Water

Topic 4 · SL and HL

Day Zero was avoided

Cape Town, February 2018

50 litres per person per day municipal-use limit.

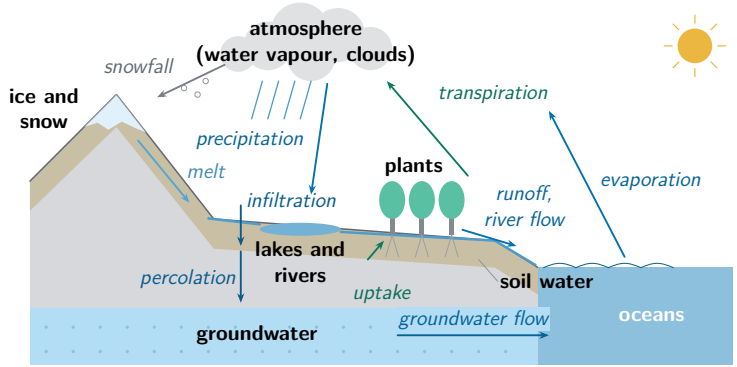
Reported dam level 24.7%; severe restrictions were planned.

Explain the outcome

Demand reductions and subsequent rainfall mattered.

A planned restriction is not proof that every tap ran dry.

The hydrological cycle



Selected storages and flows: solar energy and gravity drive different processes.

Transfers and transformations

Movement without state change

Infiltration into soil; **percolation** through porous material.

Runoff, groundwater flow and advection.

Change of physical state

Evaporation, transpiration and condensation.

Freezing, melting, sublimation and deposition.

Balance a reservoir budget

1. **Invented annual givens.** Inputs 180; withdrawals 120; **evaporation** 20; required downstream flow 30, all million m^3/year.
2. **Balance.** Storage change $= 180 - 120 - 20 - 30 = 10$ million m^3/year.
3. **Interpret.** An annual surplus does not guarantee availability during a drought month.

Decision

Protect environmental flows and test seasonal uncertainty before allocating more water.

Estimate residence time

1. **Given.** Steady lake storage 2.0×10^9 m^3; annual outflow 4.0×10^8 m^3.
2. **Divide storage by flow.** $2.0 \times 10^9 / (4.0 \times 10^8) = 5$ years.
3. **Limit.** This is an average with representative throughflow, not every molecule's exact age.

Decision

Only about 2.5% of Earth's water is fresh; global shares do not establish local safe supply.

People change the cycle

Land and abstraction

Impermeable surfaces can reduce **infiltration** and speed runoff.

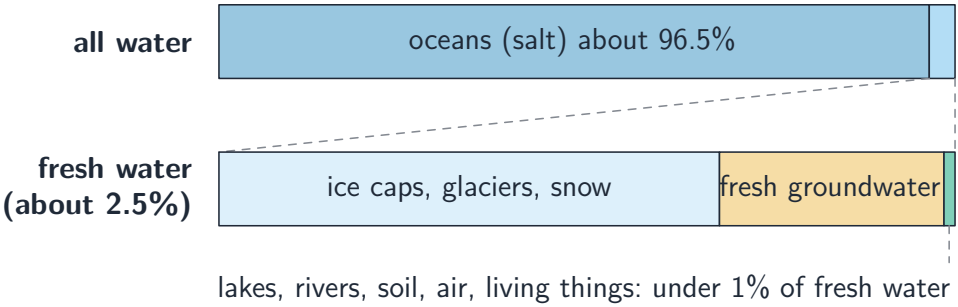
Vegetation loss and compaction depend on local conditions.

Storage and climate

Dams alter release timing; over-abstraction can lower groundwater.

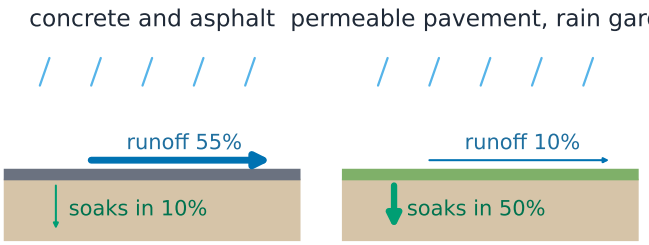
Rainfall, **evaporation** and glacier-loss effects vary by region.

Where the Earth's water is



Lakes and rivers are under 1% of fresh water

Hard surfaces and runoff



illustrative shares of rainfall; the rest evaporates

> More runoff means faster, higher floods

Withdrawal, consumption and sector shares

Definitions

Withdrawal: water removed from a source.

Consumption: water not returned within the relevant system and period.

FAO, 2023 withdrawals

72% agriculture + 15% industry + 13% services = 100%.

Services is not simply household drinking water.

Physical and economic scarcity

Physical water scarcity

Available water cannot meet demand and ecosystem needs.

Quantity, timing and quality constrain use.

Economic water scarcity

Finance, infrastructure or institutions constrain access.

Nearby water does not guarantee affordable treatment and distribution.

Aral Sea: a changed budget

Input reduction

Irrigation diversions reduced inflow.

Shrinking water and increased salinity harmed fisheries; exposed sediments supplied dust.

Recovery and interpretation

The 2005 northern dam supported partial recovery.

State basin, date and area or volume before quoting a percentage.

Singapore's Four National Taps

Diversified supplies

Local catchment and imported water.

Reclaimed NEWater and **desalination**.

Evaluate the combination

Energy, treatment, maintenance and reliability.

Metering, leak reduction and affordable basic access.

More supply and less demand

Supply measures

Reverse osmosis: pressure through a membrane; manage brine and energy.

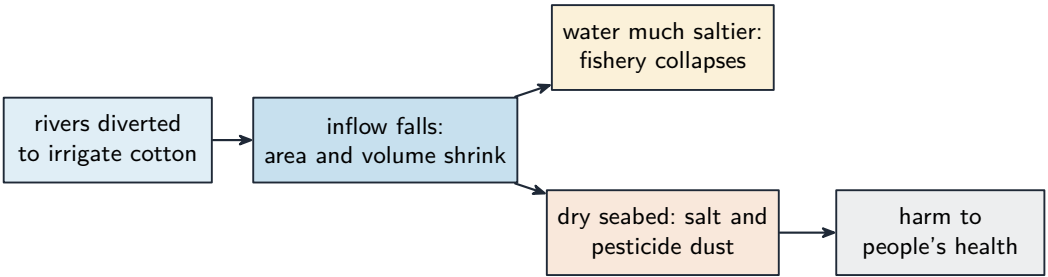
Rainwater, reservoirs and suitable groundwater recharge.

Demand measures

Low-flow fittings, metering and appropriately treated **greywater**.

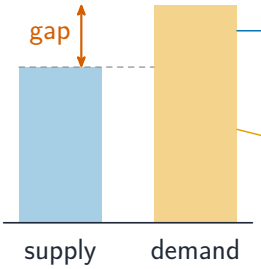
Drip irrigation and suitable crops; expansion can offset savings.

How the Aral Sea shrank



> Dust from the dry seabed harms health

Closing a water gap

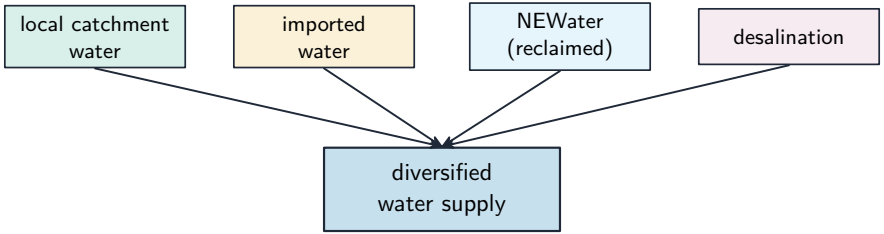


raise supply: reservoirs, desalination, rainwater harvesting, recharged groundwater, inter-regional transfer

cut demand: drip irrigation, pricing and metering, greywater reuse, fixing leaks

> Either side can close the gap

Singapore's four taps



plus demand side: metering, leak reduction, low-flow fittings

> A diversified supply is more secure

Aquatic food webs and demand

Producers to consumers

Phytoplankton, aquatic plants and algae support food webs.

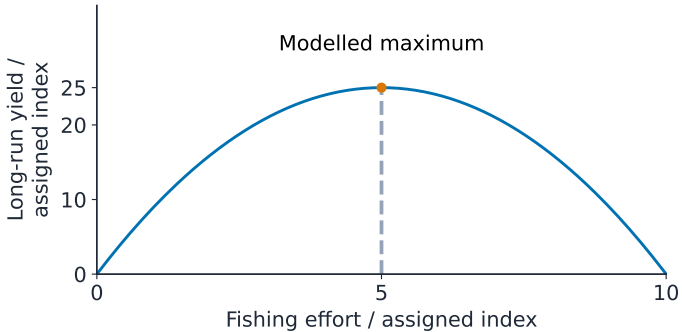
People eat lotus rhizomes, kelp, carp, shellfish and marine fish.

Pressure pathways

Demand reflects population, culture, income and trade.

Bottom trawling, ghost nets, **bycatch**, poisons and explosives affect different organisms.

Yield and fishing effort



> Invented equilibrium indices: high one-year catch is not evidence of a sustainable stock.

A common resource needs institutions

Potential incentive problem

An extra catch benefits the vessel; depletion costs are shared.

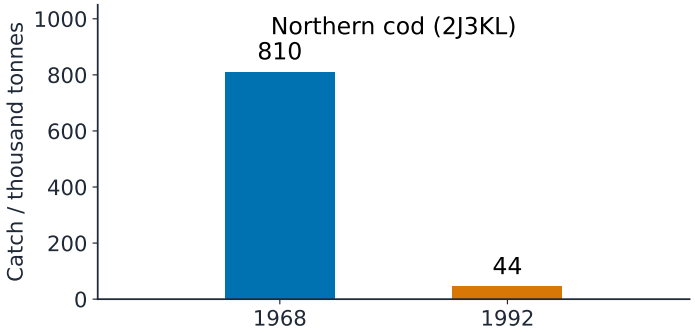
Ineffective access rules can lead to excess effort.

Management can change incentives

Rights, monitoring and enforceable quotas.

Mesh rules, closed seasons, marine protected areas and international cooperation.

Northern cod: two catch observations



1968: 810 thousand tonnes; 1992: estimated 44 thousand. Catch is not biomass.

What happened after the cod collapse?

Dated decisions

Commercial moratorium began in 1992.

Commercial fishery reopened in 2024.

Recovery evidence

Stock biomass, recruitment, prey and mortality need monitoring.

Reopening alone does not prove historical abundance has returned.

Climate and aquaculture trade-offs

Reef and wild fisheries

Great Barrier Reef bleaching: heat-related habitat stress.

Acidification is a distinct carbon-dioxide chemistry pathway.

Norwegian salmon cages

Feed, organic wastes, sea lice and escapes need controls.

Site choice, stocking, containment and fallowing address different pathways.

Compare farmed-food systems

Possible gains

More controllable food production and employment.

Potential to reduce pressure on some wild stocks.

System costs and limits

Feed substitution can move impacts onto land.

Seaweed uses dissolved nutrients; filter-feeders remove particles; capacity is finite.

Pollution sources and effects

Point and non-point sources

Defined pipe outlet versus inputs across farmland or roads.

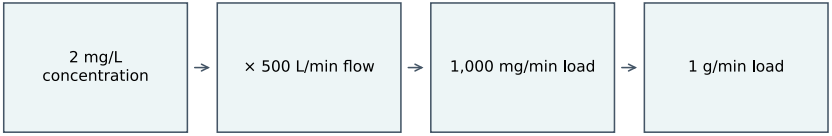
Organic matter, nutrients, pathogens, metals, plastics and heat have different effects.

Sampling evidence

Matched sites, depths, times, calibrated sensors and replicates.

Clarity is not proof of drinking-water safety.

Pollutant load



Concentration × flow gives mass per time; dilution alone does not remove the load.

Dilution with clean water

1. **Given.** 2 mg/L $\times$ 500 L/min $=$ 1000 mg/min $=$ 1 g/min.
2. **Add clean flow.** Add 500 L/min without other pollutant gains or losses: total flow is 1000 L/min.
3. **New concentration.** 1000 mg/min $\div$ 1000 L/min $=$ 1 mg/L.

Decision

For two polluted streams, add their loads and flows separately before dividing.

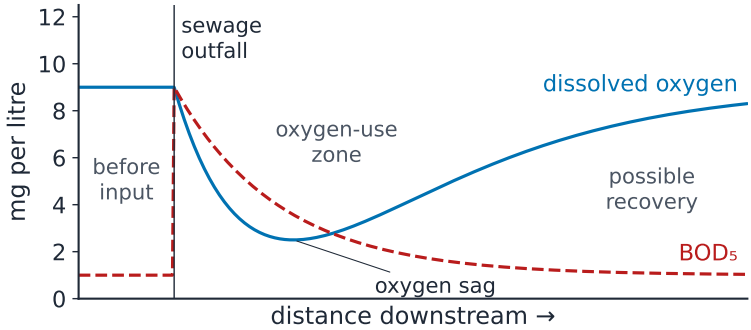
Measure BOD_5

1. **Invented valid undiluted test.** Initial oxygen 9.0 mg/L; after five days at 20 °C in darkness, 4.8 mg/L.
2. **Subtract.** $BOD_5 = 9.0 - 4.8 = 4.2$ mg/L.
3. **Protocol limits.** Real tests may need dilution and blank correction; do not ignore exhausted oxygen.

Decision

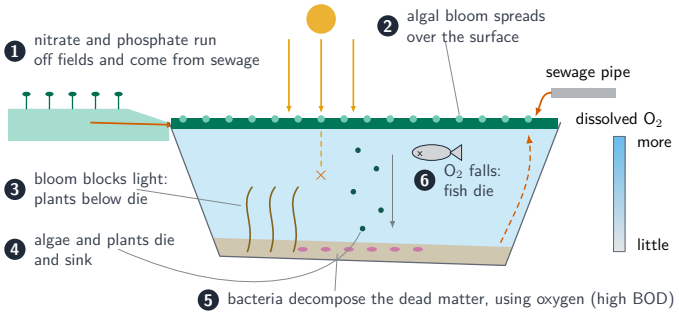
BOD describes oxygen demand under the test conditions, not every possible pollutant.

An oxygen sag is conditional



Microbial respiration uses oxygen; flow, aeration, temperature and further inputs affect recovery.

Eutrophication and feedback



Low oxygen can release sediment nutrients, feeding further blooms.

Two harmful-bloom cases

Lake Tai, 2007

Cyanobacterial bloom, severe odour and Wuxi supply disruption.

Nutrient inputs and sediment stores affect recovery.

Florida Gulf coast

Karenia brevis can produce brevetoxins.

Not every harmful bloom is red or toxic in the same way.

Treatment and three management levels

Treatment pathways

Primary settling; secondary biological reduction of degradable matter.

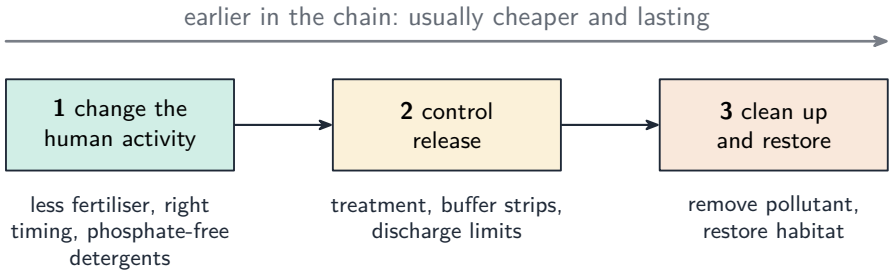
Advanced nutrient removal differs from disinfection; nitrification alone retains nitrogen.

Causal-chain management

Change activity: reduce unnecessary fertiliser.

Control release: buffer strips/treatment; repair: assess aeration and habitat restoration.

Three points to manage pollution



Acting earlier in the chain is usually cheaper

AHL: Molecular properties

Polar molecules and bonds

Hydrogen bonding, cohesion, adhesion and capillarity.

Solvent properties and transparency support transport and photosynthesis.

Thermal behaviour

High heat capacity buffers change; **evaporation** transfers latent heat.

Freshwater density peaks near 4 °C; salinity alters seawater behaviour.

AHL: Heat and paired observations

1. **Invented heat example.** 200 kg; 3 °C rise; c=4.18 kJ per kilogram per degree Celsius. Q=200×4.18×3=2508 kJ.
2. **Invented paired ranks.** Temperature 10,12,14,16,18,20 °C; oxygen 10.9,10.4,10.0,9.5,9.1,8.7 mg/L.
3. **Association.** Ranks reverse perfectly: Spearman correlation $= -1$. Independence and test assumptions still matter.

Decision

Association is not proof of causation; salinity, depth and respiration can confound a pattern.

AHL: Oceans and carbon

Circulation and nutrients

Thermohaline density effects act alongside wind, mixing and basin geometry.

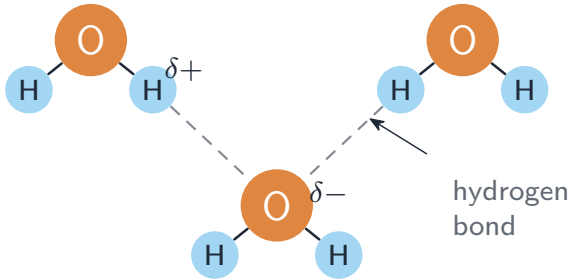
El Niño can weaken eastern Pacific **upwelling**; not all upwelling stops.

Carbon pathways

Uptake alters pH and carbonate availability.

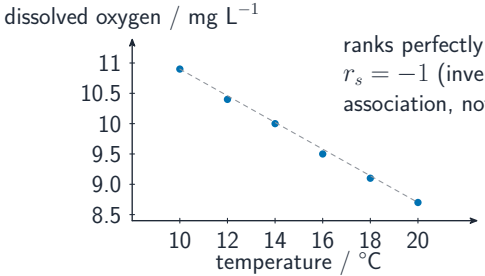
Deep export is not automatically permanent burial; respiration and circulation return carbon.

Hydrogen bonds in water



They give water its high heat capacity

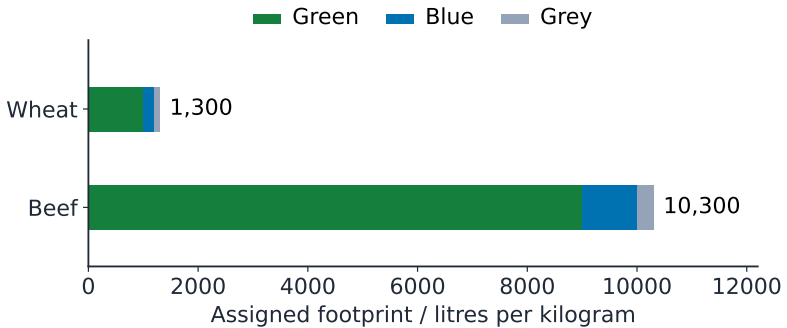
Warmer water, less oxygen



ranks perfectly reversed:
$r_s = -1$ (invented data)
association, not proof of cause

The ranks are perfectly reversed: a strong negative correlation

AHL: Compare like footprint units



Assigned teaching data: green, blue and grey components differ; grey is a dilution indicator.

AHL: Footprints and two stress indicators

1. **Assigned shirt footprint.** 0.25 kg $\times$ 10000 L/kg $=$ 2500 L/item. **Virtual water** is attributed to trade, not just liquid in products.
2. **Falkenmark availability.** 120 km^3/year $\div$ 80 million people $=$ 1500 m^3 per person per year: stress.
3. **SDG-style stress.** Withdrawals 30, resources 100, environmental requirement 40 million m^3/year: $100\times30/(100-40)=50\%$.

Decision

Freshwater-change planetary boundaries instead concern streamflow and root-zone soil-moisture departures.

AHL: Compare access and governance

Dated contexts

Jordan strategy: about 61 m^3 renewable water per person per year, not daily tap supply.

Peru 2022 safely managed coverage: urban 60%, rural 23%; gap 37 percentage points.

Governance and choices

Blue Nile: power-generation and downstream flow concerns; 2021 UN call for agreement.

Citizens' data need quality checks; recharge, **desalination** and cloud seeding need suitable conditions.

AHL: Model replacement cautiously

1. **Invented logistic stock.** K=1000 tonnes, r=0.4 per year, N=500 tonnes.
2. **Net production.** $rN(1-N/K)=0.4\times500\times0.5=100$ tonnes/year.
3. **Precaution.** Survey uncertainty, changing recruitment and unreported catch make an exact maximum risky.

Decision

Catch per effort can be distorted by technology or aggregation; combine independent evidence.

AHL: Jurisdiction and ethics

Marine governance

EEZ: up to 200 nautical miles = 370.4 km from relevant baselines.

BBNJ entered into force 17 January 2026; national rules and fisheries bodies still matter.

Narwhal hunting perspectives

Food sovereignty, culture, animal welfare and conservation evidence.

Groups contain diverse views; assess rights, alternatives and consequences without inventing quotas.

AHL: Two indices, two methods

1. **Assigned biological scores.** Four scoring families: 10,6,4,2. BMWP-style sum=22; ASPT=22/4=5.5.
2. **Assigned chemical subindices.** Normalized scores 90,80,60; weights 0.4,0.3,0.3. WQI=36+24+18=78.
3. **Limits. Biotic index** needs regional protocol and habitat context; WQI can hide one hazardous component.

Decision

Do not repeatedly score individuals from one family or add raw measurements with incompatible units.

AHL: Pollutants, standards and accountability

Evidence

TBT, endocrine-active chemicals, PCBs, methylmercury and heat have distinct pathways.

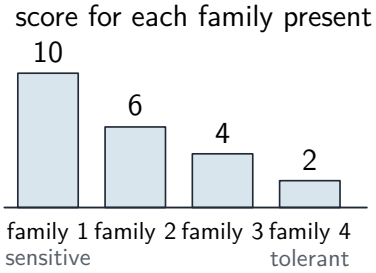
Plastic ingestion does not establish universal biomagnification.

Action

WHO guidelines inform national standards; EIA examines alternatives, flows and community access.

Monitoring, research, permit comments and lawful peaceful protest need evidence and responsible authorities.

Scoring river invertebrates

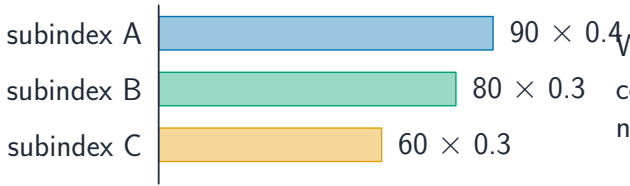


BMWP sum $= 10 + 6 + 4 + 2 = 22$

ASPT $= 22 \div 4 = 5.5$

Sensitive families score high

A weighted water-quality index



$\text{WQI} = 36 + 24 + 18 = 78$

combine dimensionless subindices, never raw pH, mg/L and °C

$$36 + 24 + 18 = 78$$

Exam tips

Quantities

Stock versus flow; catch versus biomass.

Withdrawal versus consumption; concentration versus load.

Evaluation

Give mechanism, named case and dated evidence.

Compare ecological outcomes, costs, equity and uncertainty.

Apply the water model

1. **Invented load.** Concentration 3 mg/L and flow 200 L/min. Calculate $3\times200=600$ mg/min.
2. **Add clean flow.** Add 100 L/min clean water with no other gain/loss. New concentration$=600/300=2$ mg/L.
3. **Explain.** Load is unchanged; lower concentration does not prove potability or removal.

Decision

State units, assumptions and a suitable test before extending a conclusion.

Check yourself

Your turn

Invented input: 3 mg/L at 200 L/min. Add 100 L/min clean water without any other pollutant change. Which concentration and load follow?

A. 2 mg/L and 600 mg/min.

B. 1 mg/L and zero pollutant load.

C. 3 mg/L and 300 mg/min.