

AP ENVIRONMENTAL SCIENCE STUDY GUIDE

181 High-Yield Concepts

Advanced Placement Course | College Board CED-aligned

- All 9 CED units: Ecosystems to Global Change
- Cycles, populations, pollution, and climate science
 - Energy systems, land use, and sustainability
- Perfect for the AP Environmental Science exam in May

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How to Use This Guide

This guide condenses the AP Environmental Science course and exam description into high-yield concepts. It is not a textbook replacement -- it is the fastest way to review everything the exam covers and to target your weak units.

The AP Environmental Science exam is 2 hours 40 minutes: Section I is 80 multiple-choice questions (90 minutes) and Section II is 3 free-response questions (70 minutes: one data-set, one document-based, one synthesis/analysis). The 9 units below map directly to the College Board Course and Exam Description, with unit weights shown on each section.

How to use the concepts

- Each concept = term + concise explanation + high-yield exam tip (+ example where useful).
- First pass: read every concept in order. Underline anything unfamiliar.
- Second pass: focus only on the concepts you underlined.
- Two weeks before the exam: rapid-review every tip line (they are the highest-yield).
- Use the Table of Contents to jump straight to your weakest units.

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Total: 181 high-yield concepts

How to use the TOC: work through the units in order on your first pass, then jump back to your weakest units for review. Each concept includes an Explanation, a high-yield exam tip, and where useful an Example. Mark the concepts you miss with a small dot in the margin and revisit them 48 hours later.

Unit 1: Unit 1: The Living World: Ecosystems

6-8% of the exam. Energy flow, biogeochemical cycles, and ecosystem structure.

1 Ecosystems & Biomes

Explanation: An ecosystem is a community of organisms plus their physical environment. Biomes are large regions with characteristic climates and life forms (tropical rainforest, desert, tundra, grassland, temperate forest, taiga, chaparral, savanna).

APES Tip: *match biome to climate: temperature and precipitation are the two drivers -- rainforest = warm + wet, tundra = cold + dry.*

Example: The Amazon rainforest and the Sahara desert differ mainly in precipitation, not temperature -- biome boundaries follow climate.

2 Energy Flow & the 10% Rule

Explanation: Energy flows through trophic levels: producers (plants) -> primary consumers -> secondary -> tertiary. Only ~10% of energy transfers between levels; the rest is lost as heat (respiration).

APES Tip: *the 10% rule explains why food chains rarely exceed 4-5 levels and why top predators are rare.*

Example: A 1000-kcal producer level supports only ~100 kcal of primary consumers and ~10 kcal of secondary consumers.

3 Food Chains & Food Webs

Explanation: A food chain is a single linear feeding path; a food web is the interconnected set of chains. Webs are more realistic and more stable than chains.

APES Tip: *removing a keystone species from a web causes cascading effects -- know a keystone example (sea otters, wolves).*

Example: Removing wolves from Yellowstone led to elk overpopulation and riparian habitat loss -- the wolves were keystone.

4 Primary Productivity (NPP & GPP)

Explanation: Gross primary productivity (GPP) is total energy captured by photosynthesis; net primary productivity (NPP) = GPP - plant respiration. NPP is the energy available to consumers.

APES Tip: *NPP is highest in tropical rainforests and estuaries/swamps, lowest in deserts and open oceans -- a classic comparison.*

Example: Estuaries have NPP rivaling rainforests per unit area due to abundant nutrients and sunlight.

5 Trophic Pyramids

Explanation: Pyramids of energy (always upright), biomass (usually upright), and numbers (can be inverted). Energy pyramids can never be inverted because energy is lost at each step.

APES Tip: *'energy pyramid inverted?' -- never; ask instead which biomass/number pyramid can flip.*

Example: A single oak tree (one producer) can support thousands of insects -- a pyramid of numbers inverted at the base.

6 The Carbon Cycle

Explanation: Carbon moves through atmosphere (CO₂), biosphere (photosynthesis, respiration), oceans (dissolved CO₂, shells), and lithosphere (fossil fuels, limestone). Humans add CO₂ by burning fossil fuels and deforestation.

APES Tip: *identify the FAST (photosynthesis/respiration) vs SLOW (fossil fuel formation, rock weathering) parts of the cycle.*

Example: Burning coal transfers carbon stored for 300 million years into the atmosphere in decades -- a slow pool going fast.

7 The Nitrogen Cycle

Explanation: Nitrogen (N₂) is unusable by most organisms. Key steps: nitrogen fixation (bacteria/lightning -> ammonia), nitrification (ammonia -> nitrite -> nitrate), assimilation, ammonification, and denitrification (nitrate -> N₂).

APES Tip: *know which organism does which step: Rhizobium (root nodules) fix; Nitrosomonas/Nitrobacter nitrify; denitrifying bacteria return N₂ to air.*

Example: Legumes host Rhizobium in root nodules -- farmers rotate legumes to add usable nitrogen to soil.

8 The Phosphorus Cycle

- Explanation:** Phosphorus cycles through rocks, soil, water, and organisms -- with NO atmospheric phase. It is often the limiting nutrient in freshwater ecosystems; excess causes eutrophication.
- APES Tip:** *phosphorus's lack of a gas phase makes it slow and easily limiting; runoff of phosphate fertilizer drives algal blooms.*
- Example:** Detergent phosphate runoff into a lake fuels an algal bloom; when algae die and decompose, oxygen is depleted.
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9 The Water (Hydrologic) Cycle

- Explanation:** Water moves via evaporation, transpiration, condensation, precipitation, infiltration, runoff, and groundwater flow. Human impacts: overpumping aquifers, paving over recharge zones, and dam construction.
- APES Tip:** *transpiration + evaporation = evapotranspiration; deforestation reduces it, changing local rainfall.*
- Example:** Paving a watershed prevents infiltration, increasing flood runoff and cutting groundwater recharge.
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10 The Sulfur Cycle & Acid Deposition

- Explanation:** Sulfur cycles through rocks, oceans, and air (H₂S, SO₂, sulfate). Burning coal releases SO₂, which forms sulfuric acid in the atmosphere -- acid rain that harms forests, lakes, and buildings.
- APES Tip:** *acid rain comes mainly from SO₂ (coal) and NO_x (vehicles); the Clean Air Act amendments (1990) cut SO₂ via cap-and-trade.*
- Example:** Lakes in the Adirondacks acidified as SO₂ from Midwest coal plants fell as acid rain; liming and emissions cuts helped recovery.
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11 The Law of Tolerance & Limiting Factors

- Explanation:** Organisms have ranges of tolerance for conditions (temperature, salinity, pH). A limiting factor is the resource most scarce relative to need -- it controls population size.
- APES Tip:** *the limiting factor concept explains carrying capacity: Liebig's barrel -- the shortest stave limits the water.*
- Example:** Phosphorus often limits freshwater algal growth; nitrogen limits many terrestrial and marine systems.
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12 Ecological Niches & Competition

- Explanation:** A niche is an organism's role (habitat + resource use). The competitive exclusion principle: two species cannot occupy the same niche indefinitely -- one outcompetes the other.
- APES Tip:** *resource partitioning (niche differentiation) allows coexistence -- e.g., warblers feeding at different tree heights.*
- Example:** Five warbler species share a spruce forest by feeding at different heights -- resource partitioning reduces competition.
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13 Predation, Herbivory & Symbiosis

- Explanation:** Interactions: predation (+/-), herbivory (+/-), competition (-/-), mutualism (+/+), commensalism (+/0), parasitism (+/-). These structure communities and drive coevolution.
- APES Tip:** *know the sign pairs -- mutualism is the only +/+; the exam tests interaction classification.*
- Example:** Coral and zooxanthellae algae are mutualistic: the algae photosynthesize for the coral; the coral provides shelter.
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14 Keystone Species

- Explanation:** A keystone species has a disproportionately large effect on community structure relative to its abundance. Removing it causes cascading declines.
- APES Tip:** *keystone examples to cite: sea otters (control urchins -> kelp forests), wolves (control elk -> vegetation), beavers (engineers).*
- Example:** Sea otter loss -> urchin boom -> kelp forest collapse -> loss of fish habitat; otters are keystone.
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15 Ecosystem Resilience & Resistance

- Explanation:** Resistance is an ecosystem's ability to withstand disturbance; resilience is its speed of recovery. Biodiversity generally increases both.
- APES Tip:** *diverse ecosystems recover faster; monocultures (crops, plantations) have low resilience.*
- Example:** A diverse prairie regrows after fire quickly; a single-crop field devastated by disease may not recover.
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16 Biogeochemical Cycle Review

- Explanation:** The major cycles -- carbon, nitrogen, phosphorus, water, sulfur -- move matter between pools (reservoirs) via biological, geological, and chemical processes. Matter cycles; energy flows.
- APES Tip:** *the mantra 'matter cycles, energy flows' answers many conceptual questions.*
- Example:** Energy enters ecosystems as sunlight and exits as heat, while carbon, nitrogen, and phosphorus atoms keep cycling.
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17 Estuaries & Wetlands

- Explanation:** Estuaries (where rivers meet seas) and wetlands (marshes, swamps, bogs) are among the most productive ecosystems: nurseries, flood control, water filtration, and biodiversity hotspots.
- APES Tip:** *wetlands = 'nature's kidneys' (filter pollutants) and 'nature's sponges' (flood control) -- know both functions.*
- Example:** Coastal marshes filter runoff before it reaches the ocean and buffer storm surge -- yet half have been drained for development.
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18 Aquatic Biomes & Zones

- Explanation:** Oceans: intertidal, neritic (continental shelf), oceanic, benthic zones; photic vs aphotic. Freshwater: littoral, limnetic, profundal zones. Each zone hosts distinct life adapted to light, depth, and pressure.
- APES Tip:** *the photic zone (sunlit) supports photosynthesis; the aphotic (below) relies on marine snow and chemosynthesis.*
- Example:** Coral reefs thrive in the warm, sunlit neritic zone; deep-sea vents support chemosynthetic ecosystems in the aphotic zone.
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19 Terrestrial Biomes & Climate

- Explanation:** Biomes are determined by temperature and precipitation: tundra (cold, permafrost), taiga (coniferous forest), temperate deciduous forest, temperate grassland, chaparral (Mediterranean), desert, savanna, tropical rainforest.
- APES Tip:** *put biomes on a temperature-precipitation grid; each biome's plants/animals are adapted to its climate regime.*
- Example:** Chaparral's fire-adapted shrubs survive dry summers; desert organisms conserve water with waxy coatings and nocturnal habits.
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20 Ecosystem Services

- Explanation:** Ecosystem services: provisioning (food, timber, water), regulating (climate, flood, pollination), supporting (nutrient cycling, soil formation), and cultural (recreation, aesthetics).
- APES Tip:** *classify services on FRQs -- bees pollinating crops is regulating/provisioning; forests filtering water is regulating.*
- Example:** A wetland's flood buffering is a regulating service; the fish it produces are provisioning -- one ecosystem, many services.
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Unit 2: Unit 2: The Living World: Biodiversity

6-8% of the exam. Biodiversity's value, threats, and conservation.

21 What Is Biodiversity?

Explanation: Biodiversity = the variety of life: genetic diversity (variation within species), species diversity (number/variety of species), and ecosystem diversity (variety of habitats). All three levels matter.

APES Tip: *distinguish the three levels and give examples -- genetic diversity lets populations adapt to change.*

Example: A disease that kills one banana variety (low genetic diversity) is a crisis, while a diverse crop pool has resistant strains.

22 The Value of Biodiversity

Explanation: Biodiversity provides direct value (food, medicine, timber), indirect value (ecosystem services), and existence/ethical value. It is the raw material for adaptation and innovation.

APES Tip: *'why does biodiversity matter?' -- cite ecosystem services, medicines, resilience, and ethics.*

Example: The rosy periwinkle (Madagascar) yielded cancer drugs -- a species' value unknown until discovered.

23 Species Richness vs Evenness

Explanation: Species richness = number of species; species evenness = how evenly individuals are distributed among species. Both contribute to diversity (measured by indices like Shannon's).

APES Tip: *a community can have high richness but low evenness (one dominant species) -- compute diversity carefully.*

Example: A field with 100 individuals of 10 species split evenly has higher diversity than one with 91 of species A and 1 each of nine others.

24 Threats: Habitat Loss

Explanation: Habitat destruction (deforestation, urbanization, agriculture) is the #1 driver of biodiversity loss. Fragmentation isolates populations, reducing gene flow and increasing edge effects.

APES Tip: *habitat loss > overexploitation > pollution > invasive species > climate change -- rank them on FRQs.*

Example: Clearing Amazon forest for cattle pasture fragments habitat; isolated fragments lose species to small-population effects.

25 Threats: Invasive Species

Explanation: Invasive species are non-native organisms that outcompete natives (no natural predators), altering ecosystems: kudzu, zebra mussels, cane toads, lionfish, and Burmese pythons.

APES Tip: *invasives reduce biodiversity; control methods: prevention, mechanical removal, chemical, biological (carefully).*

Example: Zebra mussels filter plankton, starving native mussels and clogging pipes across the Great Lakes.

26 Threats: Overexploitation

Explanation: Overhunting and overfishing drive extinction: the dodo, passenger pigeon, and many marine stocks (Atlantic cod collapse). Regulation (quotas, CITES) aims to sustain harvests.

APES Tip: *maximum sustainable yield (MSY) = the largest harvest that keeps a population stable; exceeding it collapses stocks.*

Example: Atlantic cod off Newfoundland collapsed in 1992 after decades of overfishing -- the stock has not recovered.

27 Threats: Pollution

Explanation: Pollution harms biodiversity directly (toxicity) and indirectly (habitat degradation, eutrophication, acid rain). Endocrine disruptors and mercury bioaccumulate with severe effects.

APES Tip: *connect pollution to the cycles -- fertilizer runoff feeds algal blooms that create dead zones.*

Example: The Gulf of Mexico dead zone (hypoxia) forms each summer as Mississippi runoff fuels algal blooms that deplete oxygen.

28 Threats: Climate Change

- Explanation:** Climate change shifts species' ranges, alters phenology (timing), and stresses ecosystems -- coral bleaching from warming oceans is the signature example.
- APES Tip:** *coral bleaching = zooxanthellae expelled during heat stress; recovery is possible but repeated stress kills the reef.*
- Example:** The 2016-17 Great Barrier Reef bleaching killed ~50% of its corals -- driven by marine heatwaves.
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29 Island Biogeography

- Explanation:** Species richness on islands balances immigration (closer to mainland = more) and extinction (larger island = fewer extinctions). The theory guides conservation design.
- APES Tip:** *S = balance of immigration and extinction: near + large = most species; far + small = least.*
- Example:** A large island near the mainland holds more species than a small remote one -- the equilibrium model predicts it.
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30 Conservation Biology & Hotspots

- Explanation:** Biodiversity hotspots are areas with high endemism and high threat. Conservation tools: protected areas, corridors, habitat restoration, captive breeding, and gene banks.
- APES Tip:** *corridors connect fragments, enabling gene flow; hotspots concentrate conservation effort efficiently.*
- Example:** The California Floristic Province is a hotspot; wildlife corridors under highways reconnect fragmented ranges.
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31 The Endangered Species Act (ESA)

- Explanation:** The U.S. Endangered Species Act (1973) protects listed species and their critical habitat; recovery plans guide conservation. Successes: bald eagle, gray wolf, California condor.
- APES Tip:** *ESA = the strongest U.S. conservation law; its trade provisions align with CITES internationally.*
- Example:** The bald eagle recovered from near-extinction to delisted (2007) -- an ESA success story.
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32 Habitat Corridors & Connectivity

- Explanation:** Corridors are strips of habitat linking fragments; they allow migration, gene flow, and range shifts under climate change. Overpasses/underpasses reduce roadkill.
- APES Tip:** *corridors are the standard answer to fragmentation -- cite them in conservation design questions.*
- Example:** Florida's panther population rebounded partly through corridor conservation connecting breeding ranges.
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33 Genetic Diversity & Adaptation

- Explanation:** Genetic diversity is the raw material for natural selection; low diversity (bottlenecks, inbreeding) makes populations vulnerable to disease and change.
- APES Tip:** *bottlenecks (population crash) reduce diversity; examples: cheetahs, northern elephant seals.*
- Example:** Cheetahs' extreme genetic similarity makes them vulnerable to disease -- a bottleneck legacy.
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34 Edge Effects

- Explanation:** Habitat edges have different conditions (more light, wind, predators) than interiors; small fragments are mostly edge, harming interior species.
- APES Tip:** *fragment shape matters: long thin fragments maximize edge; round fragments minimize it.*
- Example:** Forest interior birds decline in fragmented woods as edge predators (cowbirds, raccoons) penetrate.
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35 Ecotourism & Economic Incentives

- Explanation:** Ecotourism values living ecosystems, funding conservation (Costa Rica's rainforests, African safaris). It can protect biodiversity by making it economically valuable.
- APES Tip:** *ecotourism is a 'use it or lose it' incentive -- but must be managed to avoid harming habitats.*
- Example:** Costa Rica's ecotourism economy incentivized reforestation -- forest cover rebounded from 26% to 50%+.
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36 The Sixth Mass Extinction

- Explanation:** Current extinction rates are 100-1,000x background -- the 'sixth mass extinction,' driven by human activity (habitat loss, overexploitation, pollution, climate change).
- APES Tip:** *contrast with the five past mass extinctions: this one has an anthropogenic cause.*
- Example:** Amphibians are declining worldwide (chytrid fungus, habitat loss) -- a bellwether of the current extinction event.
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37 Indicator Species

- Explanation:** Indicator species signal environmental conditions: lichens (air quality), mayflies (stream health), and frogs (general environmental stress) -- their presence/absence reveals ecosystem status.
- APES Tip:** *indicator species are 'canaries in the coal mine' -- cheap early-warning systems.*
- Example:** Trout require cold, oxygenated water; their disappearance signals stream degradation.
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38 Umbrella & Flagship Species

- Explanation:** Umbrella species (large ranges, e.g., tigers, elephants) protect many others when conserved; flagship species (pandas, whales) attract public support and funding.
- APES Tip:** *conserving the umbrella conserves the whole habitat; flagships are marketing for conservation.*
- Example:** Protecting tiger habitat in India also protects deer, birds, and plants sharing the landscape.
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39 Restoration Ecology

- Explanation:** Restoration returns degraded ecosystems toward a historic/functional state: replanting, rewilding, dam removal, and wetland restoration.
- APES Tip:** *restoration success is measured by ecosystem function (nutrient cycling, productivity), not just species presence.*
- Example:** Kissimmee River (Florida) restoration removed channelization, reviving floodplain wetlands and wading birds.
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40 The Biodiversity-Services Connection

- Explanation:** Biodiversity underpins ecosystem services: more diverse systems are more productive, stable, and resilient -- protecting biodiversity is protecting services.
- APES Tip:** *link units 1-2: diversity -> stability -> services -> human well-being.*
- Example:** A diverse pollinator community ensures crop pollination even when one bee species declines.
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Unit 3: Unit 3: Populations

10-15% of the exam. Population ecology, growth models, and human demographics.

41 Population Ecology Basics

Explanation: A population is a group of the same species in an area. Key metrics: size, density, distribution, age structure, sex ratio, and growth rate ($r = \text{birth rate} - \text{death rate}$).

APES Tip: *growth rate $r = (\text{births} - \text{deaths} + \text{immigration} - \text{emigration})/\text{population}$; know how to compute it.*

Example: A population with 100 births, 40 deaths, 20 immigrants, and 10 emigrants in a year grows by 70 individuals.

42 Exponential Growth (J-Curve)

Explanation: Exponential growth ($N = N_0 e^{rt}$) occurs with unlimited resources: growth accelerates, producing a J-curve. r is the intrinsic rate of increase.

APES Tip: *exponential = J-curve, no carrying capacity; only possible temporarily in nature.*

Example: Bacteria doubling every 20 minutes: 1 cell → 2 billion in 11 hours -- exponential growth in action.

43 Logistic Growth (S-Curve) & Carrying Capacity

Explanation: Logistic growth levels off at carrying capacity K (the maximum population the environment sustains): $dN/dt = rN(1 - N/K)$, an S-curve.

APES Tip: *K = carrying capacity; the growth rate is fastest at $N = K/2$ and slows near K .*

Example: Deer introduced to an island grow exponentially, then plateau as food runs out -- K = the plateau level.

44 Density-Dependent vs Density-Independent Factors

Explanation: Density-dependent factors (competition, predation, disease) strengthen as population grows; density-independent factors (weather, fire, floods) affect populations regardless of density.

APES Tip: *classify each limiting factor; the exam pairs this with growth-curve questions.*

Example: A winter blizzard (density-independent) kills birds regardless of flock size; disease spreads faster in dense flocks (dependent).

45 Survivorship Curves

Explanation: Type I: high survival until old age (humans, elephants). Type II: constant death rate (birds, squirrels). Type III: high early mortality, few reach adulthood (fish, trees).

APES Tip: *match species to curves -- Type III species compensate with huge reproductive output.*

Example: Oysters release millions of larvae (Type III); most die young, a few survive to reproduce.

46 r-Strategists vs K-Strategists

Explanation: r-strategists: many small offspring, little parental care, boom-bust (insects, mice, weeds). K-strategists: few large offspring, heavy care, stable near K (elephants, whales, humans).

APES Tip: *r = 'r-selected reproduces rapidly'; K = 'K-selected near carrying capacity'.*

Example: Dandelions (r) colonize disturbed ground fast; elephants (K) invest years per calf.

47 Age Structure Diagrams

Explanation: Age pyramids show population structure: expanding (wide base), stable (column), declining (narrow base). They predict future growth and support needs.

APES Tip: *a wide base = rapid growth (schools needed); narrow base = aging (healthcare/retirement needed).*

Example: Nigeria's pyramid (wide base) means a youth boom; Japan's (narrow base) means a shrinking workforce.

48 The Demographic Transition Model

- Explanation:** Societies move through stages: 1) high birth/death, 2) death falls (growth), 3) birth falls (slowing), 4) low birth/death (stable), 5) declining (birth < death).
- APES Tip:** *the transition explains global population growth: stage 2 (industrializing) has the fastest growth.*
- Example:** Mexico is in late stage 3: death rates fell long ago, birth rates now falling -- growth slowing.
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49 The Demographic Transition & Development

- Explanation:** Falling birth rates follow development: education (especially women's), urbanization, healthcare, and family planning. The demographic dividend comes when working-age share peaks.
- APES Tip:** *women's education + contraception access = the strongest levers for reducing birth rates.*
- Example:** Bangladesh's birth rate fell sharply as girls' education and family planning access expanded.
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50 Human Population Growth & the J-Curve

- Explanation:** Human population grew slowly until ~1800, then exploded (industrialization, medicine, agriculture): from 1 billion (1804) to 8 billion (2022) -- a J-curve.
- APES Tip:** *the Green Revolution and sanitation/medicine drove the boom; growth rate has now peaked and is slowing.*
- Example:** World population added its last billion in ~12 years (2010-2022) -- growth is decelerating.
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51 The Demographic Transition & Total Fertility Rate

- Explanation:** Total fertility rate (TFR) = average children per woman. Replacement level is ~2.1 in developed countries (accounting for mortality). TFR below 2.1 shrinks a population.
- APES Tip:** *TFR vs replacement (2.1): below -> decline, above -> growth; know current global TFR (~2.3 and falling).*
- Example:** Italy's TFR of ~1.2 means its population declines without immigration.
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52 The IPAT Model

- Explanation:** $I = P \times A \times T$: environmental impact = Population x Affluence (consumption) x Technology (impact per unit). Rich countries have high A; poor countries high P.
- APES Tip:** *the IPAT model explains why high-consumption nations can out-impact populous poor ones.*
- Example:** A single American's consumption footprint rivals dozens of Ethiopians' -- affluence multiplies impact.
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53 Population Momentum

- Explanation:** Even after fertility falls to replacement, populations keep growing for decades because of the young age structure (many future parents already born).
- APES Tip:** *momentum explains why India keeps growing after its TFR fell below replacement.*
- Example:** China's population kept growing after the one-child policy because of its huge young cohorts.
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54 Family Planning & Women's Education

- Explanation:** Access to contraception and girls' education consistently lower birth rates: educated women marry later, work more, and choose smaller families.
- APES Tip:** *cite both in 'how to reduce population growth' answers -- they beat economic growth alone.*
- Example:** In Kerala, India, high female literacy correlates with a birth rate near replacement despite low income.
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55 Overpopulation vs Overconsumption

- Explanation:** Overpopulation (too many people) vs overconsumption (too much per person): the largest environmental impacts come from rich-world consumption, not just headcount.
- APES Tip:** *'which matters more?' -- a defensible answer weighs affluence (A) against population (P) in IPAT.*
- Example:** A wealthy nation with 50 million people can emit more CO₂ than a poor one with 500 million.
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56 Population Distribution & Density

Explanation: Population density = people per area; distribution is where people live (urban, coastal, river valleys). Density affects resource demand and pollution concentration.

APES Tip: *density matters for local impacts (city smog) but not total impact (that needs total population + consumption).*

Example: Bangladesh's high density stresses its deltas; Canada's low density spreads impacts thinly.

57 The Human Development Index (HDI)

Explanation: HDI combines life expectancy, education, and income per capita to measure well-being beyond GDP. High HDI usually correlates with low population growth.

APES Tip: *HDI > GDP as a welfare measure; link high HDI to stage 4-5 of the demographic transition.*

Example: Norway (HDI ~0.96) has a stable population; Niger (HDI ~0.39) grows rapidly.

58 Urbanization & Megacities

Explanation: More than half of humanity now lives in cities; megacities (10M+) concentrate people, energy, and waste -- and offer efficiency gains (shared transit, smaller footprints).

APES Tip: *urbanization cuts per-capita footprints (less driving, shared housing) but concentrates pollution.*

Example: Tokyo and Delhi each exceed 30 million people; urban per-capita energy use is lower than rural sprawl.

59 Population Growth & Resource Demand

Explanation: Growth raises demand for food, water, energy, and land -- driving deforestation, overfishing, and emissions. The 'ecological footprint' measures demand vs Earth's capacity.

APES Tip: *footprints > biocapacity = overshoot; humanity currently uses ~1.7 Earths.*

Example: If everyone lived like an average American, we would need ~5 Earths; the global average is ~1.7.

60 The Demographic Dividend

Explanation: When birth rates fall, the working-age share rises temporarily -- a window for economic growth if jobs exist (East Asia's boom).

APES Tip: *the dividend requires investment in education and employment; it can become a liability otherwise.*

Example: South Korea's rapid growth followed its fertility decline in the 1960s-80s -- the classic dividend.

Unit 4: Unit 4: Earth Systems & Resources

10-15% of the exam. Geology, soils, atmosphere, and water resources.

61 Plate Tectonics

Explanation: Earth's crust is broken into plates moving on the mantle (convection): divergent boundaries (spreading ridges, new crust), convergent (subduction, mountains/volcanoes), transform (earthquakes).

APES Tip: *map hazards to boundaries: volcanoes/earthquakes at convergent and transform zones; the Ring of Fire is a convergent zone.*

Example: The Himalayas formed where India collides with Eurasia (convergent); California's San Andreas is transform.

62 Earthquakes & Tsunamis

Explanation: Earthquakes release stress along faults; magnitude (Richter/moment) is logarithmic. Underwater quakes trigger tsunamis -- fast, deadly waves.

APES Tip: *each whole magnitude step = ~32x energy; the 2004 Indian Ocean tsunami killed ~230,000.*

Example: The 2011 Tohoku quake (M9.0) and tsunami caused the Fukushima nuclear disaster.

63 Volcanoes & Their Impacts

Explanation: Volcanoes emit lava, ash, and gases (SO₂, CO₂); eruptions can cool the climate (sulfate aerosols) and enrich soils over time.

APES Tip: *volcanic SO₂ reflects sunlight, temporarily cooling -- the 1991 Pinatubo eruption cooled Earth ~0.5C.*

Example: Pinatubo's 1991 aerosols lowered global temperatures for ~2 years.

64 Weathering & Erosion

Explanation: Weathering (physical/chemical) breaks rock into soil; erosion (water, wind, ice) transports it. Human land use accelerates erosion, degrading soil.

APES Tip: *soil loss from erosion exceeds soil formation by 10-40x on farmed land -- a sustainability crisis.*

Example: The Dust Bowl (1930s) showed wind erosion after plowing the Plains; contour plowing and cover crops reduce it.

65 Soil Composition & Properties

Explanation: Soil = minerals, organic matter, water, air, organisms. Horizons: O (litter), A (topsoil), B (subsoil), C (parent material). Texture (sand/silt/clay) affects drainage and fertility.

APES Tip: *topsoil (A horizon) holds most nutrients; clay retains water/nutrients; sand drains fast and leaches.*

Example: Loam (balanced sand/silt/clay) is ideal for farming; sandy soils dry quickly and lose nutrients to leaching.

66 Soil Degradation & Desertification

Explanation: Soil degradation: erosion, nutrient depletion, salinization (irrigation buildup), compaction. Desertification turns drylands into desert -- driven by overgrazing, deforestation, and bad irrigation.

APES Tip: *salinization comes from irrigation in dry climates; desertification is amplified by climate change.*

Example: The Sahel's desertification follows overgrazing and drought; drip irrigation reduces salinization in arid farms.

67 The Atmosphere: Structure & Composition

Explanation: Atmosphere layers: troposphere (weather, ~0-12 km), stratosphere (ozone layer, ~12-50 km), mesosphere, thermosphere. Composition: 78% N₂, 21% O₂, ~1% Ar + trace gases (CO₂ ~0.04%).

APES Tip: *weather lives in the troposphere; the protective ozone layer sits in the stratosphere -- keep the two straight.*

Example: Commercial jets fly in the lower stratosphere to avoid weather; the ozone layer shields UV there.

68 The Greenhouse Effect

- Explanation:** Greenhouse gases (CO₂, CH₄, N₂O, H₂O) trap outgoing infrared heat: sunlight in (shortwave), heat trapped (longwave). Natural + human enhancement drive global warming.
- APES Tip:** *greenhouse effect = the mechanism; global warming = the outcome; CO₂ is the main human-added gas, CH₄ a stronger-per-molecule one.*
- Example:** Venus's thick CO₂ atmosphere makes it the hottest planet -- the greenhouse effect on steroids.
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69 The Ozone Layer & Ozone Depletion

- Explanation:** Stratospheric ozone absorbs UV. CFCs (refrigerants, aerosols) destroy it; the Montreal Protocol (1987) phased out CFCs, and the ozone hole is recovering.
- APES Tip:** *CFCs -> ozone depletion (UV increase) vs CO₂ -> warming -- don't conflate the two problems.*
- Example:** The Antarctic ozone hole peaked in the 1990s-2000s; thanks to the Montreal Protocol, it is slowly closing.
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70 The Coriolis Effect & Global Wind Patterns

- Explanation:** Earth's rotation deflects moving air: trade winds, westerlies, polar easterlies. The Coriolis effect creates prevailing winds that drive currents and weather.
- APES Tip:** *the Coriolis effect deflects right in the northern hemisphere; it drives the trade winds and ocean gyres.*
- Example:** The trade winds blow NE to SW in the north -- Columbus's ships rode them west to the Caribbean.
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71 Ocean Currents & Climate

- Explanation:** Surface currents (wind-driven, gyres) and deep currents (thermohaline, density-driven) distribute heat: the Gulf Stream warms western Europe. El Nino/La Nina shift Pacific patterns.
- APES Tip:** *ocean currents = the planet's heat conveyor; thermohaline circulation depends on salty cold water sinking.*
- Example:** The Gulf Stream/North Atlantic Current keeps London ~10C warmer than similar latitudes in Canada.
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72 El Nino & La Nina

- Explanation:** El Nino: warm Pacific waters shift east, changing global weather (floods, droughts, weaker upwelling). La Nina: the opposite cooling. Both disrupt fisheries and agriculture.
- APES Tip:** *El Nino = 'Christ child' (around Christmas) -- eastern Pacific warms; Peru's anchovy fishery crashes.*
- Example:** The 1997-98 El Nino caused floods in California and drought in Indonesia -- global ripple effects.
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73 Water Resources & the Hydrologic Budget

- Explanation:** Freshwater is ~2.5% of Earth's water; most is locked in ice/groundwater. The hydrologic cycle redistributes it; humans divert it for agriculture (~70% of use).
- APES Tip:** *agriculture uses ~70% of freshwater; industry ~20%; domestic ~10% -- know the split.*
- Example:** Growing 1 kg of beef can take ~15,000 liters of water vs ~1,500 for 1 kg of wheat.
-

74 Groundwater & Aquifers

- Explanation:** Aquifers store groundwater in porous rock. Confined (artesian) vs unconfined; recharge comes from infiltration. Overpumping lowers water tables and causes subsidence/saltwater intrusion.
- APES Tip:** *the Ogallala Aquifer (Great Plains) is being mined faster than it recharges -- the classic overpumping case.*
- Example:** Coastal wells in Florida draw saltwater as freshwater is pumped out -- saltwater intrusion ruins aquifers.
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75 Dams & Water Diversion

- Explanation:** Dams provide power, flood control, and water -- but disrupt rivers: block fish migration, trap sediment, change downstream flows, and evaporate water.
- APES Tip:** *weigh dam benefits vs costs on FRQs; the Colorado River is 'over-allocated' -- its delta rarely reaches the sea.*
- Example:** The Glen Canyon Dam altered the Grand Canyon's river ecosystem; salmon runs across the Pacific Northwest are blocked by dams.
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76 Droughts & Water Scarcity

- Explanation:** Drought = prolonged water deficit; scarcity hits arid regions and growing populations. Adaptation: efficiency, drip irrigation, recycling, desalination (energy-intensive).
- APES Tip:** *desalination solves scarcity but costs huge energy; efficiency and pricing are cheaper first steps.*
- Example:** California's droughts push the state toward water recycling and efficiency; Saudi Arabia relies on desalination.
-

77 The Earth's Energy Budget

- Explanation:** Incoming solar = outgoing (reflected + infrared). Albedo (reflectivity) matters: ice/snow reflect (high albedo), dark surfaces absorb. Feedback: melting ice reduces albedo, warming more.
- APES Tip:** *albedo feedback is a positive feedback loop: warming melts ice -> less reflection -> more warming.*
- Example:** Sea ice loss in the Arctic exposes dark ocean, absorbing heat and accelerating melt -- albedo feedback.
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78 The Rock Cycle & Resources

- Explanation:** Rocks cycle: igneous (cooled magma), sedimentary (compacted sediment), metamorphic (heat/pressure). Rock types host resources: fossil fuels in sedimentary, ores in igneous/metamorphic.
- APES Tip:** *fossil fuels are found in sedimentary rocks; mining depletes ore deposits (nonrenewable).*
- Example:** Coal beds are sedimentary; copper porphyry ores are igneous-related -- geology controls resource location.
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79 Mining & Its Environmental Costs

- Explanation:** Mining provides metals and minerals but causes: habitat destruction, acid mine drainage (sulfides -> sulfuric acid), heavy-metal pollution, and tailings hazards.
- APES Tip:** *acid mine drainage is the classic mining pollution; reclamation (restoring land after mining) is required for permits.*
- Example:** Abandoned Appalachian coal mines leak acid and metals into streams -- the region's orange waterways.
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80 Earth System Interactions

- Explanation:** The spheres interact: lithosphere (rock), hydrosphere (water), atmosphere (air), biosphere (life). Human activities perturb all four -- the exam rewards tracing a perturbation across spheres.
- APES Tip:** *'tracing' questions: burning coal (lithosphere) -> CO2 (atmosphere) -> warming (climate) -> sea level (hydrosphere) -> coasts (biosphere).*
- Example:** Deforestation (biosphere) changes albedo and water cycling (atmosphere/hydrosphere) and erodes soil (lithosphere).
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Unit 5: Unit 5: Land & Water Use

10-15% of the exam. Agriculture, forestry, urban systems, and resource management.

81 Agriculture & the Green Revolution

Explanation: The Green Revolution (1940s-70s) raised yields via high-yield varieties, fertilizers, pesticides, and irrigation -- feeding billions but increasing fossil-fuel inputs and water use.

APES Tip: *weigh gains (yields, famine prevention) vs costs (soil, water, fertilizer runoff, GMO dependence).*

Example: India's wheat yields tripled after Green Revolution varieties and fertilizer -- averting famine.

82 Monoculture & Crop Diversity

Explanation: Monoculture = planting one crop over vast areas: efficient but vulnerable (pests, disease) and depleting. Crop rotation and intercropping restore soil and break pest cycles.

APES Tip: *the Irish potato famine (1845) is the classic monoculture catastrophe.*

Example: The 1845 potato blight devastated Ireland's single-crop staple, killing a million people.

83 Fertilizers & the Nitrogen Problem

Explanation: Synthetic fertilizer (Haber-Bosch) boosted yields but causes runoff -> eutrophication -> dead zones, plus N₂O (a potent greenhouse gas).

APES Tip: *nitrogen runoff -> algal bloom -> decomposition -> hypoxia; the Gulf dead zone is the US example.*

Example: Mississippi fertilizer runoff feeds the Gulf of Mexico's summer dead zone, which covers ~6,000 square miles.

84 Pesticides & Pest Management

Explanation: Pesticides (insecticides, herbicides) kill pests but harm non-targets, bioaccumulate, and select for resistance. IPM (integrated pest management) uses biological, cultural, and chemical tools.

APES Tip: *IPM = the sustainable answer: monitoring, natural predators, crop rotation, targeted chemicals.*

Example: DDT's bioaccumulation nearly drove bald eagles extinct; IPM reduced reliance on broad-spectrum sprays.

85 Irrigation & Water in Agriculture

Explanation: Irrigation feeds ~40% of crops on ~20% of farmland. Methods: flood (wasteful), sprinkler, drip (efficient). Poor drainage causes salinization and waterlogging.

APES Tip: *drip irrigation = the efficiency champion; salinization = the cost of over-irrigation in dry climates.*

Example: Israel's drip irrigation cut water use ~60% while raising yields -- the efficiency model.

86 Genetically Modified Organisms (GMOs)

Explanation: GMOs (Bt corn, Roundup-ready soy) raise yields, resist pests/herbicides, and reduce pesticide use -- but raise concerns: gene flow, biodiversity, and corporate control.

APES Tip: *give both sides on FRQs: yield benefits vs ecological and regulatory concerns.*

Example: Bt corn produces its own insect toxin, cutting insecticide applications; resistance and gene flow are the concerns.

87 Livestock & Feedlots (CAFOs)

Explanation: Concentrated animal feeding operations (CAFOs) produce meat cheaply but concentrate waste: manure runoff, antibiotics resistance, methane, and water use.

APES Tip: *beef is the most resource-intensive meat (land, water, feed, methane) -- compare with poultry/pork.*

Example: CAFO lagoons can leak into waterways; livestock produce ~14.5% of global greenhouse gas emissions.

88 Soil Conservation Practices

Explanation: Conservation: contour plowing, terracing, no-till, cover crops, crop rotation, windbreaks, and riparian buffers all reduce erosion and preserve soil.

APES Tip: *match each practice to its mechanism -- no-till keeps residue; terraces slow runoff on slopes.*

Example: The 1985 Farm Bill's Conservation Reserve Program paid farmers to retire erodible land -- dust-bowl prevention.

89 Deforestation & Its Drivers

Explanation: Deforestation (clear-cutting, slash-and-burn) for agriculture, timber, and pasture destroys habitat, releases carbon, and disrupts water cycles. Brazil and Indonesia lead losses.

APES Tip: *deforestation is ~10-15% of global emissions -- 'forests are carbon sinks'; protect them.*

Example: Amazon deforestation for cattle and soy accelerates; selective logging and reforestation reduce impact.

90 Forestry: Clearcutting vs Sustainable

Explanation: Clearcutting (cheap, maximum yield) damages ecosystems; selective cutting, shelterwood, and strip cutting are more sustainable. Forest certification (FSC) signals responsible sourcing.

APES Tip: *sustainable forestry keeps ecosystem services: carbon storage, habitat, water regulation.*

Example: The Pacific Northwest's spotted owl controversy pitted clearcutting against old-growth habitat.

91 Urbanization & Sprawl

Explanation: Urban sprawl (low-density car-dependent growth) consumes farmland and habitat, increases impervious surfaces (flooding), and raises per-capita energy use. Smart growth promotes density and transit.

APES Tip: *sprawl = more driving, more pavement, more land per person; smart growth = compact, transit-oriented.*

Example: Portland's urban growth boundary curbed sprawl, preserving farmland while concentrating development.

92 Urban Planning: Smart Growth & Green Cities

Explanation: Smart growth: mixed-use zoning, public transit, green roofs, urban forests, and brownfield redevelopment reduce footprints and improve livability.

APES Tip: *'ecological footprint' of cities drops with density and transit -- the densest cities are often the greenest per capita.*

Example: Curitiba, Brazil's BRT (bus rapid transit) cut car use and congestion -- a smart-growth model.

93 Solid Waste: The Waste Stream

Explanation: Municipal solid waste (MSW): ~50% paper/yard waste historically, now more plastics. Management hierarchy: reduce, reuse, recycle, compost, then landfill/incinerate.

APES Tip: *the waste hierarchy answers 'what to do with waste': source reduction is #1.*

Example: The U.S. recycles ~32% of MSW; the rest is landfilled (over 50%) or burned.

94 Landfills & Leachate

Explanation: Modern sanitary landfills are lined, capped, and monitored: leachate (polluted liquid) is collected; methane is captured for energy. Older dumps leaked into groundwater.

APES Tip: *landfill methane can power homes (waste-to-energy); leachate treatment is a core design feature.*

Example: A landfill's methane wells convert decomposition gas into electricity -- waste-to-energy in practice.

95 Incineration & Waste-to-Energy

Explanation: Incineration reduces waste volume ~90% and generates electricity, but emits air pollutants (dioxins, CO₂) and leaves toxic ash (fly ash).

APES Tip: *WTE plants need scrubbers/filters; siting is contested (environmental justice).*

Example: Denmark burns ~half its waste for district heat and power -- with strict emission controls.

96 Reduce, Reuse, Recycle, Compost

Explanation: The 4 Rs: reduce (consume less), reuse, recycle (paper, metal, glass, some plastics), compost (organics -> soil). Recycling saves energy vs virgin production.

APES Tip: *aluminum recycling saves ~95% of the energy of virgin smelting -- the recycling poster child.*

Example: Recycling one aluminum can saves enough energy to run a TV for three hours.

97 Plastics & the Microplastic Problem

Explanation: Plastic is durable, cheap, and persistent: only ~9% is recycled; the rest accumulates in oceans (Great Pacific Garbage Patch) and fragments into microplastics that enter food chains.

APES Tip: *microplastics = the emerging contaminant; solutions: reduce single-use, improve collection, bans.*

Example: Microplastics have been found in fish, drinking water, and human blood -- the plastic cycle's endgame.

98 Mining, Oil, and Resource Extraction (Review)

Explanation: Extraction of minerals, oil, and gas disturbs land and water: mountaintop removal, tar sands, fracking. Each has local impacts (water, habitat) plus global ones (emissions).

APES Tip: *compare extraction methods' footprints; fracking = water + methane concerns, coal = emissions + ash.*

Example: Mountaintop-removal mining buried Appalachian headwater streams; fracking's methane leaks offset its gas-climate advantage.

99 Sustainable Agriculture Systems

Explanation: Sustainable agriculture: organic farming, agroforestry, permaculture, and precision agriculture maintain yields while protecting soil, water, and biodiversity.

APES Tip: *'sustainable' = meets present needs without compromising future capacity -- soil health is the foundation.*

Example: Agroforestry (trees + crops) on degraded land rebuilds soil and yields -- farming with the ecosystem.

100 The Tragedy of the Commons

Explanation: Shared resources (oceans, atmosphere, groundwater) are depleted when individuals maximize their own use without regulation -- the 'tragedy of the commons.'

APES Tip: *solutions: regulation, property rights, quotas, and community management; name a commons and its fix.*

Example: Open-access fisheries collapse; catch shares (ITQs) assign rights, aligning incentives with sustainability.

Unit 6: Unit 6: Energy Resources & Consumption

10-15% of the exam. Fossil fuels, nuclear, renewables, and energy policy.

101 Energy Basics & Units

Explanation: Energy = capacity to do work (joules, kWh, BTUs); power = energy per time (watts). Efficiency = useful output / total input. The U.S. wastes ~2/3 of energy (heat).

APES Tip: *convert and compare: 1 kWh = 3.6 million joules; efficiency questions are arithmetic-heavy.*

Example: An LED bulb converts ~90% of electricity to light; an incandescent converts ~10% -- efficiency in lighting.

102 Fossil Fuels: Formation & Types

Explanation: Fossil fuels are stored solar energy from ancient organisms: coal (peat -> lignite -> bituminous -> anthracite), oil (marine plankton), natural gas (methane). Ranked by carbon content: coal > oil > gas.

APES Tip: *coal is the most carbon-intensive and abundant; gas the cleanest-burning fossil fuel.*

Example: Coal's carbon content ~90% (anthracite) vs methane's single carbon -- gas emits ~half the CO2 per energy.

103 Coal: Mining & Combustion

Explanation: Coal powers ~1/4 of U.S. electricity but is the dirtiest: CO2, SO2 (acid rain), mercury, particulates, and fly ash. Mining (surface, mountaintop, underground) degrades land and water.

APES Tip: *coal's full lifecycle costs (mining + burning + ash) make it the worst fossil fuel for air and climate.*

Example: Scrubbers on modern plants remove SO2; carbon capture remains expensive and rare.

104 Oil: Extraction & Refining

Explanation: Oil is refined into gasoline, diesel, jet fuel, plastics, and petrochemicals. Extraction: conventional wells, fracking (tight oil), tar sands (energy- and water-intensive). Risks: spills (Exxon Valdez, Deepwater Horizon).

APES Tip: *tar sands have high EROI costs (energy return on investment); fracking raises earthquake and water risks.*

Example: The 2010 Deepwater Horizon spill released ~200 million gallons -- the largest marine spill in U.S. history.

105 Natural Gas & Fracking

Explanation: Natural gas (methane) is the cleanest fossil fuel for CO2, but fracking (hydraulic fracturing) raises concerns: water use, chemical contamination, methane leaks (a potent greenhouse gas), and induced earthquakes.

APES Tip: *methane (CH4) traps ~25-80x more heat than CO2 per molecule over 20 years -- leaks matter.*

Example: Fracking drove the U.S. shale boom, cutting CO2 vs coal -- but methane leakage can offset the benefit.

106 Energy Return on Investment (EROI)

Explanation: EROI = energy obtained / energy invested. Conventional oil ~20-30; tar sands ~3-5; renewables vary (wind ~20+, solar ~5-10). Low EROI sources are less viable.

APES Tip: *EROI explains why tar sands and biofuels are marginal: they return little energy per unit invested.*

Example: Corn ethanol's EROI is barely above 1 -- it takes nearly as much energy to produce as it yields.

107 Electricity Generation Basics

Explanation: Most electricity comes from boiling water into steam to spin turbines: coal, gas, nuclear, geothermal, concentrated solar. Others spin directly: wind, hydro, tidal.

APES Tip: *'thermal vs mechanical' generation: thermal (heat -> steam -> turbine) vs mechanical (fluid spins turbine directly).*

Example: Wind turbines and hydro spin generators directly; coal, gas, and nuclear all use steam.

108 The U.S. Energy Mix

- Explanation:** U.S. energy: ~80% fossil fuels (petroleum ~36%, natural gas ~32%, coal ~10%), nuclear ~8%, renewables ~12%+ (hydro, wind, solar, biomass, geothermal).
- APES Tip:** *know the rough mix: fossil fuels dominate; renewables grow but still lag; electricity vs transportation differ (oil dominates transport).*
- Example:** Petroleum dominates transportation fuel; coal/gas dominate electricity; wind and solar are the fastest-growing renewables.

109 Nuclear Power Basics

- Explanation:** Nuclear fission splits uranium-235, releasing heat -> steam -> electricity: carbon-free, high energy density, reliable baseload. Risks: meltdown (Chernobyl, Fukushima), waste storage, weapons proliferation.
- APES Tip:** *nuclear = zero CO2 but radioactive waste (half-life 24,000+ years for plutonium) and accident risk.*
- Example:** France gets ~70% of its electricity from nuclear -- the low-carbon example; Yucca Mountain remains an unsolved waste site.

110 Nuclear Waste Management

- Explanation:** Spent fuel stays radioactive for millennia: current U.S. practice is on-site dry cask storage; deep geologic repositories (Finland's Onkalo) are the long-term solution.
- APES Tip:** *'what to do with nuclear waste?' -- deep geologic disposal is the standard expert answer.*
- Example:** Finland's Onkalo repository will seal spent fuel in bedrock for 100,000 years -- the world's first.

111 Solar Energy: Photovoltaic & Thermal

- Explanation:** Photovoltaic (PV) cells convert sunlight directly to electricity; concentrated solar power (CSP) uses mirrors to heat fluid -> steam. Intermittent (night/clouds) -- needs storage.
- APES Tip:** *solar's constraint is intermittency and land; storage (batteries, pumped hydro) is the enabling tech.*
- Example:** The Mojave's Ivanpah CSP plant uses mirrors to boil water; rooftop PV is growing fastest in sunny states.

112 Wind Energy

- Explanation:** Wind turbines convert kinetic energy to electricity: clean, cheap, fast-growing. Limits: intermittency, siting (visual, bird/bat kills), and land use.
- APES Tip:** *offshore wind has stronger, steadier winds; turbine siting away from migration corridors reduces bird deaths.*
- Example:** Texas leads U.S. wind; offshore projects (Vineyard Wind) are scaling up along the coasts.

113 Hydropower & Tidal

- Explanation:** Hydro dams provide reliable, dispatchable power but alter rivers (fish, sediment, methane from reservoirs). Run-of-river and tidal (Maine's Bay of Fundy) have smaller footprints.
- APES Tip:** *reservoirs emit methane from flooded vegetation; hydro's 'green' label is debated.*
- Example:** The Three Gorges Dam displaces 1.3 million people and blocks fish -- hydro's trade-offs at scale.

114 Geothermal Energy

- Explanation:** Geothermal taps Earth's internal heat: power plants (steam from hot rock) and heat pumps (shallow ground loops for buildings). Site-specific (Iceland, California).
- APES Tip:** *geothermal = baseload renewable (always available) but limited to geologically active areas.*
- Example:** Iceland heats ~90% of homes with geothermal -- the volcanic island's gift.

115 Biomass & Biofuels

- Explanation:** Biomass (wood, crops, waste) is renewable if regrown, but combustion emits CO2, particulates, and can compete with food (ethanol from corn). Ethanol/biodiesel are liquid biofuels.
- APES Tip:** *biomass's carbon neutrality depends on regrowth rate; food-vs-fuel is the sustainability critique.*
- Example:** Brazil's sugarcane ethanol is far more efficient than U.S. corn ethanol -- feedstock matters.

116 Energy Conservation & Efficiency

- Explanation:** The cheapest energy is saved energy: efficient appliances (Energy Star), LED lighting, insulation, CAFE standards, and public transit cut demand and emissions.
- APES Tip:** *conservation (use less) vs efficiency (same service, less energy) -- the exam tests both.*
- Example:** CAFE fuel standards doubled new-car efficiency since 1975; LED bulbs use ~75% less power than incandescents.
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117 The Smart Grid & Energy Storage

- Explanation:** The smart grid uses digital tech to balance supply/demand, integrate renewables, and cut losses. Storage (batteries, pumped hydro, compressed air) smooths intermittent renewables.
- APES Tip:** *renewables + storage = the grid of the future; battery costs fell ~90% in a decade.*
- Example:** Hornsdale (Australia) battery farm stabilizes the grid within milliseconds -- storage at scale.
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118 Carbon Capture & Negative Emissions

- Explanation:** Carbon capture and storage (CCS) captures CO₂ at plants for underground storage; direct air capture (DAC) removes CO₂ from air. Both are expensive and unproven at scale.
- APES Tip:** *CCS treats emissions; DAC is negative emissions -- neither is a substitute for cutting emissions.*
- Example:** Iceland's Climeworks plant captures CO₂ and mineralizes it in basalt -- the first commercial DAC site.
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119 Energy Policy & International Agreements

- Explanation:** Policies: carbon tax, cap-and-trade, renewable portfolio standards (RPS), subsidies, and net-metering. The Paris Agreement (2015) set national climate commitments (NDCs).
- APES Tip:** *cap-and-trade puts a price on carbon with a market; carbon taxes are simpler; RPS mandates renewables.*
- Example:** California's cap-and-trade and 100% clean electricity goal show state-level climate policy.
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120 The Energy Transition

- Explanation:** The transition from fossil fuels to renewables: driven by cost (solar/wind now cheapest), policy, and climate urgency; challenged by intermittency, storage, grid, and politics.
- APES Tip:** *'the energy transition' is the unit's synthesis: technology + policy + economics together.*
- Example:** Renewables now supply ~30% of global electricity and are growing faster than any source in history.
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Unit 7: Unit 7: Atmospheric Pollution

7-10% of the exam. Air pollutants, smog, and their control.

121 Primary vs Secondary Pollutants

Explanation: Primary pollutants are emitted directly (CO, SO₂, NO_x, particulates, VOCs). Secondary pollutants form in the atmosphere (ozone, PAN, nitric acid, sulfate).

APES Tip: *ozone in the troposphere is SECONDARY (formed from NO_x + VOCs + sunlight); stratospheric ozone is protective.*

Example: Ground-level ozone forms when car exhaust (NO_x + VOCs) bakes in sunlight -- a secondary pollutant.

122 The Six Criteria Pollutants

Explanation: The EPA's criteria pollutants: CO, SO₂, NO_x, ozone (O₃), particulate matter (PM), and lead. Each has health/environmental effects and NAAQS standards.

APES Tip: *memorize the six and their sources: CO (incomplete combustion), SO₂ (coal), NO_x (vehicles), O₃ (photochemical), PM (dust/combustion), Pb (legacy gasoline/industry).*

Example: Coal plants emit SO₂; cars emit NO_x and CO; both contribute to PM and smog.

123 Particulate Matter (PM₁₀, PM_{2.5})

Explanation: PM = tiny particles (dust, soot, sulfates, nitrates). PM_{2.5} (fine) penetrates deep into lungs and blood: respiratory and cardiovascular disease, visibility loss.

APES Tip: *PM_{2.5} is the most dangerous size class; sources: combustion, industry, dust; controls: filters, scrubbers.*

Example: Beijing's PM_{2.5} spikes trigger red alerts; HEPA filters and masks reduce exposure.

124 Photochemical Smog

Explanation: Photochemical (brown) smog forms when NO_x + VOCs react in sunlight: ozone, PAN, and haze. Peaks on hot sunny days with traffic; the LA basin is the classic case.

APES Tip: *smog formation needs sunlight + NO_x + VOCs; it worsens with temperature inversions.*

Example: LA's 'brown cloud' peaks in summer afternoons; reducing NO_x and VOCs cuts ozone.

125 Industrial Smog (Gray Smog)

Explanation: Industrial (gray) smog = SO₂ + particulates from coal burning; historically London's killer fogs. The 1952 Great Smog killed ~12,000 -- prompting clean air laws.

APES Tip: *gray smog = coal/SO₂; brown smog = vehicles/NO_x+O₃ -- the two-smog distinction is tested.*

Example: The 1952 London smog's death toll forced the UK Clean Air Act (1956) -- a turning point.

126 Thermal Inversions

Explanation: A temperature inversion traps a cool air layer under warm air, preventing pollutants from dispersing: smog concentrates near the ground. Common in valleys and coastal basins.

APES Tip: *inversion = warm air on top (reversed normal lapse rate) -> pollution trapped; Los Angeles and Salt Lake City are prone.*

Example: LA's mountain basin + sea breeze creates inversions that trap smog for days.

127 Acid Deposition

Explanation: SO₂ and NO_x convert to sulfuric and nitric acid in the atmosphere; acid rain/snow/dry deposition acidifies lakes and soils, harms forests, and corrodes buildings.

APES Tip: *acid rain sources: coal (SO₂) + vehicles (NO_x); effects: pH drop, aluminum mobilization, forest decline.*

Example: Acid rain killed fish in Adirondack lakes; the 1990 Clean Air Act amendments' cap-and-trade cut SO₂ ~70%.

128 Indoor Air Pollution

Explanation: Indoor pollutants: radon (radioactive soil gas, #2 lung cancer cause), CO (silent killer), VOCs (paints, carpets), mold, and smoke. Indoor concentrations can exceed outdoor.

APES Tip: *radon testing + ventilation are the fixes; developing countries suffer indoor smoke from biomass stoves.*

Example: Radon seeps into basements from soil; charcoal canisters test for it; ventilation dilutes it.

129 The Clean Air Act & Its Amendments

Explanation: The Clean Air Act (1970, amended 1977, 1990) set NAAQS, required technology (scrubbers, catalytic converters), and created SO₂ cap-and-trade. Result: criteria pollutants down ~70% while GDP grew.

APES Tip: *the CAA is the U.S. air policy backbone; the 1990 SO₂ trading program is the cap-and-trade exemplar.*

Example: Since 1970, U.S. air emissions of the six criteria pollutants fell ~78% while population and GDP rose.

130 Ozone: Stratospheric vs Tropospheric

Explanation: Stratospheric ozone (good) absorbs UV; tropospheric ozone (bad) is smog. CFCs destroy stratospheric ozone; NO_x+VOCs create tropospheric ozone.

APES Tip: *the word 'ozone' needs context: protect the stratospheric layer, reduce the tropospheric pollutant.*

Example: The Montreal Protocol (1987) healed the stratospheric ozone hole; the Clean Air Act attacks ground-level ozone.

131 CO₂, Methane & the Enhanced Greenhouse Effect

Explanation: CO₂ (from fossil fuels, deforestation) is the main long-lived greenhouse gas; methane (agriculture, leaks) is stronger per molecule but shorter-lived; N₂O (fertilizer) and CFCs also warm.

APES Tip: *CO₂ = biggest total contribution; CH₄ = highest per-molecule warming (over 20 years ~80x CO₂).*

Example: Livestock burps + rice paddies emit methane; reducing it is the fastest climate lever.

132 Climate vs Weather

Explanation: Weather = short-term atmospheric conditions (days); climate = long-term averages and patterns (decades). Climate change = shifts in long-term statistics, with more extreme weather.

APES Tip: *'a cold week doesn't disprove climate change' -- the exam tests the distinction.*

Example: A record-cold February (weather) coexists with a warming trend (climate) -- averages hide variability.

133 The Carbon Cycle & the Keeling Curve

Explanation: The Keeling Curve tracks atmospheric CO₂ at Mauna Loa: 315 ppm (1958) -> 420+ ppm (2023), rising ~2.5 ppm/year. Fossil burning + land-use change drive the rise.

APES Tip: *the Keeling Curve is the icon of anthropogenic warming -- know the numbers and the trend.*

Example: Seasonal CO₂ 'sawtooth' (northern photosynthesis dips) rides an upward trend -- nature's breathing on top of our emissions.

134 The Greenhouse Gases Table

Explanation: CO₂: fossil fuels, ~50+% of forcing, persists centuries. CH₄: agriculture/leaks, ~16-25%, persists ~12 years. N₂O: fertilizer/industry, ~6%, persists ~100 years. HFCs/CFCs: refrigerants, potent but small.

APES Tip: *compare gases by source, warming potential, and residence time; CH₄ is the fast lever, CO₂ the long-term driver.*

Example: Cutting methane from oil/gas and livestock is the fastest way to slow near-term warming.

135 Climate Feedback Loops

Explanation: Positive feedbacks amplify warming: ice-albedo (less ice -> more heat), permafrost thaw (releases CH₄/CO₂), water vapor (warmer air holds more). Negative feedbacks (clouds, CO₂ fertilization) are debated.

APES Tip: *name the feedback and its loop; the ice-albedo and permafrost loops are the exam favorites.*

Example: Thawing Arctic permafrost could release gigatons of methane -- a warming amplifier beyond human control.

136 Ocean Acidification

- Explanation:** The ocean absorbs ~25% of CO₂, forming carbonic acid: pH has dropped ~0.1 (30% more acidic). Shells and corals dissolve (calcium carbonate), threatening marine food webs.
- APES Tip:** *acidification is 'the other CO₂ problem' -- distinct from warming, same source.*
- Example:** Oyster larvae in Pacific Northwest hatcheries dissolve as upwelled acidified water arrives -- a direct economic hit.
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137 Mitigation vs Adaptation

- Explanation:** Mitigation = reducing emissions/removing CO₂ (renewables, efficiency, carbon capture). Adaptation = adjusting to impacts (sea walls, drought crops, migration).
- APES Tip:** *classify policies as mitigation (address cause) vs adaptation (address effects) on FRQs.*
- Example:** Building flood barriers (adaptation) vs installing wind farms (mitigation) -- both needed, different roles.
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138 Climate Modeling & the IPCC

- Explanation:** The IPCC synthesizes climate science; models project 1.5-4.5C+ warming by 2100 depending on emissions pathways (SSPs). Uncertainty shrinks as models improve.
- APES Tip:** *the exam expects: warming ~1.2C already, ~1.5-2C targets, and that scenarios depend on choices.*
- Example:** The Paris target of 1.5C requires global net-zero CO₂ by ~2050 -- the models make the math explicit.
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139 Environmental Justice & Pollution

- Explanation:** Pollution burdens fall unequally: low-income communities and people of color face higher exposures (siting of plants, highways, waste). Environmental justice demands equitable protection.
- APES Tip:** *EJ is a growing exam theme -- cite 'Cancer Alley' (Louisiana) or Flint's water crisis.*
- Example:** Louisiana's Cancer Alley concentrates petrochemical plants in majority-Black communities -- a justice issue.
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140 Air Pollution Control Technology

- Explanation:** Controls: scrubbers (SO₂), electrostatic precipitators/baghouse filters (PM), catalytic converters (NO_x, CO), and low-NO_x burners. Each targets specific pollutants.
- APES Tip:** *match technology to pollutant: scrubber -> SO₂; converter -> vehicle NO_x/CO; precipitator -> particles.*
- Example:** Catalytic converters cut car NO_x ~90%; scrubbers removed SO₂ from coal plants under the 1990 amendments.
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Unit 8: Unit 8: Aquatic & Terrestrial Pollution

7-10% of the exam. Water pollution, solid/hazardous waste, and their management.

141 Point vs Nonpoint Source Pollution

Explanation: Point source: a single identifiable origin (factory pipe, sewage outfall). Nonpoint source: diffuse (farm runoff, urban stormwater). Nonpoint is harder to regulate.

APES Tip: *classify each example; nonpoint (agricultural runoff) is the leading U.S. water quality problem.*

Example: A factory's discharge pipe is point source; fertilizer washing off fields is nonpoint -- the harder one to fix.

142 Eutrophication & Dead Zones

Explanation: Excess nutrients (N, P) fuel algal blooms; blooms die and decompose, depleting oxygen (hypoxia) and killing fish -- eutrophication. Dead zones occur where blooms are regular.

APES Tip: *the chain: nutrients -> bloom -> decay -> oxygen loss -> fish kills; phosphorus is often the limiting nutrient.*

Example: The Gulf of Mexico dead zone forms annually from Mississippi nitrogen; Lake Erie's 2014 Toledo bloom poisoned drinking water.

143 Indicator Species for Water Quality

Explanation: Macroinvertebrates signal stream health: mayflies, stoneflies, caddisflies (sensitive) vs leeches, sludge worms (tolerant). Fecal coliform (E. coli) indicates sewage contamination.

APES Tip: *'biotic index' questions: sensitive species = clean water; tolerant species = polluted water.*

Example: A stream with mayflies and stoneflies is clean; one with only sludge worms is polluted.

144 Thermal Pollution

Explanation: Power plants and industry discharge warm water, lowering dissolved oxygen and stressing aquatic life. Cooling towers/ponds and alternative cooling reduce it.

APES Tip: *warm water holds LESS dissolved oxygen -- thermal pollution = oxygen stress, especially for cold-water fish.*

Example: A power plant's discharge can make a river uninhabitable for trout; cooling towers mitigate.

145 Oxygen Demand: BOD & DO

Explanation: Biochemical oxygen demand (BOD) measures oxygen consumed by decomposing organic matter. High BOD = heavy organic pollution = low dissolved oxygen (DO).

APES Tip: *BOD up = DO down; sewage and manure raise BOD; the river 'recovers' downstream as BOD falls.*

Example: Raw sewage entering a river spikes BOD; DO crashes, killing fish, then recovers over miles.

146 Heavy Metals & Toxic Substances

Explanation: Heavy metals (lead, mercury, arsenic, cadmium) are persistent and toxic: they bioaccumulate (build up in an organism) and biomagnify up food chains.

APES Tip: *biomagnification = concentration INCREASES up the food web (DDT, mercury); top predators carry the most.*

Example: Mercury from coal emissions accumulates in tuna -- pregnant women are advised to limit consumption.

147 Bioaccumulation vs Biomagnification

Explanation: Bioaccumulation = buildup within one organism (absorbed faster than excreted). Biomagnification = increasing concentration at each trophic level.

APES Tip: *give both definitions on FRQs; the classic example is DDT in ospreys/eagles.*

Example: DDT biomagnified from plankton to fish to eagles, thinning eggshells -- the pesticide's lasting lesson.

148 Persistent Organic Pollutants (POPs)

Explanation: POPs (DDT, PCBs, dioxins) resist degradation, travel globally (grasshopper effect), and accumulate in fat. The Stockholm Convention (2001) phases them out.

APES Tip: *POPs = persistent + toxic + bioaccumulative + long-range transport; PCBs still contaminate the Hudson River.*

Example: PCBs from GE plants contaminate Hudson fish -- dredging and fish advisories manage exposure.

149 Emerging Contaminants & Pharmaceuticals

Explanation: Pharmaceuticals, microplastics, PFAS ('forever chemicals'), and personal-care products pass through treatment plants into water -- endocrine disruption and chronic exposure concerns.

APES Tip: *PFAS (nonstick coatings, firefighting foam) are the emerging-contaminant poster child.*

Example: PFAS contamination (e.g., in Michigan, North Carolina) drives lawsuits and new EPA limits.

150 Oil Spills & Their Impacts

Explanation: Oil spills coat wildlife, smother shorelines, and poison food webs. Cleanup: booms, skimmers, dispersants, bioremediation (oil-eating microbes) -- each has trade-offs.

APES Tip: *dispersants break slicks but add toxicity; bioremediation is the natural-fix option; prevention beats cleanup.*

Example: The 1989 Exxon Valdez spill killed ~250,000 seabirds; the 2010 Deepwater Horizon was 20x larger.

151 Water Treatment (Drinking)

Explanation: Drinking water treatment: coagulation/flocculation, sedimentation, filtration, disinfection (chlorine/UV), and fluoridation. It eliminated most waterborne disease.

APES Tip: *the order matters: coagulate -> settle -> filter -> disinfect; the Flint crisis was a corrosion-control failure.*

Example: Flint's water corroded lead pipes after a source switch -- lead leached into the supply: a treatment + infrastructure failure.

152 Wastewater Treatment (Sewage)

Explanation: Primary (settling), secondary (biological, activated sludge -- aeration), tertiary (nutrient removal, disinfection). Sludge is digested; effluent is discharged.

APES Tip: *secondary treatment uses microbes to eat BOD; tertiary removes nutrients (N, P) that cause eutrophication.*

Example: A modern plant's tertiary step removes phosphorus before discharge -- protecting downstream lakes.

153 Septic Systems & Onsite Treatment

Explanation: Rural septic systems: tank (settling) + drain field (soil filtration). Failure = groundwater contamination (nitrates, pathogens) -- worse in dense or flood-prone areas.

APES Tip: *septic density matters: too many systems overwhelm the soil's filtering capacity.*

Example: Coastal communities with dense septic systems show nitrate pollution in wells and estuaries.

154 Solid & Hazardous Waste Management

Explanation: Hazardous waste (toxic, corrosive, ignitable, reactive) requires special handling: RCRA (1976) and Superfund (CERCLA, 1980) govern cleanup. Landfills must be lined and monitored.

APES Tip: *Superfund cleans abandoned hazardous sites; RCRA regulates current waste from cradle to grave.*

Example: Love Canal (NY) -- homes built on buried chemicals -- created the Superfund program.

155 Municipal Solid Waste Trends

Explanation: The U.S. generates ~4.5 lb of waste per person per day. Composition: paper, food, plastics, yard waste, metals, glass. Landfilling dominates; recycling ~32%.

APES Tip: *food waste is a big landfill fraction and a methane source; composting diverts it.*

Example: Diverting food waste to compost cuts landfill methane and returns nutrients to soil.

156 Plastics & Marine Debris

- Explanation:** Plastic persists in oceans, breaks into microplastics, and enters food webs: the Great Pacific Garbage Patch is the symbol. Solutions: reduction, bans, cleanups, better recycling.
- APES Tip:** *the garbage patch is mostly microplastics suspended in the water column -- not a floating island.*
- Example:** Single-use plastic bans (bags, straws) and extended producer responsibility are scaling globally.
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157 Toxicity Testing & Risk Assessment

- Explanation:** Risk = toxicity x exposure. LD50 measures lethal dose (lower = more toxic); dose-response curves show effects at different doses. Risk assessment guides regulation.
- APES Tip:** *'the dose makes the poison' -- even water is toxic at high doses; LD50 comparisons are tested.*
- Example:** Botulinum toxin has a tiny LD50 (deadly); table salt's LD50 is large -- toxicity depends on dose.
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158 Endocrine Disruptors

- Explanation:** Endocrine disruptors (BPA, phthalates, atrazine, some pesticides) mimic or block hormones, causing reproductive and developmental harm at low doses.
- APES Tip:** *endocrine disruptors act at LOW doses and affect development -- a different model from typical toxicity.*
- Example:** Atrazine in waterways has been linked to feminization of amphibians -- a low-dose hormone effect.
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159 Bioremediation & Phytoremediation

- Explanation:** Bioremediation uses organisms to break down pollutants (oil-eating bacteria, fungi); phytoremediation uses plants to absorb contaminants (hyperaccumulators like sunflowers for lead).
- APES Tip:** *both are the 'natural cleanup' answers; cheaper but slower than excavation.*
- Example:** After the Deepwater spill, dispersants and natural oil-degrading bacteria worked together; sunflowers cleaned Chernobyl-area soil.
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160 The Water Quality Index & Monitoring

- Explanation:** Water quality is monitored via DO, pH, turbidity, temperature, nitrates, phosphates, and biotic indicators. The WQI combines these into a score.
- APES Tip:** *name 3-4 parameters and their ideal values (DO high, turbidity low, pH ~7) on monitoring questions.*
- Example:** A healthy stream: DO > 5 mg/L, pH 6.5-8.5, low turbidity and nitrates -- readings that 'pass' the WQI.
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Unit 9: Unit 9: Global Change

15-20% of the exam. Stratospheric ozone, climate change, and sustainability.

161 Global Change Overview

Explanation: Global change = climate change, ozone depletion, land-use change, biodiversity loss, and pollution interacting across scales. It is the unit that synthesizes the course.

APES Tip: *global change questions reward tracing interactions: one driver, many effects.*

Example: Fossil fuel burning warms the climate AND acidifies the ocean AND pollutes air -- one source, many changes.

162 Stratospheric Ozone Depletion (Review)

Explanation: CFCs (refrigerants, aerosols, solvents) rise to the stratosphere and catalytically destroy ozone, thinning the shield (especially over Antarctica).

APES Tip: *CFC chemistry: one chlorine atom can destroy ~100,000 ozone molecules -- the catalytic loop.*

Example: The Antarctic ozone hole (discovered 1985) formed over the pole's cold vortex each spring.

163 The Montreal Protocol (1987)

Explanation: The Montreal Protocol phased out CFCs globally -- the most successful environmental treaty: ozone depletion reversed, the hole is healing (recovery expected ~2060-70).

APES Tip: *Montreal = the model international agreement: binding targets, science-driven, universally ratified.*

Example: CFC production fell ~99% after Montreal; the ozone hole is at its smallest in decades.

164 CFC Substitutes & Their Trade-Offs

Explanation: HFCs replaced CFCs (no ozone harm) but are potent greenhouse gases; the Kigali Amendment (2016) phases down HFCs. Next: climate-friendly refrigerants.

APES Tip: *the ozone fix created a climate problem -- the Kigali Amendment closes that loop.*

Example: HFC-134a replaced CFC-12 in cars, but it warms thousands of times more than CO₂ -- now being phased down.

165 Climate Change: The Evidence

Explanation: Evidence: temperature records (warmest years on record), retreating glaciers/ice sheets, sea-level rise (~8 inches since 1880), earlier springs, and ocean heat content.

APES Tip: *cite 2-3 independent lines of evidence on FRQs -- 'multiple lines of evidence' is the scientific standard.*

Example: Glaciers in Glacier National Park have shrunk from 150 to ~25 since 1850 -- photographic proof of warming.

166 The Enhanced Greenhouse Effect (Mechanism)

Explanation: CO₂ and other greenhouse gases trap outgoing longwave radiation, adding to the natural greenhouse effect: more warming than the climate system can re-radiate.

APES Tip: *'enhanced' = the human-added increment; distinguish from natural greenhouse effect.*

Example: Doubling CO₂ alone adds ~1.2C of forcing, amplified by feedbacks to ~3C equilibrium warming.

167 Radiative Forcing

Explanation: Radiative forcing (W/m²) measures how much a factor changes Earth's energy balance: CO₂ +2.1, CH₄ +0.5, aerosols -0.9 (cooling). Positive forcing warms.

APES Tip: *net positive forcing ~2.7 W/m² from human activities -- the quantitative fingerprint of warming.*

Example: Aerosols (sulfates, soot) partly mask warming -- cleaning air pollution will unmask it.

168 Climate Models & Scenarios

Explanation: Climate models (GCMs) simulate the climate system; scenarios (SSP1-5) project futures from low to high emissions: ~1.5C to ~4.5C by 2100.

APES Tip: *model uncertainty vs scenario uncertainty: models agree on warming; scenarios differ on choices.*

Example: SSP1 (sustainability) holds near 1.5C; SSP5 (fossil-fueled) exceeds 4C -- the choice is policy.

169 Impacts: Ecosystems & Species

Explanation: Warming shifts species ranges poleward and uphill, disrupts phenology (mismatched timing), and stresses corals, forests (beetle outbreaks), and polar species.

APES Tip: *'range shift' + 'phenology mismatch' are the two ecosystem impact keywords.*

Example: Bark beetle outbreaks (warming winters) have killed millions of acres of western forests; pikas climb ever higher.

170 Impacts: Agriculture & Food Security

Explanation: Climate change disrupts agriculture: heat stress, drought, flooding, shifting growing zones, and CO2 effects. Some regions (northern) may gain; most tropical regions lose.

APES Tip: *net food impact is negative overall, with the poorest regions hit hardest -- a justice dimension.*

Example: The 2022 European heatwave cut maize yields ~16% -- extremes are the new normal for farming.

171 Impacts: Human Health

Explanation: Health impacts: heat deaths, expanded disease vectors (Lyme, malaria, dengue), air pollution exacerbation, food/water insecurity, and climate migration.

APES Tip: *'vector-borne disease range expansion' is a required health link.*

Example: Lyme disease ticks are expanding north with warming; dengue is spreading to new latitudes.

172 Sea-Level Rise & Coastal Impacts

Explanation: Sea level rises from thermal expansion + melting ice: ~8 inches since 1900, up to 1-2+ ft by 2100 (more with ice-sheet loss). Coastal flooding, erosion, and saltwater intrusion follow.

APES Tip: *thermal expansion is ~half of SLR; Greenland/Antarctic melt is accelerating and uncertain.*

Example: Miami floods on sunny days ('sunny-day flooding') as sea level rises -- the coast's new normal.

173 Climate Refugees & Migration

Explanation: Sea-level rise, drought, and storms displace people: tens of millions already move annually; 'climate refugees' lack formal legal status.

APES Tip: *climate migration compounds existing pressures -- the exam links it to environmental justice.*

Example: Bangladesh's coastal population faces displacement as cyclones and saltwater intrusion advance.

174 Mitigation Strategies

Explanation: Mitigation: renewable energy, efficiency, electrification (EVs, heat pumps), carbon pricing, reforestation, methane cuts, and CCS. The wedge approach: many modest cuts add up.

APES Tip: *mitigation = reducing emissions/removing carbon; name 3-4 strategies with their mechanisms.*

Example: Switching from coal to gas + renewables + EVs + forest restoration could halve U.S. emissions by 2030.

175 Adaptation Strategies

Explanation: Adaptation: seawalls and restored wetlands (coasts), drought-resistant crops and drip irrigation (agriculture), heat-action plans and cooling centers (cities), and migration planning.

APES Tip: *distinguish adaptation (living with change) from mitigation (preventing it) -- the exam loves the pair.*

Example: Rotterdam's floating neighborhoods and the Netherlands' room-for-the-river program adapt to water.

176 Geoengineering (Solar Radiation Management)

- Explanation:** Geoengineering reflects sunlight (stratospheric aerosols, space mirrors) or removes CO₂ (BECCS, DAC, ocean iron fertilization). Risky, unproven, and with side effects -- a last resort debate.
- APES Tip:** *SRM cools fast but does not fix CO₂ (acidification) and risks 'termination shock' and regional weather change.*
- Example:** Stratospheric sulfate injection mimics volcanoes' cooling -- but who controls the global thermostat?
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177 Sustainability & the Triple Bottom Line

- Explanation:** Sustainability = meeting present needs without compromising the future: the triple bottom line balances environmental, economic, and social (equity) goals.
- APES Tip:** *'three pillars' (planet, profit, people) -- the exam asks for all three in sustainability answers.*
- Example:** A solar cooperative creates clean energy (planet), jobs (people), and local profit (profit) -- all three pillars.
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178 Sustainable Development Goals (SDGs)

- Explanation:** The UN's 17 SDGs (2015) integrate poverty, health, education, climate, and ecosystems by 2030 -- the global sustainability framework.
- APES Tip:** *SDGs show sustainability as interlinked -- climate action (SDG 13) connects to poverty (1) and health (3).*
- Example:** SDG 7 (clean energy) and SDG 13 (climate) reinforce each other -- the goals are designed to interact.
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179 The Ecological Footprint & Biocapacity

- Explanation:** Ecological footprint = land/sea area needed to support consumption; biocapacity = the area available. Global overshoot: humanity uses ~1.7 Earths' worth of resources yearly.
- APES Tip:** *footprint per person: the U.S. ~8 gha vs world ~2.7 gha -- affluence drives footprints.*
- Example:** Earth Overshoot Day (when demand exceeds the year's biocapacity) now falls in late July -- it was December in 1970.
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180 The Tragedy of the Commons & Climate

- Explanation:** The atmosphere is the ultimate commons: everyone benefits from emitting, everyone pays for warming. International cooperation (Paris, Kigali) is the collective-action answer.
- APES Tip:** *climate = a commons problem -> needs shared rules and enforcement, not just individual virtue.*
- Example:** Carbon pricing internalizes the externality -- making emitters pay for the commons they use.
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181 Environmental Legislation & International Agreements

- Explanation:** Key laws: NEPA (1969), Clean Air Act (1970), Clean Water Act (1972), ESA (1973), RCRA (1976), Superfund (1980). Treaties: Montreal (1987), Kyoto (1997), Paris (2015), Kigali (2016).
- APES Tip:** *match each law/agreement to its purpose -- a memorization list that pays on multiple choice.*
- Example:** The Clean Water Act made waters 'fishable and swimmable'; NEPA requires environmental impact statements for federal actions.
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What's Next?

You have now reviewed every unit of the AP Environmental Science course. The concepts that matter most are the ones you almost knew -- go back to the Table of Contents, find the units you marked, and reread just those tip lines. Two weeks out, do a rapid pass over the entire guide; the day before, review only the tip lines. On free-response questions, define your terms, give specific examples (cycles, pollutants, laws, species), and always state units -- the exam rewards precise, quantitative answers.

Pair it with the Study Mastery Cheat Sheet (\$19) -- how to actually retain all of it

Also available: AP Biology, AP Chemistry, AP Physics 1, and AP Psychology study guides

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