

Supported Focus Companion

International Baccalaureate · IB Diploma · Environmental Systems and Societies · HL

Source-supported focus teaching; remaining qualification requirements are held

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Original teaching and practice · exercises.lol

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Foundation • supported focus

International Baccalaureate • IB Diploma • Environmental Systems and Societies • HL

Scope and prerequisites

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Prerequisites: read the stated quantities and units, use arithmetic and the model conditions below. Each lesson develops its own method before independent transfer.

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Environmental systems, feedback and perspectives

■ What would explain this observation?

- A lake can respond to the same nutrient input differently depending on its current state. Environmental outcomes depend on **stocks**, **flows** and feedback.
 - Start with a prediction. State the quantities or features you would compare, then decide what evidence could distinguish two explanations.
-

■ Build the model

- A system model has a boundary, stores and flows. Negative feedback counteracts change; positive feedback amplifies it. An environmental perspective shapes what people value and which management outcomes they prioritize.
- stock : An amount held within a system; flow : Transfer of an amount per unit time.



■ Choose evidence that can test it

- Separate physical evidence from value judgements. A stock is an amount at a time; a flow is an amount per time. Sustainability decisions require ecological, social and economic evidence and a stated scale.
 - Draw the system boundary before calculating a budget. Identify inflows, outflows and possible unmeasured terms. Compare stakeholder claims using the same evidence, then explain where values lead to different choices.
-

■ Work from known quantities

- State the known values and their units. Choose the relation because its assumptions fit this case, then rearrange before substitution.
- Known: a reservoir begins with 800 units, receives 120 and loses 90 during a week. Change in storage = inflow-outflow = $120-90 = 30$. Final storage = $800+30 = 830$ units. The model assumes no omitted flow.

Example:

A stock starts at 600, receives 80 and loses 110. Find final stock. Use the same sequence: known quantities → model → relation → substitution → unit and interpretation.

■ Check the conclusion and its limits

- A balance that closes mathematically can still omit a real process if terms were estimated to fit. Positive feedback does not mean a socially desirable result.
- Return to the original observation. Explain what the result supports, which conditions it assumes, and one way to test a competing explanation.

Warn:

Positive feedback always produces a socially beneficial outcome. This claim is false: A balance that closes mathematically can still omit a real process if terms were estimated to fit. Positive feedback does not mean a socially desirable result.

Key:

Environmental systems, feedback and perspectives: Separate physical evidence from value judgements. A stock is an amount at a time; a flow is an amount per time. Sustainability decisions require ecological, social and economic evidence and a stated scale.

Ecology · supported focus

International Baccalaureate · IB Diploma · Environmental Systems and Societies · HL

Scope and prerequisites

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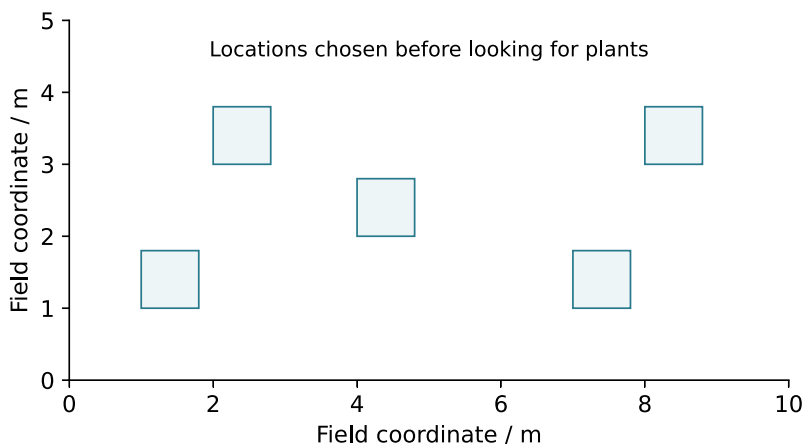
Sampling populations without choosing the answer

■ What would explain this observation?

- A field edge looks richer in plants than its centre. Choosing only the richest patches would build the desired result into the sampling method.
- Start with a prediction. State the quantities or features you would compare, then decide what evidence could distinguish two explanations.

■ Build the model

- A **population** consists of organisms of one species in a defined area. Random **quadrats** estimate density without deliberately selecting patches. A transect investigates change along an environmental gradient.
- quadrat : A defined area used for sampling; population: Organisms of one species in a defined area.



■ Choose evidence that can test it

- Estimate total abundance by multiplying mean density by area, with consistent units. This assumes sampled areas represent the habitat. Patchiness and too few samples widen uncertainty.
 - Choose coordinates with random numbers before visiting the patches. Record quadrat area and counting rules. For a transect, use fixed distances and measure a relevant abiotic variable. Do not damage habitats or sample unsafe locations.
-

■ Work from known quantities

- State the known values and their units. Choose the relation because its assumptions fit this case, then rearrange before substitution.
- Known: five 0.25 square metre quadrats contain 3, 4, 6, 5 and 2 plants. Mean count = $20/5 = 4$. Density = $4/0.25 = 16$ plants per square metre. Estimated abundance in 100 square metres = $16 \times 100 = 1,600$ plants.

Example:

Mean count is 6 in a 0.5 square metre quadrat. Find density per square metre. Use the same sequence: known quantities $\rightarrow$ model $\rightarrow$ relation $\rightarrow$ substitution $\rightarrow$ unit and interpretation.

■ Check the conclusion and its limits

- Quadrats suit organisms that do not move quickly. A food chain arrow shows the direction of energy transfer, not the direction a predator travels.
- Return to the original observation. Explain what the result supports, which conditions it assumes, and one way to test a competing explanation.

Warn:

Sampling only the most crowded patches gives an unbiased population estimate. This claim is false: Quadrats suit organisms that do not move quickly. A food chain arrow shows the direction of energy transfer, not the direction a predator travels.

Key:

Sampling populations without choosing the answer: Estimate total abundance by multiplying mean density by area, with consistent units. This assumes sampled areas represent the habitat. Patchiness and too few samples widen uncertainty.

Biodiversity and conservation · supported focus

International Baccalaureate · IB Diploma · Environmental Systems and Societies · HL

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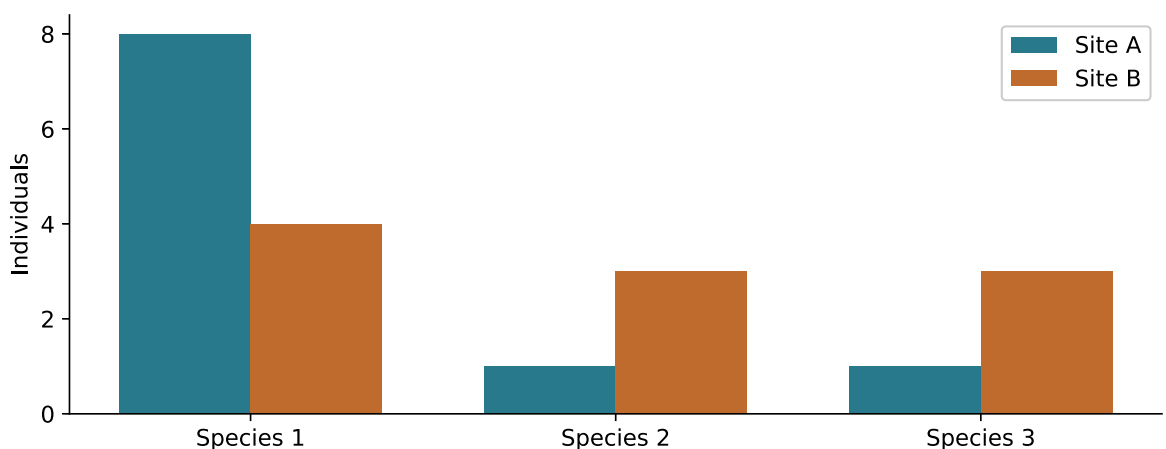
Biodiversity, conservation and sampling evidence

■ What would explain this observation?

- A site with many individuals can still be dominated by one species. Abundance, richness and **evenness** describe different features of biodiversity.
- Start with a prediction. State the quantities or features you would compare, then decide what evidence could distinguish two explanations.

■ Build the model

- **Species richness** counts species. Evenness concerns relative abundance. Conservation can protect habitats, populations or genetic diversity; a management judgement must state the conservation goal.
- species richness: The number of species recorded; evenness: How evenly individuals are distributed among species.



■ Choose evidence that can test it

- Compare surveys with similar area, effort, season and identification rules. A diversity index is meaningful only with its formula and conventions specified. Habitat fragmentation can affect movement and gene flow even when total area changes little.
 - Use non-destructive field sampling approved by the school. Identify organisms with a suitable key and record uncertain identifications rather than inventing species. Combine ecological evidence with stakeholder perspectives on land use.
-

■ Work from known quantities

- State the known values and their units. Choose the relation because its assumptions fit this case, then rearrange before substitution.
- Known: site A has counts 8, 1 and 1; site B has 4, 3 and 3. Both have richness 3 and total abundance 10. The most abundant species occupies 80% in A and 40% in B. B is more even under these counts.

Example:

A survey records 6, 5, 3 and 2 individuals in four species. Find species richness. Use the same sequence: known quantities → model → relation → substitution → unit and interpretation.

■ Check the conclusion and its limits

- An index cannot by itself explain the cause of a difference. A newly recorded species may reflect improved observation rather than a recent ecological arrival.
- Return to the original observation. Explain what the result supports, which conditions it assumes, and one way to test a competing explanation.

Warn:

A larger total number of individuals always means greater species richness. This claim is false: An index cannot by itself explain the cause of a difference. A newly recorded species may reflect improved observation rather than a recent ecological arrival.

Key:

Biodiversity, conservation and sampling evidence: Compare surveys with similar area, effort, season and identification rules. A diversity index is meaningful only with its formula and conventions specified. Habitat fragmentation can affect movement and gene flow even when total area changes little.

Water · supported focus

International Baccalaureate · IB Diploma · Environmental Systems and Societies · HL

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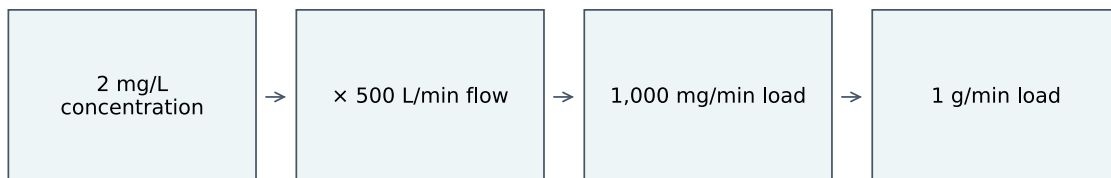
Water, pollution and management trade-offs

■ What would explain this observation?

- A downstream sample has less dissolved oxygen after a nutrient input. The explanation must connect biological processes with the water-system evidence.
- Start with a prediction. State the quantities or features you would compare, then decide what evidence could distinguish two explanations.

■ Build the model

- **Eutrophication** can begin with nutrient enrichment, followed by greater producer growth and increased decomposition after organisms die. Decomposer respiration can lower dissolved oxygen. Water availability depends on quantity, quality and access.
- eutrophication: Nutrient enrichment with ecological consequences; **pollutant load**
: Mass of pollutant transferred per time.



■ Choose evidence that can test it

- Distinguish concentration from total pollutant load. Dilution can reduce concentration without removing the pollutant mass. A management plan should consider upstream causes, users and effects on other parts of the catchment.
 - Collect approved water-quality observations at matched sites and times. Use calibrated instruments and consistent sampling depth. Avoid contact with contaminated water and do not infer potability from clarity.
-

■ Work from known quantities

- State the known values and their units. Choose the relation because its assumptions fit this case, then rearrange before substitution.
- Known: concentration is 2 mg per litre and flow is 500 litres per minute. Load = concentration $\times$ flow = $2 \times 500 = 1,000$ mg per minute = 1 g per minute. A lower concentration during high flow can still produce a high total load.

Example:

Concentration is 3 mg/L and flow 200 L/min. Find load in mg/min. Use the same sequence: known quantities $\rightarrow$ model $\rightarrow$ relation $\rightarrow$ substitution $\rightarrow$ unit and interpretation.

■ Check the conclusion and its limits

- Clear water is not necessarily safe water. Nutrient enrichment does not directly use up oxygen; the pathway includes biological activity and decomposition.
- Return to the original observation. Explain what the result supports, which conditions it assumes, and one way to test a competing explanation.

Warn:

Clear water is always safe to drink. This claim is false: Clear water is not necessarily safe water. Nutrient enrichment does not directly use up oxygen; the pathway includes biological activity and decomposition.

Key:

Water, pollution and management trade-offs: Distinguish concentration from total pollutant load. Dilution can reduce concentration without removing the pollutant mass. A management plan should consider upstream causes, users and effects on other parts of the catchment.

Land · supported focus

International Baccalaureate · IB Diploma · Environmental Systems and Societies · HL

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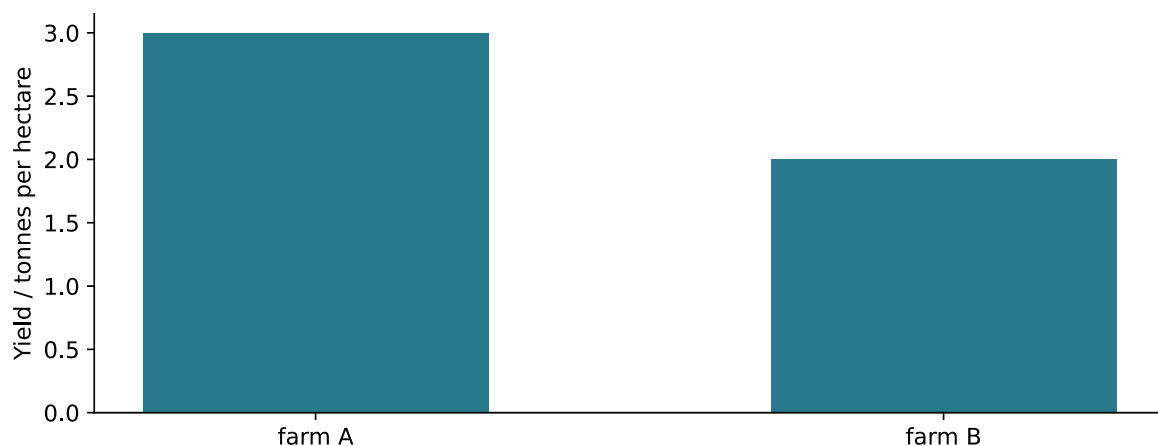
Land, food and resource decisions

■ What would explain this observation?

- A farm can increase yield while increasing soil loss or water demand. Food-system evaluation requires more than tonnes harvested.
- Start with a prediction. State the quantities or features you would compare, then decide what evidence could distinguish two explanations.

■ Build the model

- Soil supports nutrient cycling, water storage and organisms. **Erosion** removes soil; nutrient depletion changes fertility. **Resource** use involves extraction, production, distribution and waste.
- erosion: Removal and transport of soil or rock; resource: A material or service used to meet needs.



■ Choose evidence that can test it

- Distinguish total yield from yield per area and energy input. Sustainable management must consider regeneration rates and impacts beyond the farm boundary. Different stakeholders may rank food security, biodiversity and income differently.
 - Compare management options using a stated functional unit and the same timescale. Use approved secondary datasets or non-destructive soil observations. Explain trade-offs instead of claiming a method has no disadvantages.
-

■ Work from known quantities

- State the known values and their units. Choose the relation because its assumptions fit this case, then rearrange before substitution.
- Known: farm A harvests 18 tonnes from 6 hectares. Yield per area = $18/6 = 3$ tonnes per hectare. Farm B harvests 20 tonnes from 10 hectares, so its yield is 2 tonnes per hectare despite a larger total harvest.

Example:

A farm harvests 28 tonnes from 7 hectares. Find yield per hectare. Use the same sequence: known quantities → model → relation → substitution → unit and interpretation.

■ Check the conclusion and its limits

- A high yield is not proof of long-term soil health. Renewable resources can be depleted when use exceeds regeneration.
- Return to the original observation. Explain what the result supports, which conditions it assumes, and one way to test a competing explanation.

Warn:

A renewable resource cannot be depleted. This claim is false: A high yield is not proof of long-term soil health. Renewable resources can be depleted when use exceeds regeneration.

Key:

Land, food and resource decisions: Distinguish total yield from yield per area and energy input. Sustainable management must consider regeneration rates and impacts beyond the farm boundary. Different stakeholders may rank food security, biodiversity and income differently.

Atmosphere and climate change · supported focus

International Baccalaureate · IB Diploma · Environmental Systems and Societies · HL

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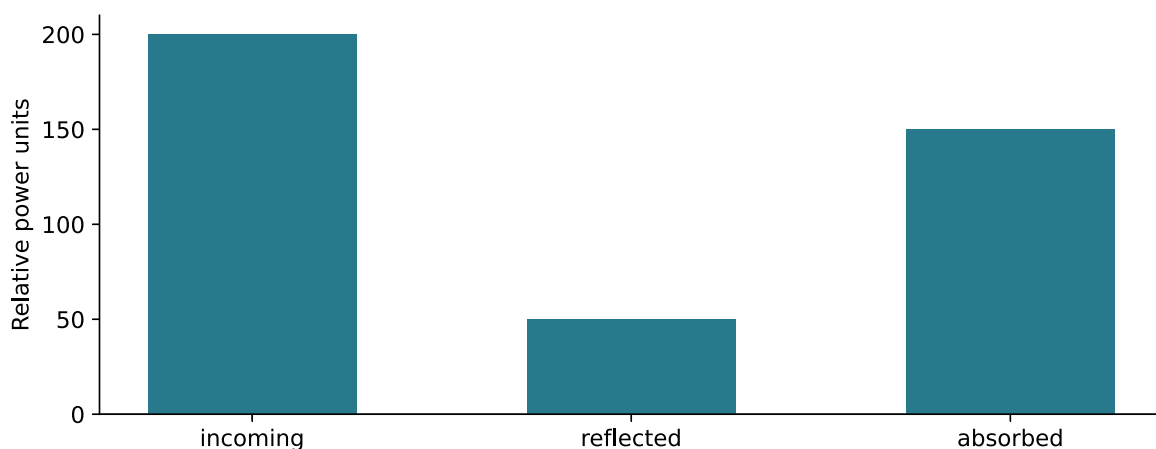
Climate evidence, energy budgets and policy

■ What would explain this observation?

- One cold day does not disprove a warming climate. Weather describes short-term conditions; climate describes distributions over longer times and regions.
- Start with a prediction. State the quantities or features you would compare, then decide what evidence could distinguish two explanations.

■ Build the model

- The Earth energy balance includes incoming solar radiation, reflection, absorption and outgoing infrared radiation. Greenhouse gases absorb and emit infrared radiation. Feedback can alter the response to an initial forcing.
- **mitigation** : Actions addressing causes of environmental change; **adaptation** : Actions reducing harm from environmental impacts.



■ Choose evidence that can test it

- Distinguish mitigation, which addresses drivers, from adaptation, which reduces harm from impacts. A policy assessment needs evidence about effectiveness, cost, equity and uncertainty; one criterion is not the entire decision.
 - Compare multi-year data using consistent baselines. State the region, timescale and uncertainty. At HL, connect a management decision to law, economics and ethics rather than treating these lenses as extra definitions only.
-

■ Work from known quantities

- State the known values and their units. Choose the relation because its assumptions fit this case, then rearrange before substitution.
- Known: a surface receives 200 power units and reflects 50. Absorbed input = incoming-reflected = $200 - 50 = 150$. Reflected fraction = $50/200 = 0.25 = 25\%$. A change in reflectivity alters the absorbed budget under this model.

Example:

Incoming energy is 240 units and reflected energy 72. Find reflected percentage. Use the same sequence: known quantities → model → relation → substitution → unit and interpretation.

■ Check the conclusion and its limits

- The greenhouse effect is not the same process as ozone depletion. A carbon footprint estimate depends on its system boundary.
- Return to the original observation. Explain what the result supports, which conditions it assumes, and one way to test a competing explanation.

Warn:

One local weather observation establishes a global climate trend. This claim is false: The greenhouse effect is not the same process as ozone depletion. A carbon footprint estimate depends on its system boundary.

Key:

Climate evidence, energy budgets and policy: Distinguish mitigation, which addresses drivers, from adaptation, which reduces harm from impacts. A policy assessment needs evidence about effectiveness, cost, equity and uncertainty; one criterion is not the entire decision.

Human populations and urban systems · supported focus

International Baccalaureate · IB Diploma · Environmental Systems and Societies · HL

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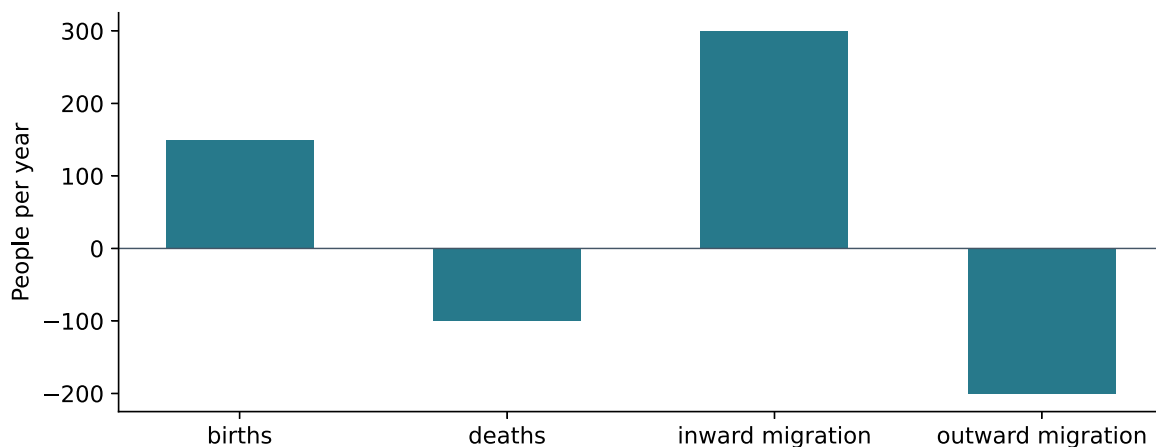
Population, urban systems and indicators

■ What would explain this observation?

- A city can grow because people move into it even when births equal deaths. Population change has several flows.
- Start with a prediction. State the quantities or features you would compare, then decide what evidence could distinguish two explanations.

■ Build the model

- Population change depends on births, deaths, **immigration** and emigration. Urban systems exchange energy, materials and waste with a wider region. A sustainability **indicator** measures a specified feature rather than total wellbeing.
- immigration: Movement into a population; indicator: A measure of a specified condition.



■ Choose evidence that can test it

- Compare rates with a common denominator and interval. An average can hide unequal access to services. At HL, evaluate how economic incentives, legal responsibilities and ethical priorities change an urban management proposal.
 - Use published demographic and city-service data with dates and definitions. Protect privacy when collecting local opinions. Compare the same geographical boundary rather than mixing an urban core with a whole metropolitan region.
-

■ Work from known quantities

- State the known values and their units. Choose the relation because its assumptions fit this case, then rearrange before substitution.
- Known: a city has 10,000 people; births 150, deaths 100, immigration 300 and emigration 200 in one year. $\text{Change} = 150 - 100 + 300 - 200 = 150$. $\text{Growth percentage} = 150 / 10,000 \times 100 = 1.5\%$.

Example:

A population of 2,000 grows by 40 in a year. Find percentage growth. Use the same sequence: known quantities → model → relation → substitution → unit and interpretation.

■ Check the conclusion and its limits

- A projected population is conditional on assumptions. Urban growth does not automatically mean improved health, income or environmental quality for every resident.
- Return to the original observation. Explain what the result supports, which conditions it assumes, and one way to test a competing explanation.

Warn:

Population growth depends only on births and deaths. This claim is false: A projected population is conditional on assumptions. Urban growth does not automatically mean improved health, income or environmental quality for every resident.

Key:

Population, urban systems and indicators: Compare rates with a common denominator and interval. An average can hide unequal access to services. At HL, evaluate how economic incentives, legal responsibilities and ethical priorities change an urban management proposal.

Environmental law · supported focus

International Baccalaureate · IB Diploma · Environmental Systems and Societies · HL

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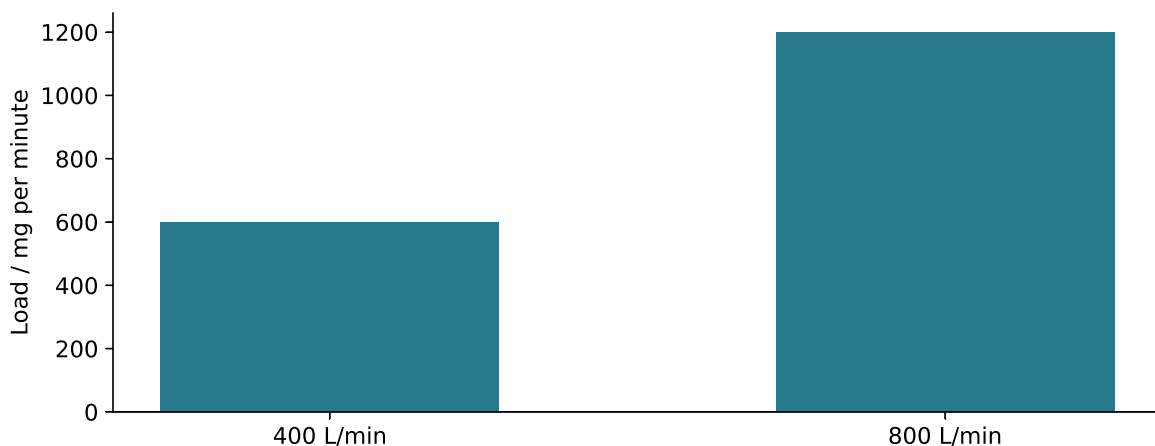
Environmental law: rules, evidence and enforcement

■ What would explain this observation?

- Two catchments have the same discharge limit but different water quality. A legal rule can influence behaviour only through its coverage, implementation and **enforcement**.
- Start with a prediction. State the quantities or features you would compare, then decide what evidence could distinguish two explanations.

■ Build the model

- Environmental law defines obligations and permissions within a **jurisdiction**. A discharge permit may specify a concentration, a total load, monitoring and consequences of non-compliance. International agreements require implementation through institutions; signing an agreement alone does not show that an environmental outcome has improved.
- enforcement: Implementation of rules through monitoring and consequences; jurisdiction: The geographical or institutional scope of an authority.



■ Choose evidence that can test it

- Distinguish the legal instrument from the evidence about its effect. A concentration limit can be satisfied while total pollutant load rises if flow increases. Evaluate monitoring coverage, detection probability, incentives, access to justice and effects on different groups. An observed change after a policy is compatible with an effect but also with rainfall, industrial changes or other interventions.
- Use an attributed historical or clearly fictional permit and paired monitoring data. Identify the regulated activity, responsible authority, geographical boundary and date. Compare upstream/downstream and before/after observations where available, document sampling gaps, and discuss whose evidence or costs are excluded. Do not present this classroom model as advice about current local law.

■ Work from known quantities

- State the known values and their units. Choose the relation because its assumptions fit this case, then rearrange before substitution.
- Known: a fictional permit caps discharge at 2 mg/L. A monitored discharge is 1.5 mg/L at 400 L/min. Load = concentration $\times$ flow = 600 mg/min. At the same concentration and 800 L/min the load is 1,200 mg/min. Both concentration observations satisfy the fictional cap, while the second transports twice the mass.

Example:

A discharge contains 1.2 mg/L at 500 L/min. Calculate transported mass per minute. Use the same sequence: known quantities $\rightarrow$ model $\rightarrow$ relation $\rightarrow$ substitution $\rightarrow$ unit and interpretation.

■ Check the conclusion and its limits

- Compliance with one indicator does not prove ecological safety or fair enforcement. Compare actual outcomes with the policy objective and consider both administrative feasibility and affected communities.
- Return to the original observation. Explain what the result supports, which conditions it assumes, and one way to test a competing explanation.

Warn:

A concentration-compliant discharge necessarily has a small total pollutant load. This claim is false: Compliance with one indicator does not prove ecological safety or fair enforcement. Compare actual outcomes with the policy objective and consider both administrative feasibility and affected communities.

Key:

Environmental law: rules, evidence and enforcement: Distinguish the legal instrument from the evidence about its effect. A concentration limit can be satisfied while total pollutant load rises if flow increases. Evaluate monitoring coverage, detection probability, incentives, access to justice and effects on different groups. An observed change after a policy is compatible with an effect but also with rainfall, industrial changes or other interventions.

Environmental and ecological economics · supported focus

International Baccalaureate · IB Diploma · Environmental Systems and Societies · HL

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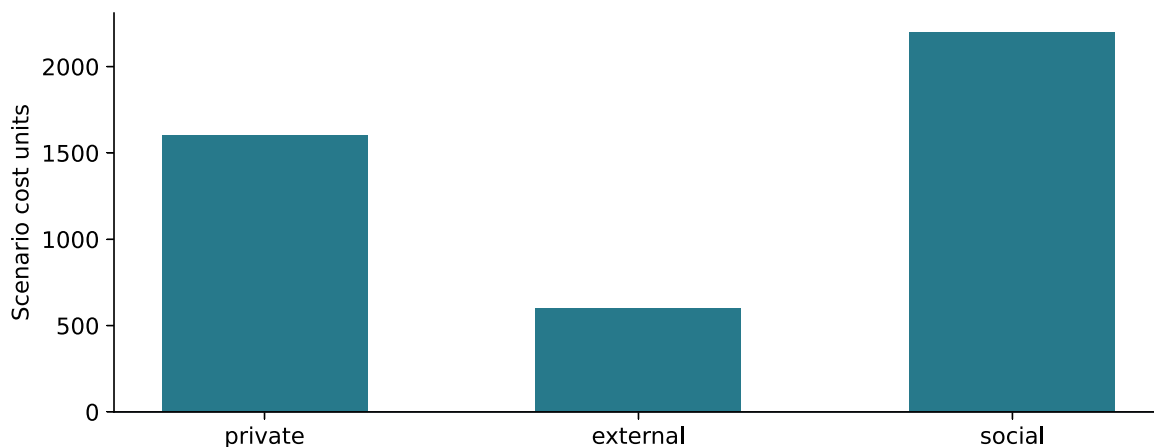
Environmental economics: costs beyond the market price

■ What would explain this observation?

- A cheap product can impose waste or pollution costs on people who did not buy it. Its market price may omit part of its environmental cost.
- Start with a prediction. State the quantities or features you would compare, then decide what evidence could distinguish two explanations.

■ Build the model

- An **externality** is a cost or benefit affecting a third party that is not fully reflected in a transaction. Environmental economics examines incentives and valuation, including instruments such as taxes, subsidies and tradable permits. Ecological economics also questions growth assumptions and emphasizes ecological limits and relationships between the economy and its supporting systems.
- externality: A transaction effect on a third party not fully reflected in its price;
social cost : Private cost plus external cost within the stated model.



■ Choose evidence that can test it

- In a simplified model, marginal social cost equals marginal private cost plus marginal external cost. A pollution charge can alter incentives, but selecting a charge requires evidence and a stated objective. Monetary totals do not by themselves settle distribution, irreversibility, uncertainty or whether a service can be substituted.
- Construct a transparent table with a common currency, time period and system boundary. Separate measured expenditure from estimated environmental damage. Compare at least two valuation assumptions, identify who pays and who benefits, and consider a non-monetary indicator such as habitat condition. Label these as classroom scenarios rather than forecasts.

■ Work from known quantities

- State the known values and their units. Choose the relation because its assumptions fit this case, then rearrange before substitution.
- Known: producing one item costs the producer 8 units, while the scenario estimates an external cost of 3 units. Social cost is 11 units per item. For 200 items, private cost is 1,600 units and estimated external cost is 600 units, giving 2,200 units total under this model. If external damage is estimated at 1–5 units per item, the social-cost range is 1,800–2,600 units.

Example:

Private cost is 6 units per item and external cost is 2 units. Calculate social cost for 50 items. Use the same sequence: known quantities → model → relation → substitution → unit and interpretation.

■ Check the conclusion and its limits

- A money value is an assumption-dependent estimate, not a measurement of intrinsic ecological value. A policy that lowers total cost can still place a disproportionate burden on a vulnerable group.
- Return to the original observation. Explain what the result supports, which conditions it assumes, and one way to test a competing explanation.

Warn:

The cheapest market price necessarily identifies the smallest total environmental cost. This claim is false: A money value is an assumption-dependent estimate, not a measurement of intrinsic ecological value. A policy that lowers total cost can still place a disproportionate burden on a vulnerable group.

Key:

Environmental economics: costs beyond the market price: In a simplified model, marginal social cost equals marginal private cost plus marginal external cost. A pollution charge can alter incentives, but selecting a charge requires evidence and a stated objective. Monetary totals do not by themselves settle distribution, irreversibility, uncertainty or whether a service can be substituted.

Environmental ethics · supported focus

International Baccalaureate · IB Diploma · Environmental Systems and Societies · HL

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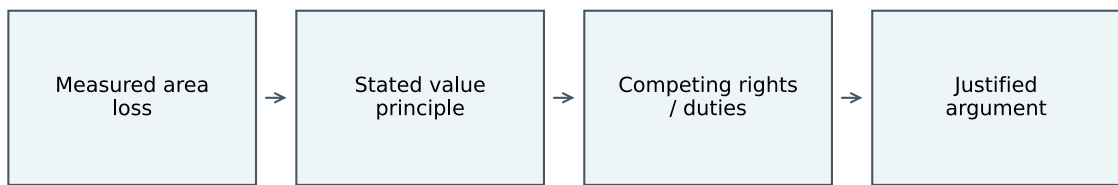
Environmental ethics: make the value judgement explicit

■ What would explain this observation?

- People may agree on the measured loss of a wetland but disagree on whether a development is acceptable. The disagreement can concern values as well as scientific uncertainty.
- Start with a prediction. State the quantities or features you would compare, then decide what evidence could distinguish two explanations.

■ Build the model

- Environmental ethics examines reasons for responsibilities toward people, other organisms and ecological systems. Anthropocentric reasoning emphasizes human interests; biocentric reasoning recognizes moral standing of living organisms; ecocentric reasoning emphasizes ecological wholes. These positions are lenses for analysing arguments, and real individuals can combine them.
- **intrinsic value** : Value considered independent of usefulness to another party; **environmental justice** : Fair treatment in environmental burdens, benefits and decision-making.



■ Choose evidence that can test it

- Separate descriptive claims from normative claims. A species count is evidence about the sampled community; deciding that every species has intrinsic value is a value position. Compare consequences, rights, duties and fairness across generations. A defensible argument states its values, uses accurate evidence and acknowledges competing claims rather than disguising a value choice as a calculation.
- Use a fictional planning dispute or an attributed historical case. Build an argument table: stakeholder, factual claim, evidence, value principle and possible response. Include affected communities and future generations without pretending to speak for them. Use voluntary anonymous classroom positions; assess the reasoning rather than agreement with a preferred worldview.

■ Work from known quantities

- State the known values and their units. Choose the relation because its assumptions fit this case, then rearrange before substitution.
- Known: a wetland proposal affects 12 hectares of a 60-hectare site, or 20%. This quantifies the stated area change. An anthropocentric argument might examine flood protection and livelihoods; a biocentric argument might consider affected organisms; an ecocentric argument might consider hydrological connections. The 20% figure cannot alone decide which ethical argument is strongest.

Example:

A project affects 9 hectares within a 45-hectare site. Calculate the percentage of area affected. Use the same sequence: known quantities → model → relation → substitution → unit and interpretation.

■ Check the conclusion and its limits

- Worldview labels are analytical aids, not fixed stereotypes of cultures or people. Neither a stakeholder majority nor a numerical index automatically resolves a rights-based or intergenerational objection.
- Return to the original observation. Explain what the result supports, which conditions it assumes, and one way to test a competing explanation.

Warn:

A percentage of habitat lost alone settles the ethical acceptability of a development. This claim is false: Worldview labels are analytical aids, not fixed stereotypes of cultures or people. Neither a stakeholder majority nor a numerical index automatically resolves a rights-based or intergenerational objection.

Key:

Environmental ethics: make the value judgement explicit: Separate descriptive claims from normative claims. A species count is evidence about the sampled community; deciding that every species has intrinsic value is a value position. Compare consequences, rights, duties and fairness across generations. A defensible argument states its values, uses accurate evidence and acknowledges competing claims rather than disguising a value choice as a calculation.

Experimental programme · supported focus

International Baccalaureate · IB Diploma · Environmental Systems and Societies · HL

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Prerequisites: read the stated quantities and units, use arithmetic and the model conditions below. Each lesson develops its own method before independent transfer.

These are original or explicitly fictional teaching examples, not actual measurements or completed assessed learner investigations.

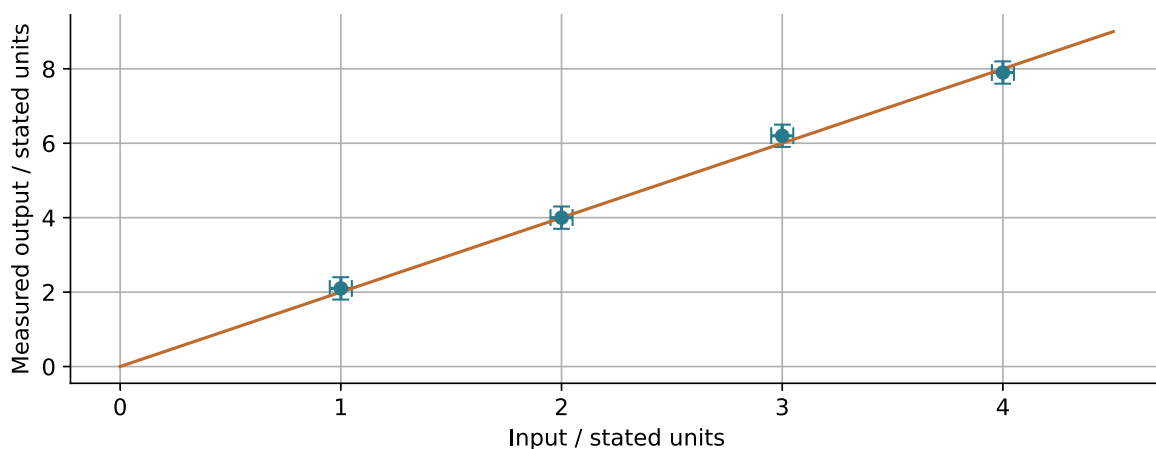
Uncertainty, gradients and model testing

■ What would explain this observation?

- A line passing near every data point is useful, but its gradient can still be uncertain. A graph is evidence for a model within the measurement range.
- Start with a prediction. State the quantities or features you would compare, then decide what evidence could distinguish two explanations.

■ Build the model

- Random variation makes repeated readings differ. **Systematic error** shifts results consistently. Absolute **uncertainty** has the measured unit; relative or percentage uncertainty compares uncertainty with the measured value.
- uncertainty: A quantified limitation on a measured result; systematic error: A consistent measurement bias.



■ Choose evidence that can test it

- For a product or quotient, adding fractional uncertainties is a common maximum-uncertainty approximation. For a difference, add absolute uncertainties. A nonzero intercept can reveal an offset or an incomplete model.
- Show units on axes and choose a sensible scale. Plot uncertainty bars where justified, draw a best-fit line rather than joining every point, and estimate steepest and shallowest plausible gradients when the course method calls for them.

■ Work from known quantities

- State the known values and their units. Choose the relation because its assumptions fit this case, then rearrange before substitution.
- Known: length = 50.0 mm with uncertainty 1.0 mm. Percentage uncertainty = $\text{absolute uncertainty}/\text{value} \times 100 = 1.0/50.0 \times 100 = 2.0\%$. For a quotient of two independently measured quantities with maximum percentage uncertainties 2% and 3%, the summed maximum estimate is 5%.

Example:

A 40 cm reading has an absolute uncertainty of 1 cm. Find percentage uncertainty. Use the same sequence: known quantities → model → relation → substitution → unit and interpretation.

■ Check the conclusion and its limits

- Repeating readings reduces random uncertainty in a mean but does not automatically remove a zero error. Do not quote more decimal places than your measurement can support.
- Return to the original observation. Explain what the result supports, which conditions it assumes, and one way to test a competing explanation.

Warn:

Repeating a measurement always removes a calibration offset. This claim is false: Repeating readings reduces random uncertainty in a mean but does not automatically remove a zero error. Do not quote more decimal places than your measurement can support.

Key:

Uncertainty, gradients and model testing: For a product or quotient, adding fractional uncertainties is a common maximum-uncertainty approximation. For a difference, add absolute uncertainties. A nonzero intercept can reveal an offset or an incomplete model.