so the hypothesis is not supported for that pond. 2 points.
- DO falls from 8.4 to a minimum of 3.2 mg/L at 4 km and then rises to 7.5 by 10 km. 1 point.
  - About 2 to 7 km downstream, where DO is below 5 mg/L. 1 point.
  - Sewage adds organic matter; bacteria decompose it using oxygen, so DO falls. Downstream the organic matter is used up and oxygen diffuses in from the air and from photosynthesis, so DO recovers. 2 points.
  - Add secondary (or tertiary) treatment with aeration so microbes remove organic matter before discharge, which lowers BOD in the effluent. 1 point.
- $40,000 \times 2.0 \times 365 = 29,200,000$  kg = 29,200 t. 2 points.
  - $29,200 \times 0.65 = 18,980$  t. 1 point.
  - $500,000/18,980 = 26.3$  years. 1 point.
  - Leachate contaminating groundwater; methane emissions (or odor, land use, loss of habitat). 2 points.
- Ospreys are top consumers. The persistent pesticide dissolves in fat and is retained, so it accumulates in prey, and each level eats many contaminated prey, so concentrations multiply up the food chain. 2 points.
  - Bioaccumulation: buildup in a single organism over time. Biomagnification: concentration increases with each trophic level. 1 point.
  - Persistence (resists breakdown) and fat solubility (also toxicity or long-distance transport). 1 point.
  - A ban or restriction on the chemical, or a requirement for monitoring and cleanup; valid benefit: recovery of raptor populations. 1 point.

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# Unit 9: Global Change

Exam weighting: about 15-20% of the multiple-choice section. Concept review, worked examples, exam-style writing, and 10 practice items, all with full explanations.

## 9 Global Change

Ozone depletion, the greenhouse effect, climate change, oceans, invasive and endangered species, and biodiversity loss.

### Why This Matters

Unit 9 is the heaviest in this book, about 15-20% of the multiple-choice section, and climate and biodiversity show up in FRQs of every style. Points are lost by saying CO<sub>2</sub> destroys the ozone layer, blaming melting sea ice for sea level rise, and listing "no predators" as an invasive trait.

### Core Ideas

#### 9.1 Stratospheric Ozone Depletion

Ozone (O<sub>3</sub>) in the stratosphere absorbs most ultraviolet-B (UV-B) radiation. **Chlorofluorocarbons** (CFCs, once used in refrigerants, aerosols and foams), halons and other halogenated compounds are stable at the surface, drift into the stratosphere, and release chlorine or bromine atoms when hit by UV. One chlorine atom destroys many thousands of ozone molecules because it is a catalyst. Over Antarctica, polar stratospheric clouds make the spring ozone hole. Ozone is measured in **Dobson units** (about 300 DU is typical; below 220 DU is a hole). More UV-B means more skin cancer and cataracts, weaker immune systems, crop damage and harm to phytoplankton. **Carbon dioxide does not destroy ozone.**

#### Ozone depletion vs the greenhouse effect

Ozone depletion: CFCs and halons release Cl and Br in the stratosphere; result is more UV-B at the surface; treaty is the Montreal Protocol.

Greenhouse effect: gases absorb infrared in the troposphere; result is warming; treaties include the Kyoto Protocol.

Ozone depletion does not cause global warming and warming does not cause the ozone hole, although some gases (CFCs, HFCs) affect both.

#### 9.2 Reducing Ozone Depletion

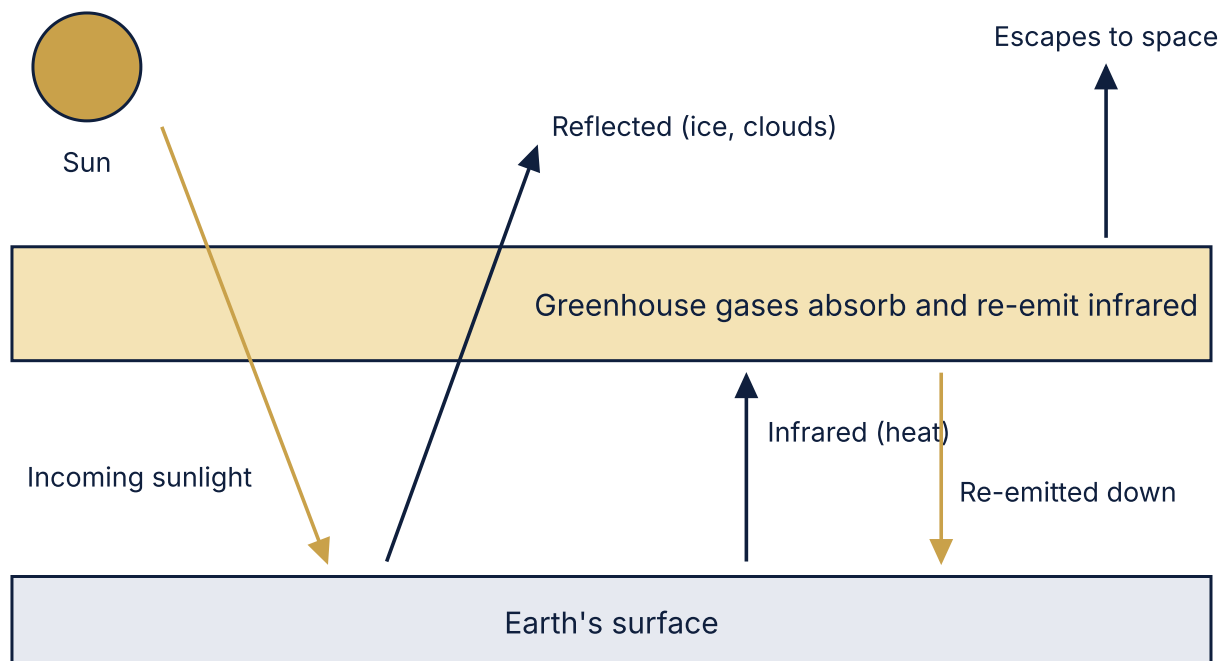
The **Montreal Protocol** (1987) phased out CFCs and other ozone-depleting substances and is considered a successful international treaty; the ozone layer is slowly recovering. Replacements were HCFCs, then HFCs, which do not harm ozone but are strong greenhouse gases, so later agreements phase them down. Individuals can ensure old refrigerators and air conditioners are recycled properly.

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### 9.3 The Greenhouse Effect



Greenhouse effect: sunlight warms the surface, which emits infrared; greenhouse gases return part of it to the surface, warming it.

Sunlight passes through the atmosphere and warms the surface. The surface emits infrared (heat) radiation, which greenhouse gases absorb and re-emit in all directions, including back to the surface. This natural effect keeps Earth about 33 degrees C warmer than it would otherwise be. The problem is enhancement from added gases. Greenhouse gases: CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, water vapor, ozone and fluorinated gases. **Global warming potential (GWP)** compares gases to CO<sub>2</sub> over 100 years: methane is about 28 and nitrous oxide roughly 270 (values vary a bit by report), so emissions are often converted to CO<sub>2</sub>-equivalent: CO<sub>2</sub>e = mass × GWP.

### 9.4 Increases in the Greenhouse Gases

| Gas               | Main human sources                                                                  |
|-------------------|-------------------------------------------------------------------------------------|
| CO <sub>2</sub>   | Fossil fuel combustion, deforestation, cement making                                |
| CH <sub>4</sub>   | Livestock digestion, rice paddies, landfills, natural gas leaks, thawing permafrost |
| N <sub>2</sub> O  | Fertilizer, manure, some combustion                                                 |
| Fluorinated gases | Refrigeration, air conditioning, industrial processes                               |

Atmospheric CO<sub>2</sub> has risen from about 280 ppm before industry to above 420 ppm today. Ice cores, direct measurements and isotope data show the rise comes from fossil carbon. Burning one gallon of gasoline releases about 8.9 kg of CO<sub>2</sub>; a kilowatt-hour from coal releases roughly twice as much as one from natural gas.

#### Carbon math

Emissions (kg) = activity × emission factor, for example gallons × kg CO<sub>2</sub> per gallon.

CO<sub>2</sub>e = mass of gas × GWP.

Rule of 70: doubling time (years) =  $\frac{70}{\text{percent growth rate per year}}$ . For a target year, add the doubling time to the starting year.

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## 9.5 Global Climate Change

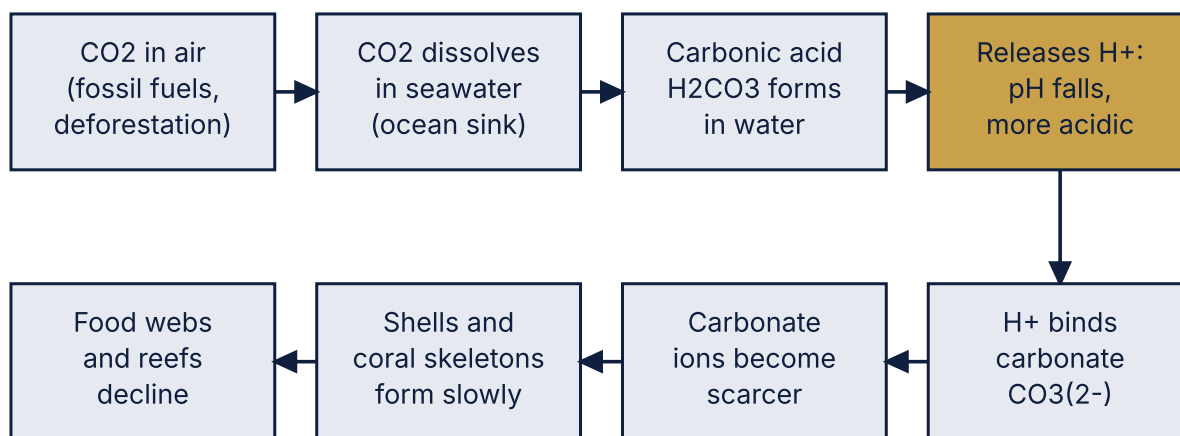
Global average temperature has risen about 1.2 degrees C since the late 1800s, mostly from greenhouse gases. Consequences: melting glaciers and ice sheets, **sea level rise**, heat waves, heavier rainfall, drought, wildfires, shifting species ranges, and coral bleaching. Sea level rises from **thermal expansion** of warming water and **melting land ice**; melting sea ice does not raise it much because floating ice already displaces its own weight. Positive feedbacks speed warming: less ice lowers **albedo** (reflectivity), and thawing permafrost releases  $\text{CH}_4$  and  $\text{CO}_2$ . Responses: mitigation (renewable energy, efficiency, reforestation, methane capture) and adaptation (sea walls, drought-tolerant crops). The **Kyoto Protocol** (1997) set binding emissions targets for developed countries.

## 9.6 Ocean Warming

Oceans absorb over 90% of the extra heat trapped by greenhouse gases. Warming causes thermal expansion, melting of ice shelves, **coral bleaching** (corals expel their algae), lower dissolved oxygen, fish moving toward the poles, and stronger tropical storms.

## 9.7 Ocean Acidification

### Ocean acidification chain



Shell-builders need carbonate ( $\text{CaCO}_3$ ) to grow

Ocean acidification: extra  $\text{CO}_2$  lowers pH and reduces the carbonate ions that shell-forming animals use.

The ocean absorbs about a quarter of human  $\text{CO}_2$ . In water  $\text{CO}_2$  forms carbonic acid, which releases  $\text{H}^+$ . Surface pH has fallen by about 0.1 since industrialization, a rise of about 26% in  $[\text{H}^+]$ . Extra  $\text{H}^+$  binds carbonate ions, leaving less for corals, oysters, snails and plankton that build  $\text{CaCO}_3$  shells. Acidification and warming together threaten reefs. Acidification is caused by dissolved  $\text{CO}_2$ , not by melting ice or acid rain.

## 9.8 Invasive Species

An **invasive species** is a nonnative species that spreads and harms ecosystems, economies or health. Typical traits are generalist, fast reproduction (r-selected), high dispersal and tolerance of disturbance. Missing natural enemies in the new range helps it spread, but that is a feature of the ecosystem, not a trait of the species. Pathways: ship ballast water, pets, ornamental plants, cargo. Examples: zebra mussels, kudzu, lionfish, Burmese pythons. Impacts include competition, predation, disease and loss of biodiversity. Control: prevention, inspection, early detection, removal, and (carefully) biological control.

## 9.9 Endangered Species

The **Endangered Species Act** (ESA) protects listed endangered and threatened species and their habitat, and **CITES** regulates international trade in wildlife. Species at greatest risk are specialists with small, isolated populations, narrow ranges, slow reproduction (K-selected) or high market value. Conservation tools include protected areas, wildlife corridors, captive breeding, reintroduction and anti-poaching laws.

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## 9.10 Human Impacts on Biodiversity

The main drivers are summarized as HIPPCO: **H**abitat loss and fragmentation, **I**nvasive species, **P**ollution, human **P**opulation growth, **C**limate change, and **O**verexploitation. Losing species reduces ecosystem services such as pollination, water filtration and genetic resources. Global extinction rates today far exceed the natural background rate.

### Worked Examples

#### EXAMPLE 1: RULE OF 70

Global emissions of a country grow 2.5% per year. In what year will annual emissions be double their 2026 value?

| Step          | Result        |
|---------------|---------------|
| Growth rate   | 2.5% per year |
| Doubling time | 28 years      |
| Target year   | 2054          |

#### SOLUTION

Doubling time =  $\frac{70}{2.5} = 28$  years.

Year =  $2026 + 28 = 2054$ .

Common error: stopping at "28 years" when the question asks for the year.

#### EXAMPLE 2: HOUSEHOLD CARBON

A household uses 9,600 kWh of electricity per year (0.40 kg CO<sub>2</sub> per kWh) and drives 12,000 miles in a car that gets 30 miles per gallon (8.9 kg CO<sub>2</sub> per gallon). (a) Find total annual CO<sub>2</sub>. (b) Rooftop solar supplies 60% of the electricity. Find the percent change in total emissions.

| Source      | Before (kg) | After (kg) |
|-------------|-------------|------------|
| Electricity | 3,840       | 1,536      |
| Car         | 3,560       | 3,560      |
| Total       | 7,400       | 5,096      |

#### SOLUTION

(a) Electricity:  $9,600 \times 0.40 = 3,840$  kg. Car:  $\frac{12,000}{30} = 400$  gal  $\times 8.9 = 3,560$  kg. Total = 7,400 kg.

(b) New electricity =  $3,840 \times 0.40 = 1,536$  kg. New total =  $1,536 + 3,560 = 5,096$  kg.

Percent change =  $\frac{5,096 - 7,400}{7,400} \times 100 = -31\%$ , a 31% decrease.

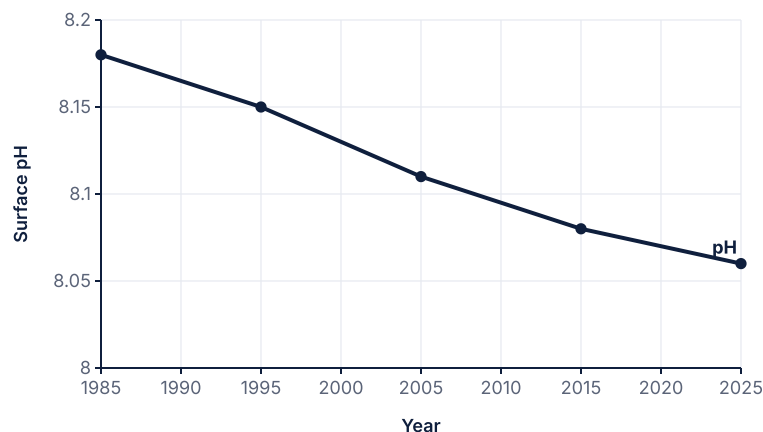
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**EXAMPLE 3: OCEAN PH**

Surface seawater pH falls from 8.18 to 8.06. By what percent does the hydrogen ion concentration increase?



Illustrative pH decline.

**SOLUTION**

pH change = 0.12.

Ratio =  $10^{0.12} = 1.32$ .

Percent increase =  $(1.32 - 1) \times 100 = 32\%$ .

A drop of 0.1 corresponds to  $10^{0.1} = 1.26$ , a 26% rise.

**EXAMPLE 4: CO<sub>2</sub> EQUIVALENTS**

A landfill leaks 500 metric tons of methane per year. Methane has a GWP of 28. A capture system removes 80%. Find CO<sub>2</sub>e released before and after.

**SOLUTION**

Before:  $500 \times 28 = 14,000$  t CO<sub>2</sub>e.

After:  $14,000 \times 0.20 = 2,800$  t.

The system avoids 11,200 t CO<sub>2</sub>e per year, a decrease of 80%.

**Write It Like a 5****Model Response**

Prompt: Explain how burning fossil fuels causes ocean acidification and one effect on marine life. Response: Burning fossil fuels adds CO<sub>2</sub> to the atmosphere, and the ocean absorbs part of it. Dissolved CO<sub>2</sub> reacts with water to form carbonic acid, which releases hydrogen ions and lowers pH. The extra hydrogen ions bind carbonate ions, so fewer are available for corals and oysters to build calcium carbonate shells, and shell growth decreases.

**What the grader looks for**

Names CO<sub>2</sub> absorption by the ocean; mentions carbonic acid or increased H<sup>+</sup>; states that carbonate availability falls; connects to organisms (shell or skeleton formation); uses direction words and does not confuse acidification with warming or ozone loss.

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## Coach's Playbook

- 1 Keep the three big gas stories separate: ozone (CFCs, UV), greenhouse effect (heat), and ocean acidification (pH).
- 2 For a climate effect, state the direction and the mechanism ("because...").
- 3 In calculations, write the emission factor with units so they cancel, and report a decrease as a decrease.
- 4 Offer realistic solutions with a stated added benefit.

### Common traps

1. Stating that CO<sub>2</sub> destroys the ozone layer. 2. Attributing sea level rise to melting sea ice. 3. Writing that invasive species have "no natural predators" as a trait. 4. Giving the doubling time but not adding it to the starting year.

### Quick Check

Q1: Which treaty phased out CFCs? A: The Montreal Protocol. Q2: What causes sea level rise? A: Thermal expansion and melting land ice. Q3: 3.5% growth, doubling time? A:  $70/3.5 = 20$  years.

### Challenge Corner

Ozone over a station falls from 300 DU to 180 DU. (a) Find the percent decrease. (b) UV-B rises. Explain why a higher-latitude city may see more skin cancer risk even though ozone loss is largest over Antarctica. Solution: (a)  $\frac{180-300}{300} \times 100 = -40\%$ . (b) Ozone-poor air and the ozone hole can drift to populated areas, and thinner ozone anywhere lets more UV-B through.

## Practice

### PRACTICE Unit 9 Practice

Show your work. A calculator is allowed. Justify conclusions.

1. What is the main cause of the Antarctic ozone hole?
  - (A) Carbon dioxide absorbing UV radiation
  - (B) Rising levels of ground-level ozone
  - (C) Chlorine and bromine from CFCs and halons catalytically destroying stratospheric ozone
  - (D) Sulfur dioxide from acid rain
2. Greenhouse gases warm Earth mainly because they
  - (A) absorb outgoing infrared radiation and re-emit some of it toward the surface
  - (B) block incoming ultraviolet radiation
  - (C) reflect visible sunlight back to space
  - (D) destroy stratospheric ozone
3. Which two processes mainly drive sea level rise from climate change?
  - (A) Melting sea ice and heavier rain
  - (B) Dissolving of CO<sub>2</sub> in seawater and melting sea ice
  - (C) Increased evaporation and ocean acidification
  - (D) Thermal expansion of seawater and melting of land ice
4. A decrease in ocean pH makes it harder for oysters to form shells because
  - (A) calcium becomes too abundant
  - (B) extra hydrogen ions bind carbonate ions, lowering the carbonate available
  - (C) rising temperature melts calcium carbonate
  - (D) lower pH raises dissolved oxygen

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5. Which trait most increases the chance that a species becomes invasive?
- (A) Generalist diet with rapid reproduction and high dispersal
  - (B) Specialist diet and a narrow temperature range
  - (C) Few offspring with long parental care
  - (D) Dependence on one host plant
6. A country's carbon emissions grow 1.4% per year. About how long until the emissions double?
- (A) 20 years
  - (B) 98 years
  - (C) 50 years
  - (D) 25 years
7. Scientists want to know whether lower seawater pH reduces shell growth in marine snails.
- (a) Write a testable hypothesis.
  - (b) Describe an experiment using three pH treatments (8.1, 7.9, 7.7) and at least 6 tanks per treatment. Identify the dependent variable and two controlled variables.
  - (c) Predict the results and explain the mechanism.
  - (d) Explain how the open ocean's uptake of CO<sub>2</sub> relates to your experiment.
8. The table gives yearly data (year: CO<sub>2</sub> in ppm: global temperature anomaly in degrees C): 1980: 338: 0.26; 1990: 354: 0.44; 2000: 369: 0.62; 2010: 389: 0.72; 2020: 414: 1.02.
- (a) Describe the trends.
  - (b) Calculate the percent increase in CO<sub>2</sub> from 1980 to 2020 and the average annual increase in ppm.
  - (c) Explain how CO<sub>2</sub> changes temperature and why this does not prove cause on its own.
  - (d) Propose one local government action to reduce CO<sub>2</sub> emissions and describe one added benefit.
9. A county operates 120 diesel buses. Each bus travels 30,000 miles per year at 5 miles per gallon. Diesel releases 10.2 kg of CO<sub>2</sub> per gallon.
- (a) Calculate the fleet CO<sub>2</sub> per year in metric tons.
  - (b) An electric bus uses 2.0 kWh per mile; the grid emits 0.40 kg CO<sub>2</sub> per kWh. Calculate CO<sub>2</sub> per electric bus per year.
  - (c) If 60 diesel buses are replaced, calculate the CO<sub>2</sub> saved and the percent decrease in the fleet total.
  - (d) Identify one limitation of this estimate.
10. A native ground-nesting bird on an island is declining after an invasive predator arrived.
- (a) Explain how an invasive predator can cause a native bird to become endangered.
  - (b) Identify two traits of successful invasive species.
  - (c) Identify one law that protects endangered species and one law that regulates global trade of wildlife.
  - (d) Explain why the Montreal Protocol is considered successful.

**Answers****Unit 9: Answers and Explanations**

Read every explanation, including the ones for problems you answered correctly.

**9 Global Change****PRACTICE · UNIT 9 PRACTICE**

1. C. Halogens from CFCs act as catalysts in the stratosphere. Choice A is the common error; CO<sub>2</sub> does not destroy ozone.
2. A. Greenhouse gases absorb infrared emitted by the surface and re-emit some downward. Choice B describes the ozone layer, not greenhouse gases.
3. D. Warming water expands and land ice adds water to the ocean. Choice A is tempting, but floating sea ice already displaces its mass, so melting adds little.
4. B. Extra H<sup>+</sup> ions bind carbonate and reduce what shell builders can use. Choice D is false; acidification does not raise oxygen.
5. A. Generalists with rapid reproduction and dispersal spread widely. Choice B describes specialists, which are vulnerable instead.
6. C.  $70/1.4 = 50$  years. Choice B (98) comes from multiplying 70 by 1.4.
7. (a) If seawater pH is lowered, then snail shell growth will decrease. 1 point.  
(b) 18 tanks (or more), 6 each at pH 8.1 (control), 7.9 and 7.7; same species, size, temperature, salinity, light and food. DV: shell length or mass gain over a set time. 3 points.  
(c) Shell growth decreases as pH falls because extra H<sup>+</sup> lowers carbonate availability. 2 points.  
(d) The ocean absorbs part of the CO<sub>2</sub> from the air, which forms carbonic acid and lowers real ocean pH, so the experiment models what snails face. 1 point.

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8. (a) CO<sub>2</sub> and temperature anomaly both increase over time; CO<sub>2</sub> from 338 to 414 ppm, anomaly from 0.26 to 1.02 degrees C. 1 point.  
(b)  $\frac{414-338}{338} \times 100 = 22.5\%$  increase;  $\frac{76}{40} = 1.9$  ppm per year. 2 points.  
(c) CO<sub>2</sub> absorbs infrared and warms the surface; the trends match but correlation alone is not causation, other factors could contribute, which is why mechanisms and many lines of evidence are needed. 2 points.  
(d) Example: ordinance and incentives for building efficiency or solar; added benefit is lower electric bills or less air pollution. 2 points.
9. (a) Gallons per bus:  $30,000/5 = 6,000$ ; CO<sub>2</sub> per bus =  $6,000 \times 10.2 = 61,200$  kg; fleet = 7,344 t. 2 points.  
(b)  $30,000 \times 2.0 \times 0.40 = 24,000$  kg per bus. 1 point.  
(c) Saved:  $60 \times (61,200 - 24,000) = 2,232,000$  kg = 2,232 t;  $2,232/7,344 = 30.4\%$  decrease. 2 points.  
(d) Emissions depend on how the grid makes electricity; manufacturing and battery emissions are not counted. 1 point.
10. (a) The native bird has not evolved defenses, so the predator kills adults or eggs and the population declines; with a small range it becomes endangered. 2 points.  
(b) Generalist diet; rapid reproduction (also high dispersal). 1 point.  
(c) Endangered Species Act; CITES. 2 points.  
(d) Nations agreed to phase out CFCs, emissions of ozone-depleting substances fell, and the ozone layer is recovering. 1 point.

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# Mixed Practice Test

A mixed set of multiple-choice and free-response questions across all units, with answers, explanations, and scoring guidance.

## T Mixed Practice Test

A cumulative practice test weighted like the exam, with scoring guides.

Instructions and timing (about 50 minutes): Part A has 12 multiple-choice questions. Part B has three free-response questions of 10 practice points each, matching the three FRQ styles. Point values are Scholar Coach practice values. A calculator is allowed. Score with the guide that follows.

### PRACTICE TEST Mixed Practice Test

Part A: choose the best answer for items 1 to 12. Part B: items 13 to 15 are free response; show setup and units.

- Which process converts atmospheric nitrogen gas ( $N_2$ ) into ammonium that plants can use?  
(A) Denitrification by bacteria in waterlogged soil  
(B) Nitrogen fixation by soil microbes  
(C) Volatilization of ammonia from manure  
(D) Uptake of nitrate by plant roots
- Which island is expected to hold the most species, according to island biogeography?  
(A) A small island close to the mainland  
(B) A small island far from the mainland  
(C) A large island far from the mainland  
(D) A large island close to the mainland
- A country has a crude birth rate of 28 and a crude death rate of 8 per 1,000 people, with no migration. About how many years will it take the population to double?  
(A) 35 years  
(B) 14 years  
(C) 20 years  
(D) 70 years
- Compared with a normal year, a La Nina event is characterized by  
(A) warmer-than-average surface water in the eastern Pacific and weakened trade winds  
(B) weaker upwelling off the coast of Peru  
(C) cooler-than-average surface water in the eastern Pacific and stronger trade winds  
(D) a shift of the jet stream with no change in ocean temperature
- A city wants to reduce flooding of a stream after heavy storms. Which action is most likely to help?  
(A) Add storm drains that discharge directly into the stream  
(B) Replace parking lot asphalt with permeable pavement  
(C) Pave more roads to move water away faster  
(D) Line the stream channel with concrete
- Which is a known environmental risk of hydraulic fracturing (fracking)?  
(A) It releases large amounts of strontium-90  
(B) It increases acid rain in the stratosphere  
(C) It lowers the temperature of local streams  
(D) It can contaminate groundwater and release VOCs
- A coal-fired power plant installs wet scrubbers. Which pollutant is mainly reduced?  
(A) Sulfur dioxide  
(B) Carbon dioxide  
(C) Ground-level ozone  
(D) Radon

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8. Mercury is measured at 0.01 ppm in plankton, 0.1 ppm in small fish and 1.0 ppm in large predatory fish. This pattern is best explained by
- (A) eutrophication that depletes dissolved oxygen
  - (B) thermal pollution that lowers solubility
  - (C) biomagnification of a persistent pollutant
  - (D) decomposition by bacteria in sewage treatment
9. Ocean acidification threatens coral reefs mainly because
- (A) warmer water causes the corals to expel algae
  - (B) extra hydrogen ions reduce the carbonate ions that corals use to build skeletons
  - (C) more oxygen is dissolved at low pH
  - (D) sea ice melts and lowers salinity
10. Which change would raise global sea level the most?
- (A) Melting of Arctic sea ice
  - (B) Melting of a floating ice shelf
  - (C) Increased evaporation over the ocean
  - (D) Melting of the Greenland land ice sheet
11. A 60 W incandescent bulb is replaced with a 9 W LED that gives the same light. Both run 4 hours a day for 365 days. How much electricity is saved per year?
- (A) 74.5 kWh
  - (B) 87.6 kWh
  - (C) 13.1 kWh
  - (D) 74,460 kWh
12. A country has an age structure diagram with a very wide base. If the total fertility rate dropped to replacement level today, the population would most likely
- (A) stop growing immediately
  - (B) shrink within a decade
  - (C) continue to grow for decades because of the many young people who will have children
  - (D) become dominated by older adults at once
13. [10 points] Design an investigation. Farmers near a stream plant a strip of trees and grasses (a riparian buffer) between fields and the stream. A town wants to know whether buffers reduce nitrate in the stream.
- (a) Write a testable hypothesis. [1]
  - (b) Identify the independent and dependent variables. [2]
  - (c) Describe a procedure with sites, number of samples and timing, and identify two controlled variables. [4]
  - (d) Predict the results and explain the mechanism. [1]
  - (e) Explain how excess nitrate harms the stream. [1]
  - (f) Propose one additional action the town could take to reduce nitrate pollution. [1]
14. [10 points] Analyze data. A region reported its electricity mix. Total generation was 400 TWh in 2010 and 420 TWh in 2025. Source / 2010 share (%) / 2025 share (%): Coal 46 / 12; Natural gas 24 / 38; Nuclear 19 / 18; Hydro 7 / 6; Wind 3 / 18; Solar 1 / 8.
- (a) Calculate the generation from coal in each year and the percent change. [2]
  - (b) Calculate the combined share of wind, solar and hydro in 2010 and 2025. [2]
  - (c) Describe how the change in coal use affects acid rain and explain the mechanism. [2]
  - (d) Explain one reason carbon dioxide emissions fell even though total generation rose. [2]
  - (e) Identify one drawback of wind power and propose a way to address it. [2]
15. [10 points] Analyze an environmental problem with calculations. A country has 5.2 million people, a crude birth rate of 22 and a crude death rate of 8 per 1,000, and no migration. In 2026 each person uses 6,000 kWh of electricity per year, generated with 0.45 kg of CO<sub>2</sub> per kWh.
- (a) Calculate the annual population growth rate as a percent. [2]
  - (b) Use the rule of 70 to find the doubling time and the year the population doubles if the rate stays constant. [2]
  - (c) Calculate the country's total annual electricity use in kWh, in scientific notation. [2]
  - (d) Calculate annual CO<sub>2</sub> emissions from electricity in metric tons. [2]
  - (e) Solar replaces 25% of the electricity. Calculate the CO<sub>2</sub> avoided in metric tons. [2]

**Key****Mixed Practice Test: Answers, Explanations, and Scoring****T****Mixed Practice Test**

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## PRACTICE TEST · MIXED PRACTICE TEST

1. B. Unit 1 (nitrogen cycle): bacteria fix  $N_2$  to ammonium. Choice A returns nitrogen to the air and is the tempting wrong direction.
2. D. Unit 2 (island biogeography): large islands support more species and nearby islands receive more colonists. Choice C ignores distance.
3. A. Unit 3:  $(28 - 8)/10 = 2.0\%$ , so doubling time  $= 70/2.0 = 35$  years. Choice D uses 70 divided by 1.
4. C. Unit 4 (El Nino and La Nina): La Nina is cooler-than-average water with stronger trade winds. Choice A describes El Nino.
5. B. Unit 5 (urban runoff): permeable pavement raises infiltration and cuts runoff. Choices A and C send more water to the stream faster.
6. D. Unit 6 (fossil fuels): fracking can contaminate groundwater and release VOCs. Choice A confuses fracking with nuclear waste.
7. A. Unit 7: scrubbers remove  $SO_2$ . Choice B is tempting but scrubbers do not remove  $CO_2$ .
8. C. Unit 8: concentration rising up the food chain is biomagnification. Choice A concerns nutrients, not toxic persistence.
9. B. Unit 9: acidification reduces carbonate for shell and skeleton building. Choice A describes coral bleaching from warming.
10. D. Unit 9: land ice adds new water; floating ice already displaces its mass. Choice B is the tempting error.
11. A. Unit 6:  $(60 - 9) W = 51 W$ ;  $51 \times 1460 h = 74,460 Wh = 74.5 kWh$ . Choice D forgets to convert Wh to kWh.
12. C. Unit 3 (age structure): population momentum. Choice A ignores the large reproductive-age cohort coming.
13. Scoring (10 points).
  - (a) 1: If a stream bank has a riparian buffer, then stream nitrate concentration will be lower than where there is no buffer.
  - (b) 2: IV: presence or width of buffer; DV: nitrate concentration (mg/L).
  - (c) 4: 1 for sampling at least 3 buffered and 3 unbuffered sites; 1 for repeated samples over time; 2 for two controls (similar fertilizer use, rainfall or flow, season, sampling method).
  - (d) 1: Nitrate is lower with buffers because plants absorb nitrogen and roots and soil slow runoff.
  - (e) 1: Excess nitrate fuels algal blooms and oxygen depletion.
  - (f) 1: Apply less fertilizer, time applications, or restore wetlands.
 Model: I predict nitrate will be lower in buffered sites because vegetation takes up nitrogen before runoff reaches the stream.
14. Scoring (10 points).
  - (a) 2: 2010:  $0.46 \times 400 = 184$  TWh; 2025:  $0.12 \times 420 = 50.4$  TWh; percent change  $= \frac{50.4 - 184}{184} \times 100 = -72.6\%$  (1 setup, 1 answer).
  - (b) 2: 2010:  $7 + 3 + 1 = 11\%$ ; 2025:  $6 + 18 + 8 = 32\%$ .
  - (c) 2: Coal burning releases  $SO_2$  and  $NO_x$ ; less coal means less acid precursors, so acid rain decreases.
  - (d) 2: Coal replaced by wind, solar and natural gas, which emit little or less  $CO_2$  per kWh.
  - (e) 2: Intermittency or bird and bat deaths; address with storage, grid connections or careful siting.
15. Scoring (10 points).
  - (a) 2:  $(22 - 8)/10 = 1.4\%$  per year.
  - (b) 2:  $70/1.4 = 50$  years;  $2026 + 50 = 2076$ .
  - (c) 2:  $5.2 \times 10^6 \times 6,000 = 3.12 \times 10^{10}$  kWh.
  - (d) 2:  $3.12 \times 10^{10} \times 0.45 = 1.404 \times 10^{10}$  kg  $= 1.4 \times 10^7$  metric tons (14.04 million).
  - (e) 2:  $0.25 \times 14.04$  million  $= 3.51$  million metric tons avoided.

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# Free-Response Clinic

Exam-style free-response questions with point-by-point scoring guides and full-credit model responses.

## X Free-Response Clinic

Three full free-response questions in the exam styles plus two short ones, with scoring guides.

### How to Use This Clinic

Time yourself: about 20 minutes per full question. The point values here are Scholar Coach practice values (10 points for each full question, 5 for the short ones). Write in complete sentences, show setup with units, and name the mechanism after every "because".

| FRQ style                               | What earns points                                                                                  | Typical loss                                                          |
|-----------------------------------------|----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------|
| Design an investigation                 | Testable hypothesis with IV and DV, replication, controls, predicted pattern, mechanism            | Hypothesis written as a question; no replicates; repeating the prompt |
| Analyze and interpret data              | Direction with numbers from the table, correct percent change with setup, explanation of the cause | Citing one point; missing parentheses; wrong region of the graph      |
| Environmental problem with calculations | Setup, unit cancellation, answer with units, then a solution with a valid benefit                  | No setup shown; forgetting to round up or to add to the start year    |

- ◆ Read each part for its command word: identify, describe, explain, calculate, propose.
- ◆ Answer the part asked and nothing more; extra wrong statements can cost the point.
- ◆ For every calculation, write the formula, the substitution with units, and the answer.

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**CLINIC Free-Response Clinic**

Answer every part. Show formulas, substitutions and units.

1. FRQ 1 [10 points, design an investigation]. A city is considering green roofs (soil and plants on a rooftop). A model of a building shows that rain falling on a flat gray roof runs into storm drains, while on a green roof some water soaks into the soil layer and some is taken up by plants. City planners want to know whether green roofs reduce stormwater runoff and rooftop temperature.
  - (a) Write a testable hypothesis about green roofs and stormwater runoff. [1]
  - (b) Identify the independent variable and the dependent variable. [2]
  - (c) Describe a procedure using at least two roof types and replicate roofs, and identify two variables to hold constant. [3]
  - (d) Describe the data pattern that would support the hypothesis. [1]
  - (e) Explain why a green roof reduces runoff. [1]
  - (f) Identify one other environmental benefit of green roofs. [1]
  - (g) Identify one limitation of the investigation. [1]
2. FRQ 2 [10 points, analyze and interpret quantitative data]. A fishery recorded its catch per unit effort (kg per boat-day): 1995: 820; 2000: 640; 2005: 430; 2010: 300; 2015: 210; 2020: 190. A no-take marine reserve was created in 2015. Fish density (fish per hectare) was surveyed in 2015 and 2020: inside the reserve 60 and 95; outside 52 and 48.
  - (a) Describe the trend in catch per unit effort from 1995 to 2020. [1]
  - (b) Calculate the percent change in catch per unit effort from 1995 to 2015. [2]
  - (c) Calculate the percent change in density from 2015 to 2020 inside the reserve and outside it. [2]
  - (d) Explain why density increased inside the reserve while it fell outside. [2]
  - (e) Identify two policies besides reserves that could rebuild the fishery. [2]
  - (f) Explain how overfishing a top predator can affect a food web. [1]
3. FRQ 3 [10 points, analyze an environmental problem with calculations]. A household uses 11,000 kWh of electricity per year from a coal plant. A rooftop solar panel is rated at 400 W and operates at 18% of its rated power averaged over the year (8,760 hours). Coal contains 24 MJ per kg, the plant is 35% efficient, and 1 kWh = 3.6 MJ. Burning 1 kg of coal releases 2.5 kg of CO<sub>2</sub>.
  - (a) Calculate the electricity one panel produces per year in kWh. [2]
  - (b) Calculate how many whole panels are needed to supply all 11,000 kWh. [2]
  - (c) Calculate the mass of coal burned per kWh delivered, in kg. [2]
  - (d) Calculate the mass of CO<sub>2</sub> avoided per year if the panels replace all 11,000 kWh. [2]
  - (e) Identify one environmental drawback of solar panels and one solution. [2]
4. FRQ 4 [5 points, short]. A coastal town plans to clear mangroves to build shrimp ponds.
  - (a) Identify two ecosystem services provided by mangroves. [2]
  - (b) Predict how clearing will affect storm damage and explain. [1]
  - (c) Describe one pollution problem caused by shrimp ponds. [1]
  - (d) Propose a realistic alternative that keeps income. [1]
5. FRQ 5 [5 points, short]. A lake in a granite region has pH 4.8. Unpolluted rain is pH 5.6.
  - (a) Identify two precursors of acid rain and one human source of each. [2]
  - (b) Calculate how many times more acidic pH 4.8 is than pH 5.6. [1]
  - (c) Explain why a lake over limestone would be less harmed. [1]
  - (d) Liming a lake raises pH; identify one limitation of this approach. [1]

**Key Free-Response Clinic: Scoring Guides and Model Responses****X Free-Response Clinic**

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**CLINIC · FREE-RESPONSE CLINIC****1. FRQ 1 scoring (10 points).**

- (a) 1: If a roof is a green roof, then stormwater runoff volume per rain event will be lower than from a gray roof.  
 (b) 2: IV: roof type (green or gray); DV: volume of runoff in liters per storm (or rooftop temperature).  
 (c) 3: 1 for at least two roof types with replicates (for example 4 each); 1 for measuring the runoff at downspouts during the same storms; 1 for two constants (roof area and slope, building type, rainfall amount, season).  
 (d) 1: Green roofs show consistently lower runoff than gray roofs.  
 (e) 1: Soil and plants allow infiltration and plant uptake and evapotranspiration, so less water flows to drains.  
 (f) 1: Lower building temperature and energy use, reduced urban heat island, or habitat for insects.  
 (g) 1: Roofs differ in age or sun exposure, or a single season is sampled.

Model: I predict that green roofs will have lower runoff because the soil holds water instead of letting it run off. Common lost points: writing the hypothesis as a question; naming only "runoff" without units or a measurement method; forgetting replication; controls that are not actually held constant.

**2. FRQ 2 scoring (10 points).**

- (a) 1: Catch per unit effort declined steadily, from 820 to 190 kg per boat-day, with the decline slowing after 2015.  
 (b) 2:  $\frac{210-820}{820} \times 100 = -74.4\%$ , a 74% decrease (1 setup, 1 answer).  
 (c) 2: Inside  $\frac{95-60}{60} \times 100 = +58.3\%$ ; outside  $\frac{48-52}{52} \times 100 = -7.7\%$ .  
 (d) 2: No fishing inside allows fish to grow, live longer and reproduce; outside, continued fishing removes fish faster than they are replaced.  
 (e) 2: Catch quotas or seasonal closures; larger mesh nets or banning destructive gear; limits on boats. Any two.  
 (f) 1: Removal of a predator can raise prey numbers and change the abundance of species lower in the web (a trophic cascade).

Model response: Catch per unit effort fell steadily from 1995 to 2015 because fishers removed fish faster than the stock could reproduce, a decrease of 74% by 2015. Inside the reserve density rose 58% because fish were protected, grew larger and produced more offspring, some of which move out to nearby waters. Outside it fell 8% because fishing continued. To rebuild stocks the fishery could set catch quotas and ban bottom trawling.

**3. FRQ 3 scoring (10 points).**

- (a) 2:  $0.400 \text{ kW} \times 8,760 \text{ h} \times 0.18 = 631 \text{ kWh per year}$ .  
 (b) 2:  $11,000/630.72 = 17.4$ , so 18 panels (must round up).  
 (c) 2: Coal energy delivered per kg =  $24 \text{ MJ} \times 0.35 = 8.4 \text{ MJ}$ ; per kWh =  $3.6/8.4 = 0.43 \text{ kg of coal per kWh}$ .  
 (d) 2: Coal =  $11,000 \times 0.4286 = 4,714 \text{ kg}$ ; CO<sub>2</sub> =  $4,714 \times 2.5 = 11,786 \text{ kg}$ , about 11.8 metric tons.  
 (e) 2: Drawback: mining and toxic materials in manufacture, or land use; solution: recycling panels, or placing them on roofs.

Model response: Coal burned per kWh is  $3.6/(24 \times 0.35) = 0.43 \text{ kg}$ . Over a year 4,714 kg of coal is avoided, and since each kg gives 2.5 kg of CO<sub>2</sub>, 11,786 kg of CO<sub>2</sub> is not released. Units cancel: kWh x kg/kWh x kg CO<sub>2</sub>/kg coal = kg CO<sub>2</sub>. Rounding up to 18 panels matters because 17 panels would leave the home short of electricity.

**4. FRQ 4 scoring (5 points).**

- (a) 2: Any two: storm and wave buffer, nursery habitat for fish, carbon storage, water filtering.  
 (b) 1: Storm damage will increase because the roots no longer slow waves and surge.  
 (c) 1: Pond effluent with nutrients, antibiotics or salt causes eutrophication or contaminates groundwater.  
 (d) 1: Mangrove-friendly aquaculture, ecotourism or sustainable harvest.

Model response: Mangroves protect the coast from storm surge and shelter young fish. Clearing them will increase storm damage because waves are no longer slowed by the dense roots. Shrimp ponds release nutrient-rich water that causes eutrophication in nearby estuaries. The town could use sustainable harvesting of mangrove crabs and ecotourism instead.

**5. FRQ 5 scoring (5 points).**

- (a) 2: SO<sub>2</sub> from burning coal; NO<sub>x</sub> from vehicle engines.  
 (b) 1:  $10^{5.6-4.8} = 10^{0.8} = 6.3$  times more acidic.  
 (c) 1: Limestone is carbonate that neutralizes acid (buffering).  
 (d) 1: Liming is temporary and expensive and does not stop the source, so the lake re-acidifies.

Model response: Burning coal releases sulfur dioxide and vehicles release nitrogen oxides; these form sulfuric and nitric acid. The lake is 6.3 times more acidic than clean rain. Limestone neutralizes acid and raises pH, so lakes in limestone areas are buffered. Liming only treats the symptom, so it must be repeated until emissions fall.

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# Reference: Formulas, Skills Checklist, and Glossary

Quick-reference pages to review the night before the exam.

## R1 Equations, Constants and Skills Reference

Formulas, conversions and calculation routines you should be able to use from memory. Check the reference information inside the exam software for what it supplies.

### Core Equations

| Quantity                   | Equation                                                                                         | Note                                                                |
|----------------------------|--------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|
| Percent change             | $\frac{\text{new-old}}{\text{old}} \times 100$                                                   | Keep the parentheses; state increase or decrease                    |
| Percent (part of whole)    | $\frac{\text{part}}{\text{whole}} \times 100$                                                    | Per capita = total divided by population                            |
| Rule of 70                 | Doubling time = $\frac{70}{\text{percent growth rate}}$                                          | $\ln 2/\text{rate}$ (decimal) also works; add to start year         |
| Population growth rate (%) | $\frac{\text{CBR}-\text{CDR}}{10}$                                                               | Rates per 1,000; add migration per 1,000 if included                |
| Half-life                  | $N = N_0(0.5)^{t/t_{1/2}}$                                                                       | Count half-lives: $t/t_{1/2}$                                       |
| pH                         | $\text{pH} = -\log[\text{H}^+]$                                                                  | One unit = 10-fold; 0.1 unit = about 26%                            |
| Trophic transfer           | Energy at next level $\approx 0.10 \times$ energy at this level                                  | About 10% passes up                                                 |
| Net primary productivity   | $\text{NPP} = \text{GPP} - R$                                                                    | R = respiration by producers                                        |
| Dilution                   | $C_1V_1 = C_2V_2$                                                                                | Same units on both sides                                            |
| 5-day BOD                  | $(\text{DO}_i - \text{DO}_5) \times \frac{\text{bottle volume}}{\text{sample volume}}$           | mg/L                                                                |
| Dose                       | Dose (mg) = dose (mg/kg) $\times$ mass (kg)                                                      | Applies to LD50 values                                              |
| Energy                     | $E(\text{kWh}) = P(\text{kW}) \times t(\text{h})$                                                | Efficiency = $\frac{\text{useful output}}{\text{input}} \times 100$ |
| CO <sub>2</sub> equivalent | mass $\times$ GWP                                                                                | Methane about 28 (100-year)                                         |
| Photosynthesis             | $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$ | Respiration is the reverse                                          |

### Constants and Conversions

| Quantity         | Value                                                                                                                                                                                         |
|------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Metric prefixes  | tera 10 <sup>12</sup> , giga 10 <sup>9</sup> , mega 10 <sup>6</sup> , kilo 10 <sup>3</sup> , centi 10 <sup>-2</sup> , milli 10 <sup>-3</sup> , micro 10 <sup>-6</sup> , nano 10 <sup>-9</sup> |
| Mass and volume  | 1 metric ton = 1,000 kg; 1 kg = 2.205 lb; 1 L = 1,000 mL; 1 m <sup>3</sup> = 1,000 L; 1 gal = 3.785 L                                                                                         |
| Length and area  | 1 mile = 1.609 km; 1 hectare = 10,000 m <sup>2</sup> = 2.47 acres; 1 acre = 43,560 ft <sup>2</sup>                                                                                            |
| Energy and power | 1 kWh = 3.6 MJ = 3,412 BTU; 1 W = 1 J/s                                                                                                                                                       |
| Concentration    | 1 ppm = 1,000 ppb; 1 ppm = 1 mg/L in dilute water; 1% = 10,000 ppm                                                                                                                            |
| Fuel (typical)   | Gasoline: about 8.9 kg CO <sub>2</sub> per gallon. Use the value a problem gives.                                                                                                             |

### Calculation Routine

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- 1 Write the formula and what each symbol means.
- 2 Substitute numbers with units on every term.
- 3 Cancel units in a line of dimensional analysis.
- 4 Compute, then round only at the end; use scientific notation for very large or small values.
- 5 State the answer with units and direction (increase or decrease), and add the doubling time to the start year if a year is asked.

### Scientific notation

Multiplying: add exponents. Dividing: subtract exponents.  
Area uses squared conversion factors and volume cubed.

## R2 Skills Checklist and Glossary

Check your readiness on the seven science practices and review key pollution and global change terms.

### Skills Checklist

Rate yourself 1 to 3 on each skill. Revisit anything below 3 before the exam.

| Practice                | I can...                                                                           |
|-------------------------|------------------------------------------------------------------------------------|
| Concept Explanation     | explain a process and give a mechanism with "because"                              |
| Visual Representations  | read and sketch cycles, food webs, maps and diagrams                               |
| Text Analysis           | pull evidence and claims from a short passage                                      |
| Scientific Experiments  | write a testable hypothesis, name IV and DV, and describe controls and replication |
| Data Analysis           | describe trends with numbers, and read graphs at the right place                   |
| Mathematical Routines   | show setup, units, and sign for percent change, rule of 70, half-life and dilution |
| Environmental Solutions | propose a realistic action with a valid benefit and a trade-off                    |

### Glossary

| Term                | Meaning                                                                        |
|---------------------|--------------------------------------------------------------------------------|
| Albedo              | fraction of sunlight a surface reflects                                        |
| Bioaccumulation     | buildup of a substance in one organism over time                               |
| Biomagnification    | rising concentration at higher trophic levels                                  |
| BOD                 | oxygen used by microbes decomposing organic matter                             |
| Carrying capacity   | largest population an environment can sustain                                  |
| Catalytic converter | device that turns CO, NO <sub>x</sub> and hydrocarbons into less harmful gases |
| CERCLA              | Superfund law for cleaning abandoned toxic sites                               |
| CFCs                | chlorine compounds that destroy stratospheric ozone                            |
| Clean Air Act       | law setting air quality standards and limiting emissions                       |
| Clean Water Act     | law regulating discharges into surface water                                   |
| CITES               | treaty regulating international wildlife trade                                 |
| Criteria pollutants | six common air pollutants regulated by the EPA                                 |
| Delaney Clause      | bans food additives shown to cause cancer                                      |
| Dissolved oxygen    | oxygen in water, in mg/L                                                       |
| Doubling time       | years to double: 70 divided by percent growth rate                             |

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| Term                    | Meaning                                                     |
|-------------------------|-------------------------------------------------------------|
| Dose response           | relationship between dose and effect                        |
| Ecosystem services      | benefits ecosystems provide to people                       |
| Endangered Species Act  | law protecting listed species and habitat                   |
| Endocrine disruptor     | chemical that interferes with hormones                      |
| Eutrophication          | nutrient over-enrichment that causes blooms and oxygen loss |
| Fecal coliform          | bacteria that signal sewage contamination                   |
| Fertility rate (TFR)    | average children per woman in a lifetime                    |
| Greenhouse effect       | warming from gases that absorb infrared                     |
| GWP                     | warming power of a gas relative to CO <sub>2</sub>          |
| Half-life               | time for half a substance to decay                          |
| Hypoxia                 | low dissolved oxygen                                        |
| Invasive species        | nonnative species that harms an ecosystem                   |
| Kyoto Protocol          | treaty with emissions targets for developed nations         |
| LD50                    | dose that kills half of a test population                   |
| Leachate                | liquid that drains through waste and picks up pollutants    |
| Mangrove                | coastal tree wetland that buffers storms                    |
| Montreal Protocol       | treaty phasing out ozone-depleting substances               |
| Nonpoint source         | diffuse pollution source such as runoff                     |
| NO <sub>x</sub>         | nitrogen oxides from combustion                             |
| Ocean acidification     | pH decline from absorbed CO <sub>2</sub>                    |
| Ozone (ground-level)    | secondary pollutant in smog                                 |
| Ozone layer             | stratospheric layer absorbing UV-B                          |
| PAN                     | irritant formed in photochemical smog                       |
| Particulate matter      | tiny solid or liquid particles in air                       |
| Point source            | single identifiable pollution source                        |
| POPs                    | persistent organic pollutants                               |
| Primary pollutant       | pollutant emitted directly                                  |
| Radon                   | radioactive soil gas that enters homes                      |
| RCRA                    | law controlling hazardous waste                             |
| Safe Drinking Water Act | law setting standards for public water                      |
| Scrubber                | device removing SO <sub>2</sub> from exhaust                |
| Secondary pollutant     | pollutant formed by reactions in the air                    |
| Sea level rise          | from thermal expansion and melting land ice                 |
| Thermal inversion       | warm air layer trapping cool air and pollution below        |
| Thermal pollution       | heated water discharge that lowers oxygen                   |
| Threshold               | dose below which no effect occurs                           |
| VOC                     | volatile organic compound, such as gasoline vapor           |
| Wetland                 | saturated land that filters water and stores floods         |

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