DP IB Environmental Systems & Societies (ESS): HL

Your notes

4.4 Water Pollution

Contents

Sources of Water Pollution

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Sources of Water Pollution

- Water pollution has multiple sources and has major impacts on marine and freshwater systems
- Types of aquatic pollutants include:
  - Organic material
  - Inorganic nutrients (nitrates and phosphates)
  - Industrial effluent
  - Urban run-off
  - Solid waste disposal
  - Toxic metals
  - Synthetic compounds
  - Suspended solids
  - Hot water
  - Oil
  - Radioactive pollution
  - Pathogens
  - Light
  - Noise
  - Invasive species

Water Pollution Effects

Pollutant	Description	Effect
Organic material	Excessive organic matter from untreated human **sewage**, animal waste, or decaying plant material	Leads to **oxygen depletion**, harmful **algal blooms** and **eutrophication** in water bodies

Inorganic nutrients	Excess **nitrates** and **phosphates** from agricultural run-off, sewage and fertilisers	Causes nutrient enrichment, leading to **algal overgrowth** and water quality degradation
Industrial effluent	**Wastewater discharged** by industrial facilities after being used in **production processes**, containing a variety of pollutants e.g. heavy metals, toxic chemicals, organic matter and pathogens	Can be toxic to aquatic life, disrupt ecosystems, and **contaminate drinking water** sources
Urban run-off	Rainwater or melted snow that flows over impervious surfaces, such as roads, pavement and rooftops, picking up pollutants along the way e.g. oil, grease, pesticides, fertilisers, pet waste and litter	Degrades water quality, harming aquatic life, promoting algae blooms, and contaminating drinking water sources
Solid waste disposal	Rain falling on **landfills** leaches contaminants into soil and groundwater, whilst **litter** can end up in waterways, entangling wildlife and releasing harmful chemicals into the water	Contaminates groundwater sources and harms aquatic life
Heavy metals	Heavy metals such as mercury, lead and arsenic from industrial activities, mining, or improper waste disposal	Metals **accumulate** in aquatic organisms, leading to toxic effects and posing risks to human health
Synthetic compounds	**Human-made chemicals**, including pesticides, herbicides, pharmaceuticals and industrial pollutants	Enter water bodies through run-off, discharges, or improper disposal, potentially harming aquatic life and human health
Suspended solids	Solid particles in water, typically **sediment, silt, or fine particles** from erosion, construction, or dredging activities	High concentrations can impair water clarity, clog fish gills, smother **benthic** habitats and impact aquatic organisms such as invertebrates and their larvae
Hot water	Release of heated water into aquatic systems, often associated with industrial processes or power generation	Disrupts aquatic ecosystems, **reduces oxygen levels** and negatively impacts fish and other organisms (e.g. disrupting migration patterns or natural breeding cycles)

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Oil	Oil spills, leaks, or discharges from shipping, oil exploration, or industrial activities	Oil coats the water surface, affecting marine and freshwater ecosystems, harming aquatic life such as seabirds and leading to long-term environmental damage
Radioactive pollution	Release of radioactive substances, often associated with nuclear accidents, mining, or waste disposal	Severe ecological and human health impacts, with **prolonged exposure** potentially leading to **genetic mutations** and **cancer**
Pathogens	Presence of disease-causing microorganisms, including bacteria, viruses and parasites, often originating from **sewage** or **animal waste**	Contaminate water sources, leading to **waterborne diseases** (e.g. cholera) and posing risks to human and animal health
Light	**Excessive artificial lighting**, particularly in coastal areas	Disrupts natural light cycles, affecting **nocturnal marine species** and disrupting reproduction, navigation and feeding patterns of marine organisms
Noise	Noise from human activities such as shipping, sonar, construction, or offshore energy production	**Disrupts** communication, feeding and migration patterns of marine species (e.g. whales), leading to ecological disturbances
Invasive species	Introduction of **non-native species** into aquatic ecosystems, often through ballast water or occasionally intentional release (e.g. for biological control or recreational fishing purposes)	Outcompete native species, alter habitat structure, disrupt food webs and cause **severe ecological imbalances** (e.g. the invasion of lionfish into U.S. Atlantic coastal waters)

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Plastic Pollution

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Plastic Pollution

- Plastic pollution refers to the **accumulation** of plastic products in the environment, negatively affecting wildlife, habitat and humans
  - Plastic debris is a significant issue in **marine environments**, where it accumulates and causes various problems

Harm from oceanic plastic pollution

Wildlife impacts

- **Ingestion:**
  - Many marine animals mistake plastic debris for **food**
  - This can lead to **starvation**, **malnutrition** and **death**
    - For example, sea turtles often mistake plastic bags for jellyfish, leading to ingestion, which can eventually be fatal
    - Birds, such as albatrosses, have been found with stomachs full of plastic, leading to starvation
- **Entanglement:**
  - Animals become entangled in plastic waste like fishing nets, six-pack rings for drinks cans and plastic bags, causing **injury** or **death**
    - For example, seals often get caught in discarded fishing gear, leading to severe injuries or drowning
    - Whales are often found with fishing nets wrapped around their bodies, restricting movement and causing distress
- **Invasive species:**
  - Plastics can transport invasive species to new areas, **disrupting local ecosystems**
    - Barnacles and other small crustaceans can hitch rides on floating plastic debris, spreading to new regions and potentially **outcompeting** local species
- **Chemical leaching:**
  - Plastics can release **toxic additives** into the water, such as bisphenol A (BPA)

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        - BPA, used in manufacturing plastics, can leach into water and has been shown to interfere with the reproductive systems of some aquatic species

Human and economic impacts

- **Water quality:**
    - Plastic pollution can degrade water quality, affecting human populations that rely on these water sources
- **Tourism industry:**
    - Polluted beaches and coastal areas can deter tourists, affecting local businesses and economies
        - For example, beaches littered with plastic waste can lead to a decline in tourism, impacting local hotels, restaurants and other businesses
- **Recreational activities:**
    - Plastic pollution can interfere with recreational activities such as swimming, diving and boating

Aggregation in oceanic gyres

- Plastics are carried by rivers and streams into the ocean
- Ocean currents transport these plastics, which then become trapped in the **rotating currents** of **gyres**
    - Gyres are large systems of circular ocean currents
    - They are formed by global wind patterns and forces created by the Earth's rotation
- This leads to plastic **accumulating** in these gyres over time, forming **large patches of debris**
    - For example, the Great Pacific Garbage Patch is a well-known gyre, containing an estimated 1.8 trillion pieces of plastic

Microplastics and the food chain

- Microplastics are small plastic particles **less than 5mm in diameter**
- They come from larger plastic debris breaking down or from products like cosmetics and clothing
- **Food chain entry:**
    - Microplastics are ingested by small marine organisms
    - These organisms are then eaten by larger predators in higher trophic levels
    - This leads to bioaccumulation and biomagnification
        - This is where **concentrations** of microplastics and their associated toxins **increase up the food chain**

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- This can eventually lead to microplastics in human food sources
  - For example, studies have found microplastics in fish and shellfish sold for human consumption, indicating a direct pathway to humans
- **Transport of toxins**
  - Plastics can absorb harmful chemicals from the environment
  - When ingested by marine life, these toxins can enter the food chain, posing health risks to **animals** and **humans**
    - For example, chemicals like polychlorinated biphenyls (PCBs) and pesticides found on microplastics have been linked to cancer, reproductive issues and disruption of hormonal systems in animals and humans

Management and Solutions

- Management is needed to remove plastics from the supply chain and to clear up existing pollution
  - Some management strategies include:

1. **Reduction strategies:**
   - Implementing policies to reduce plastic production and usage
   - Promoting alternatives to plastic, such as biodegradable materials
     - For example, the UK has introduced a ban on single-use plastic straws, drinks stirrers and cutlery
2. **Cleanup efforts:**
   - Organising beach cleanups and developing technologies for ocean cleanups to remove existing plastic pollution
     - For example, the Ocean Cleanup project aims to remove large quantities of plastic from the Great Pacific Garbage Patch and other water bodies using advanced technology
3. **Recycling and waste management:**
   - Improving recycling rates and waste management systems to prevent plastic from entering the ocean
   - Encouraging the public to recycle and dispose of waste responsibly

Examiner Tips and Tricks

Be prepared to critically evaluate different management and solution strategies for plastic pollution, considering their effectiveness and feasibility.

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Monitoring & Assessing Water Quality

- Water quality is the measurement of chemical, physical and biological characteristics of water
  - **Chemical** characteristics include: levels of dissolved substances like minerals, pollutants and nutrients
  - **Physical** characteristics include water clarity, temperature and turbidity (cloudiness)
  - **Biological** characteristics include the presence of microorganisms (e.g. bacteria) and invasive species
- Water quality is **highly variable** and is often measured using a **water quality index** (WQI)
  - Scientists use various **tests** to measure different water quality parameters
  - A water quality index is then calculated
  - This combines multiple measurements into a **single value or score**
  - This provides an **assessment** of the overall water quality of a particular water body
  - This index helps in easily **communicating** the quality of the water body to the public and policymakers
    - E.g. indicating whether water quality is good, acceptable, or poor for various uses such as drinking, recreation and aquatic organisms
  - A high WQI indicates good water quality

Water quality parameters

- Some of the different water quality parameters that can be used are:

1. **Dissolved oxygen (DO)**
   - Measures the amount of oxygen dissolved in water
   - Sufficient oxygen levels are important for the survival of aquatic organisms
   - Low dissolved oxygen can lead to **hypoxia**
     - This can suffocate or kill aquatic life
2. **pH**
   - Measures the acidity or alkalinity of water

- pH impacts the survival, growth and reproduction of aquatic organisms
- Unusual pH levels can indicate pollution, acidification, or other environmental changes

3. **Temperature**
   - Measures the degree of heat or coldness of water
   - Temperature affects the metabolic rates, behaviour and distribution of aquatic organisms
   - Abnormal temperature fluctuations can **stress** or **kill** aquatic life
4. **Nitrates and phosphates**
   - Measuring nitrates and phosphates assesses nutrient pollution in water
   - High nutrient levels can lead to **eutrophication**
   - Monitoring nutrient concentrations helps manage **nutrient inputs** and prevent water quality degradation
5. **Metals**
   - Testing for metals, such as mercury, lead, cadmium, or arsenic assesses contamination levels
   - Metals can **accumulate** in aquatic organisms
     - This poses risks to their health and the health of organisms in higher trophic levels
   - Monitoring metal concentrations helps identify **pollution sources** and evaluate potential ecological impacts
6. **Total suspended solids (TSS)**
   - TSS is the concentration of **solid particles** suspended in water
   - High levels of TSS can decrease water quality by **blocking sunlight**
     - This reduces photosynthesis in aquatic plants and disrupts aquatic food chains
   - Suspended solids can also **smother** the **gills** or **breathing apparatus** of aquatic invertebrates and fish
   - High TSS can be a sign of erosion, wastewater discharge, or runoff from urban and agricultural areas, leading to habitat degradation
7. **Turbidity**
   - Turbidity measures the **clarity** or **cloudiness** of water
     - This is affected by suspended particles
   - High turbidity can **reduce light penetration**

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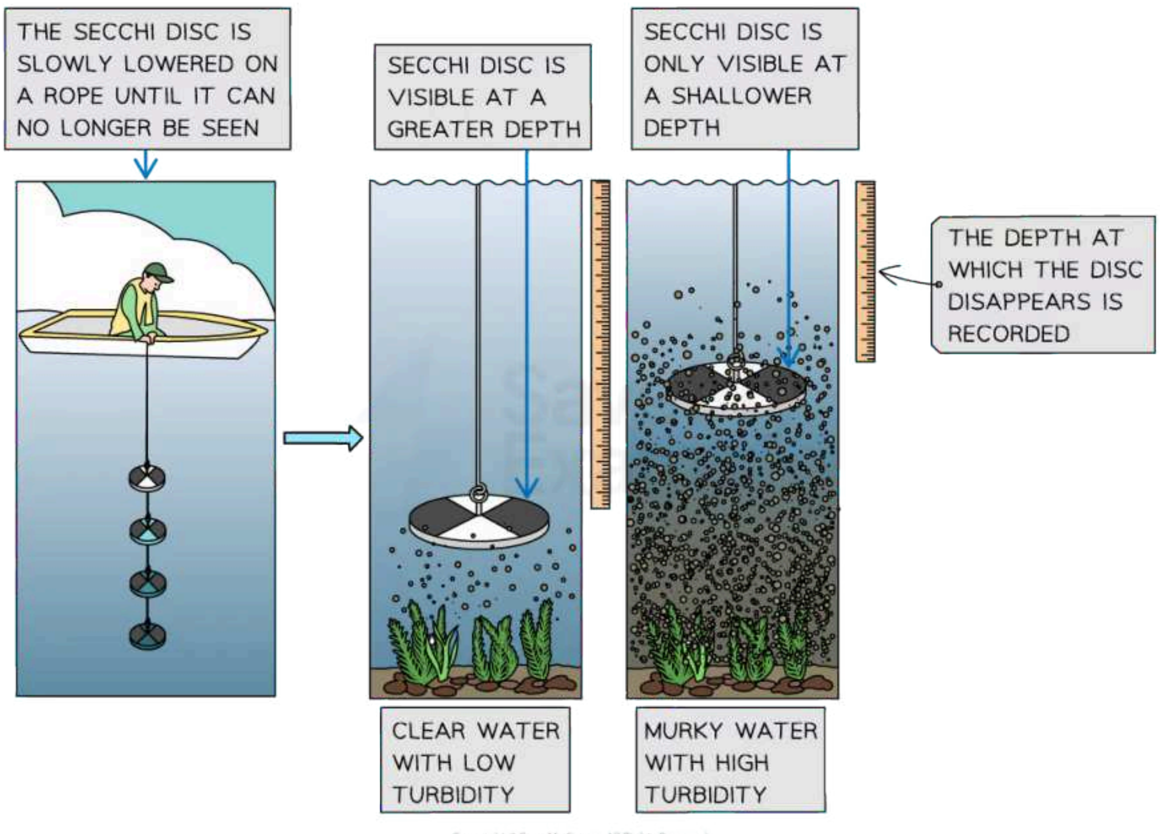
    - This reduces photosynthesis in aquatic plants and visibility for predators and prey
- High turbidity can indicate soil erosion or urban, agricultural or industrial run-off

Turbidity increases as the level of sediment present in the water samples increases

Measuring key abiotic factors in aquatic systems

Abiotic factor	**How abiotic factor is measured**
Dissolved oxygen (DO)	Measured using an **oxygen meter** equipped with a **probe**
pH	pH levels are determined using a **pH meter** equipped with a **probe**
Temperature	Water temperature is assessed using a **digital thermometer** or a **temperature probe**
Nitrate and phosphate concentrations	Measured using **test kits**, specific to each nutrient These kits use **colorimetric tests** where the water sample reacts with chemicals, producing a **colour change** corresponding to the **concentration** level of the **nutrient**
Total suspended solids (TSS)	Measured by filtering a known volume of water through a pre-weighed filter paper, then **drying** and **weighing** the paper again The **difference in weight** represents the **mass of TSS** collected

	This can then be converted to a **concentration**
Turbidity	Measured using a **Secchi disc**—a black and white disc lowered into the water The **depth** at which the disc **disappears** from sight is recorded This indicates **light penetration** and turbidity in the water column



An example of how a Secchi disc can be used to measure water turbidity

- These parameters provide valuable information about the health and condition of aquatic ecosystems
- It is crucial to compare readings from **various locations**, such as upstream and downstream of a sewage outlet or factory, to assess any potential impacts on the ecosystem
- Monitoring and analysing these parameters at **regular intervals** helps scientists, environmental agencies and policymakers to:
  - Understand the overall water quality

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- Identify potential issues
- Implement appropriate management strategies to protect and restore aquatic ecosystems

Measuring water pollution parameters near factory outlets is vital to assessing the impact on ecosystems (photo by Tarek Badr on Unsplash)

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Examiner Tips and Tricks

Turbidity and total suspended solids (TSS) are closely related but are not exactly the same thing.

Turbidity focuses on the **effect**—it measures how light scatters and absorbs due to suspended particles, making the water cloudy. It doesn't tell you the exact amount or type of these particles, just their presence and impact on light.

TSS focuses on the **cause**—it measures the actual mass of all the suspended particles in a water sample and is given as a **concentration** e.g. milligrams per litre (mg/L) or parts per million (ppm).

Biochemical Oxygen Demand

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- Biochemical oxygen demand (**BOD**) is a measure of the amount of **dissolved oxygen** required to break down the organic material in a **given volume** of water through **aerobic** biological activity
- Aerobic organisms rely on oxygen for respiration
- When there is a higher abundance of organisms or an increased rate of respiration, more oxygen is consumed
- This means that the biochemical oxygen demand (BOD) is influenced by:
  - The **quantity of aerobic organisms** present in the water
  - The **rate** at which these organisms **respire**
- BOD can be used as an **indirect measure** to evaluate:
  - The amount of organic matter within a sample
  - The pollution levels in water
    - The introduction of organic pollutants, such as sewage, leads to an increase in the population of organisms that feed on and break down the pollutants
    - This, in turn, results in **increased BOD values**
    - Certain species, such as bloodworms and *Tubifex* worms, show **tolerance** to organic pollution and the associated low oxygen levels
    - On the other hand, mayfly nymphs and stonefly larvae are typically only found in **clean-water** environments

Tubifex worms are able to withstand quite polluted water (Matthias Tilly, CC BY 3.0, via Wikimedia Commons)

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Example of how BOD is used to indirectly measure the amount of organic matter within a sample

- Higher BOD values indicate a larger amount of organic matter present in the water sample
  - This is because more oxygen is needed for its decomposition
- By measuring the **decrease** in dissolved oxygen levels over a **specific incubation period**, BOD provides an estimate of the organic load or pollution level in the water
- BOD values are typically expressed in **milligrams of oxygen consumed per litre** of water (mg/L) or as a percentage of the initial dissolved oxygen level
- The BOD test involves:
  - Collecting a water sample in a closed container
  - Measuring the **initial** dissolved oxygen concentration
  - Re-measuring the dissolved oxygen concentration **after a specific incubation period** (usually 5 days) at a **constant temperature** (usually 20℃)
- For example:

- A water sample has an initial dissolved oxygen concentration of 8 mg/L
- After 5 days, the dissolved oxygen concentration decreases to 2 mg/L
- The BOD value would be calculated as 8 mg/L - 2 mg/L = **6 mg/L**
  - As the dissolved oxygen levels have decreased substantially, this indicates that the sample has a **relatively high organic load**

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Eutrophication

Eutrophication

What is eutrophication?

- Eutrophication occurs when water bodies like lakes, estuaries and coastal areas receive large amounts of **mineral nutrients**, mainly **nitrates** and **phosphates**
  - This often results in the excessive growth of phytoplankton, a type of microscopic algae, as well as aquatic plants
- Main nutrients involved:
  - Nitrates: often from agricultural run-off
  - Phosphates: commonly found in detergents and sewage that is discharged into waterways without proper treatment

The process of eutrophication

1. **Nutrient enrichment**:
   - Excess nitrates and phosphates enter the water
   - This encourages rapid growth of **phytoplankton**, **algae** and **aquatic plants**
2. **Excessive aquatic plant growth**:
   - Nutrient availability causes fast growth of aquatic plants (macrophytes) e.g. duckweed and water hyacinth
   - Dense plant growth nearer the surface can **block sunlight** reaching **underwater plants**
3. **Algal bloom formation**:
   - Algae also use available nutrients to grow quickly
   - For example, when the mineral ions from excess fertilisers leach from farmland into waterways, they cause rapid growth of algae at the surface of the water
   - This is known as an algal bloom
   - Eventually, algae can **completely cover** the water surface
4. **Blocking of sunlight**:
   - The algal bloom can completely **block out sunlight** and stop it from penetrating below the water surface

- Aquatic plants below the water surface start to **die** as they can no longer **photosynthesise**
  - As this photosynthesis normally helps to oxygenate the water, dissolved oxygen levels begin to **decrease**
- The algae also start to die when competition for nutrients becomes too intense Phytoplankton and excess aquatic plants die off

5. **Decay of phytoplankton and plants leading to oxygen depletion**:
   - Bacteria decompose the dead plants and algae
   - As the bacteria respire aerobically, they use up the dissolved oxygen in the water
   - The amount of dissolved oxygen in the water **rapidly decreases**, so aquatic organisms such as fish and insects may be unable to survive
   - **Dead zones** in both oceans and freshwater can occur when there is not enough oxygen to support aquatic life
   - **Hypoxia** = low oxygen levels in water
   - **Anoxia** = severe or complete depletion of oxygen in water
6. **Impact on aquatic life**:
   - Fish and other aquatic life die in large numbers due to lack of oxygen
   - This can eventually lead to a loss of species and imbalances in aquatic ecosystems

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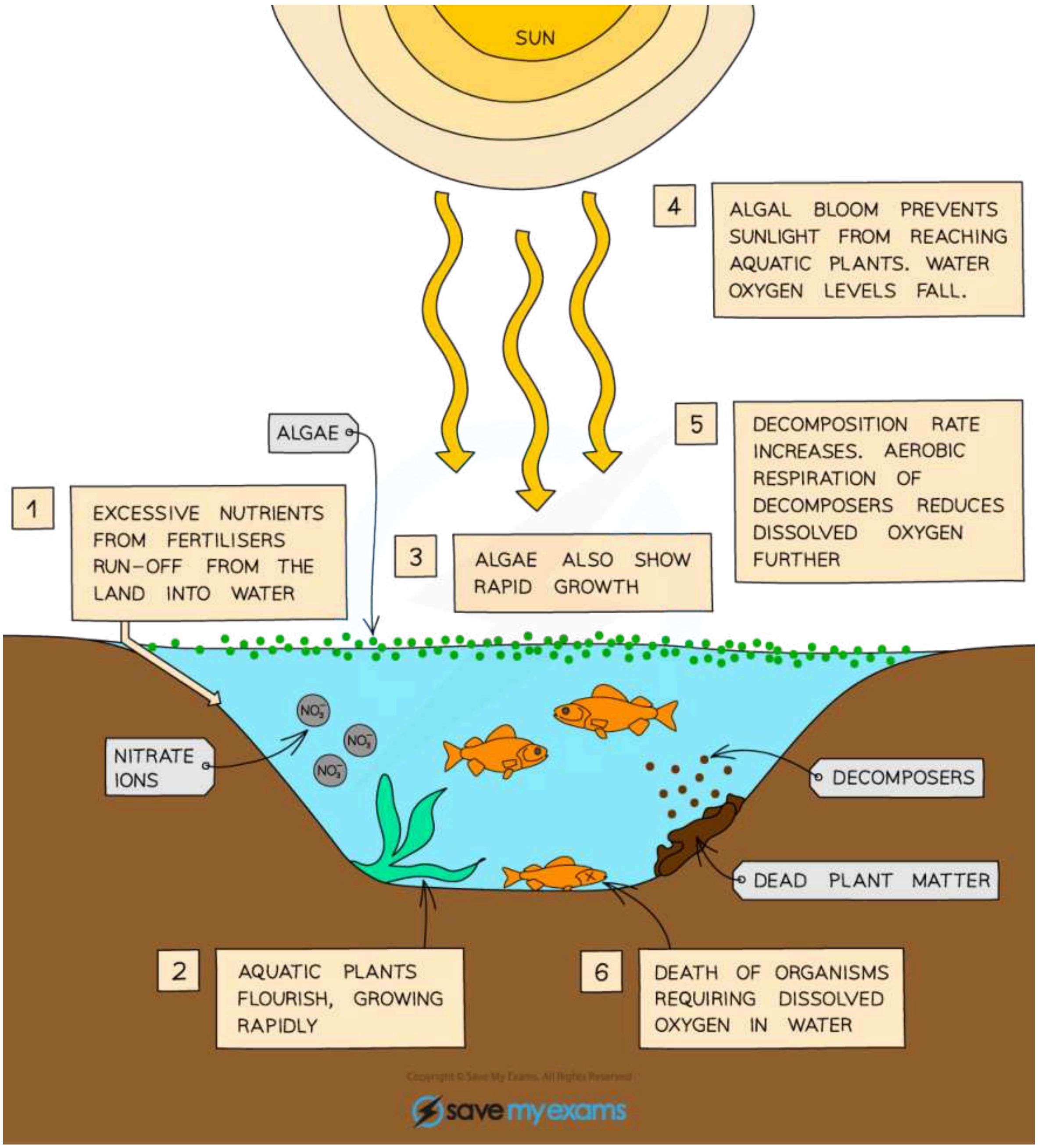

The sequence of events causing eutrophication in lakes, rivers and coastal waters

Positive feedback in eutrophication

- Positive feedback **amplifies changes**, creating a reinforcing cycle in eutrophication:

1. **Increased nutrients**:

- Excess nitrates and phosphates from run-off or sewage
- Promotes rapid growth of algae and aquatic plants

2. **Increased death**:
   - Algae and plants die off in large numbers
   - Adds organic matter to the water
3. **Increased decomposition**:
   - Bacteria decompose dead organisms, consuming oxygen
   - This decomposition releases more nutrients back into the water
4. **Cycle repeats**:
   - Released nutrients promote further algal and plant growth
   - Each step reinforces the next, worsening eutrophication and its impacts on the aquatic ecosystem

Impacts of eutrophication

- Eutrophication can greatly affect various ecosystem services:
- **Fisheries**:
  - **Fish kills**: sudden losses of fish due to low oxygen
  - **Reduced fish stocks**: long-term depletion of fish populations in certain areas
- **Recreation and aesthetics**:
  - **Unpleasant odours**: decaying algae and plants release unpleasant smells
  - **Water quality**: poor water conditions make swimming and boating unpleasant
  - **Visual pollution**: algal blooms create green or murky water
  - **Foam and slime**: algal blooms and decaying algae can cause foam and slimy water surfaces
- **Health**:
  - **Toxins**: some algal blooms produce harmful toxins
  - **Drinking water**: eutrophication can lead to contamination of drinking water sources

Examiner Tips and Tricks

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Pay attention to the difference between key terms such as eutrophication, decomposition, hypoxia and anoxia.

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Water Pollution Management Strategies

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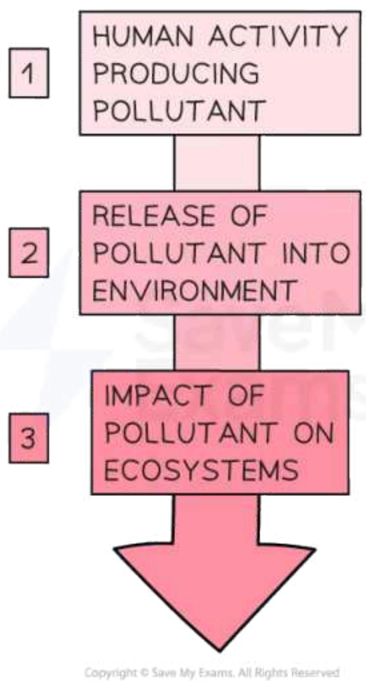
Water Pollution Management Strategies

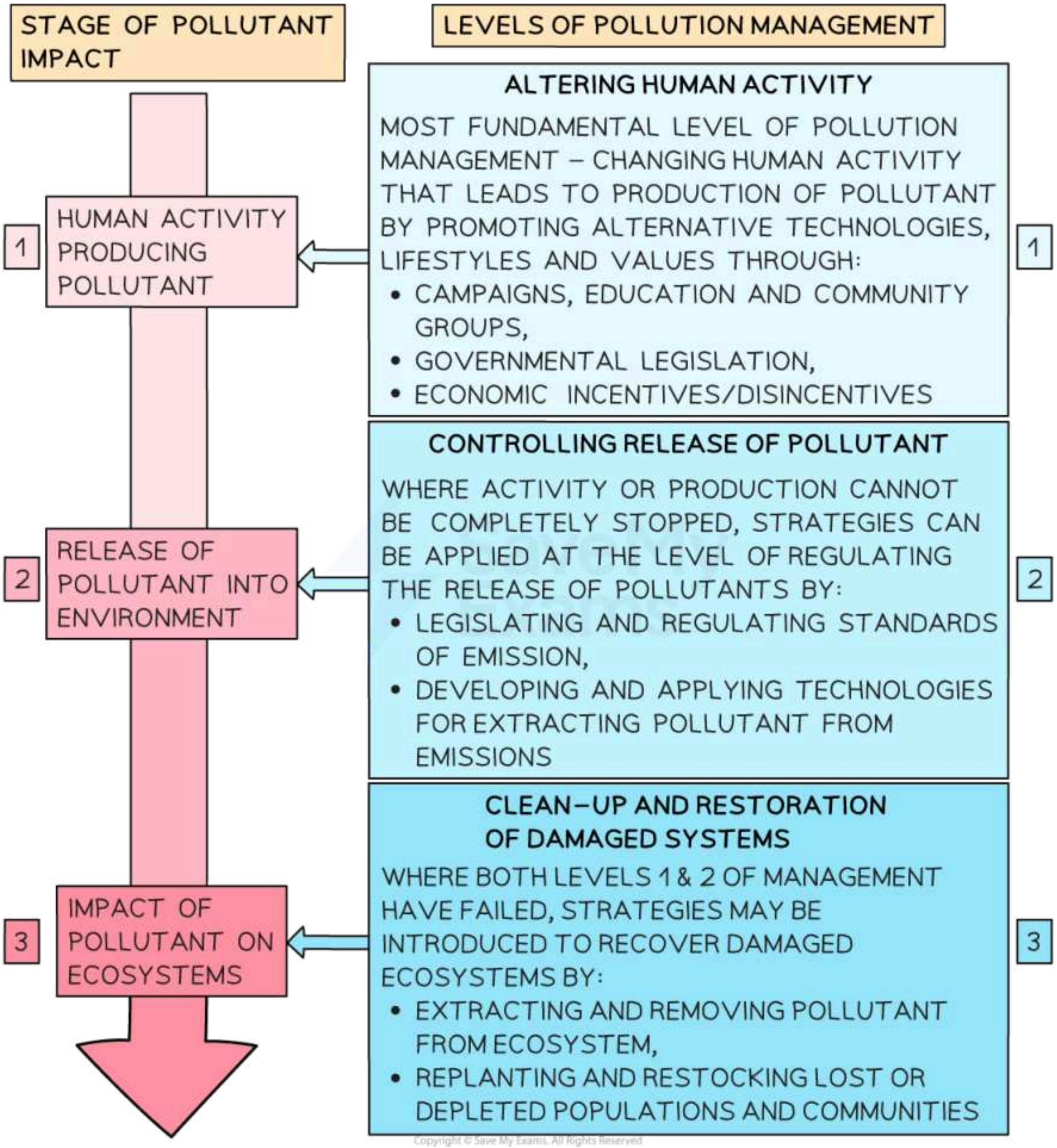
- Human activities, such as farming and industrial practices, urbanisation, development of transport, and energy production, are the major causes of pollution
  - The amount of material released into the environment determines the **impact**
- There are **three main stages** leading to the impact of pollutants on the environment:
  - Stage 1: Human activity producing the pollutant
  - Stage 2: Releasing of the pollutant into the environment
  - Stage 3: The impact of the pollutant on ecosystems



The main stages leading to the impact of pollutants

- There are **three types of strategies** for managing the impacts of pollution (which relate to the stages of pollutant impact shown above):
  - Changing human activity
  - Regulating and reducing quantities of pollutants released at the point of emission

- Cleaning up the pollutants and restoring the ecosystem after pollution has occurred



The main strategies for managing the impacts of pollution

Management Strategies for Eutrophication

- Eutrophication and other types of water pollution can be addressed at three different levels of management:

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- The reduction of human activities that produce pollutants
- The reduction of the release of pollution into the environment
- The removal of pollutants from the environment and restoration of ecosystems

1. Reduction of human activities producing pollutants

- This level aims to prevent pollution at the **source** by changing human practices and products
- **Alternatives to fertilisers**:
  - **Organic fertilisers**: use compost or manure instead of synthetic fertilisers
  - **Slow-release fertilisers**: release nutrients gradually, reducing the amount of nitrate and phosphate leaching into water bodies
- **Alternatives to detergents**:
  - **Phosphate-free detergents**: use products without phosphates to minimise pollution
- **Sustainable farming practices**:
  - **Crop rotation**: improve soil health and fertility by alternating crops with different nutrient needs, reducing the need for chemical fertilisers
  - **Buffer strips**: plant vegetation along waterways to absorb excess nutrients

2. Reduction of pollution release into the environment

- This level focuses on treating pollution **before** it reaches natural waters
- **Wastewater treatment**:
  - **Nutrient removal**: use treatment plants that remove nitrates and phosphates from sewage
  - **Advanced treatment methods**: use methods like **constructed wetlands** and **biofilters**
- **Regulation and monitoring**:
  - **Enforce pollution controls**: introduce and enforce regulations on nutrient discharge from industries and farms
  - **Monitoring programmes**: regularly test water bodies for nutrient levels
- **Agricultural practices**:
  - **Controlled fertiliser application**: apply fertilisers at optimal times to minimise run-off (e.g. apply during the growing season and avoid periods of heavy rain)
  - **Cover crops**: plant cover crops to absorb excess nutrients and prevent soil erosion

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3. Removal of pollutants and restoration of ecosystems

- This level involves cleaning up polluted environments and restoring natural ecosystems
- **Pollutant removal**:
  - **Dredging**: remove nutrient-rich mud and sediments from eutrophic lakes
  - **Algae removal**: physically remove excess algae from water bodies
- **Ecosystem restoration**:
  - **Reintroduction of species**: reintroduce native plants and fish that may have become locally extinct, to restore ecosystem balance
  - **Habitat restoration**: create or restore wetlands to filter nutrients naturally

Application to other types of pollution

These strategies can also be applied to manage other types of pollution:

- **Plastic pollution**:
  - **Prevention**: reduce plastic use and improve recycling
  - **Treatment**: implement systems to capture and remove plastics from waterways
  - **Cleanup**: remove plastic waste from beaches and oceans
- **Chemical pollution**:
  - **Prevention**: reduce the use of harmful chemicals in agriculture and industry
  - **Treatment**: use filtration and treatment systems to remove chemicals from wastewater
  - **Cleanup**: clean contaminated soils and sediments e.g. using bioremediation

Examiner Tips and Tricks

Make sure you are able to explain each level of pollution management and can apply these to different types of pollution. These management strategies may be implemented in different way across different regions or industries to address specific pollution issues.

Water Quality in Aquatic Ecosystems (HL)

Your notes

Water Pollutants

Types of pollutants

- A wide variety of pollutants can negatively impact aquatic ecosystems
  - These pollutants harm both water quality and the organisms living in these environments

Organic matter

- Organic pollutants, such as untreated sewage, add large amounts of **biological material** to water systems
- As bacteria break down the sewage, they consume dissolved oxygen
  - This can lead to oxygen depletion, resulting in the death of fish and other aquatic life
- For example, rivers in rapidly urbanising areas without proper waste treatment, like the Ganges River in India, suffer from sewage contamination
  - This kills fish and poses risks to human health

Dissolved substances

- **Tributyltin (TBT)** is an example of a harmful dissolved substance
- TBT is an anti-fouling agent once used on ship hulls
- It was found to disrupt the endocrine systems of marine animals, particularly causing reproductive issues in molluscs
  - TBT pollution was responsible for **severe declines** in **oyster populations** in some European estuaries before it was banned

Persistent organic pollutants (POPs)

- These include chemicals like **polychlorinated biphenyls (PCBs)**
- PCBs are resistant to breakdown and can persist in the environment for decades
- These toxins accumulate in organisms (bioaccumulation) and become more concentrated as they move up the food chain (biomagnification)
  - PCBs have accumulated in marine top predators like **killer whales** and **polar bears**, leading to immune and reproductive issues

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Plastics

- Plastics, especially microplastics, are widespread pollutants in marine environments
- Larger plastics can cause entanglement or ingestion problems
- Ingested microplastics have been found in many species of fish, affecting their health

Heat energy

- Thermal pollution occurs when industrial plants or power stations release warm water into rivers or oceans
- Warmer water holds less dissolved oxygen and can harm species adapted to cooler conditions
    - Some freshwater ecosystems near nuclear power plants experience reduced fish populations due to increased water temperatures

Harmful Algal Blooms (HABs)

- **Harmful Algal Blooms (HABs)** occur when certain types of **algae** or **microorganisms** grow rapidly
- They form dense blooms that **produce toxins** or **deplete oxygen** in the water
- These blooms can significantly impact water quality
    - This poses threats to aquatic ecosystems, human health, and economic activities like fishing and tourism
- HABs contain a variety of organisms, including:
    - Cyanobacteria
    - Protists
    - Algae
    - Dinoflagellates
- **Freshwater examples**:
    - In freshwater environments, **cyanobacteria** (also known as blue-green algae) are the main contributors to HABs
    - These bacteria release **cyanotoxins** that can:
        - Contaminate drinking water
        - Cause liver damage
        - Affect the nervous system of both animals and humans

- **Marine examples**:
  - In marine environments, **dinoflagellates** (a type of protist) are responsible for many HABs
  - They sometimes produce 'red tides' that are toxic
  - The **neurotoxins** produced by these organisms can cause paralytic shellfish poisoning (PSP) in humans who consume contaminated seafood
- **Economic impacts**:
  - HABs affect fisheries, aquaculture, and tourism as toxins from blooms can lead to the closure of fisheries and swimming areas
    - This negatively impacts local economies

Anoxic & Hypoxic Water

- Anoxic waters lack oxygen completely
  - This state is known as **anoxia**
- Hypoxic waters have very low oxygen levels that are insufficient to support most aquatic life
  - This state is known as **hypoxia**
- Both conditions can create "**dead zones**", where marine organisms cannot survive
  - These zone usually occur in coastal regions where nutrient runoff is high
  - For example, the **Gulf of Mexico** experiences one of the largest dead zones, largely caused by nutrient pollution from agricultural runoff in the Mississippi River
  - The **Baltic Sea** is another region plagued by dead zones, largely due to nutrient runoff from agriculture and sewage
  - Dead zones can lead to:
    - Severe disruptions in marine food chains
    - Collapse of local fisheries

Causes

- Hypoxia and anoxia are driven by a combination of factors, including:
  - **Global warming**: Warmer water holds less oxygen, making conditions increasingly hypoxic
  - **Thermal stratification**: Layering of water by temperature prevents oxygen-rich surface water from mixing with deeper layers
  - **Sewage disposal**: Decomposing organic matter from sewage lowers oxygen levels

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- **Eutrophication**: excess nutrients, often from agricultural runoff, fuel algal blooms
    - When the algae die and decompose, oxygen is consumed, creating hypoxic conditions
- With climate change and continued pollution, the occurrence of hypoxic and anoxic waters is expected to **rise**
    - This will threaten fisheries and coastal ecosystems globally

Examiner Tips and Tricks

The prefix **hypo-** means '**below normal'** or '**deficient'**. So, hypoxia refers to low oxygen levels in tissues, but not necessarily a complete lack. You might recall **hypothermia** (low body temperature) to remember that hypo- indicates a deficiency.

The prefix **an-** means '**without'**. Therefore, anoxia means a complete absence of oxygen. You can link this to **anaemia**, where blood lacks sufficient healthy red blood cells or haemoglobin, leading to insufficient oxygen transport.

Sewage Treatment (HL)

Your notes

Sewage Treatment

- Sewage treatment is the process of **removing harmful substances from wastewater** so it can be:
  - Safely returned to the environment
  - Used for domestic purposes (e.g. for toilets, showers, drinking water)
- It prevents pollution, protects public health, and helps conserve water by recycling treated water

The three stages of sewage treatment

Primary treatment

- **Purpose**: Removes large solid materials (e.g. debris) and some suspended solids
- **Process**:
  - **Screening**: Large objects like sticks, rubbish, and plastic are filtered out using screens (usually made from metal bars)
  - **Comminution**: Any remaining large solids are ground up by a device called a comminutor to prevent pipe blockages
  - **Grit removal**: Sand and gravel settle to the bottom of the grit chamber
  - **Sedimentation**: Wastewater flows into sedimentation tanks (also known as primary clarifier) where smaller suspended solid particles settle at the bottom as **sludge**
  - **Skimming**: Floating materials like grease and oil are skimmed from the surface
- **Result**: Water is partially cleaned but still contains dissolved and smaller particles

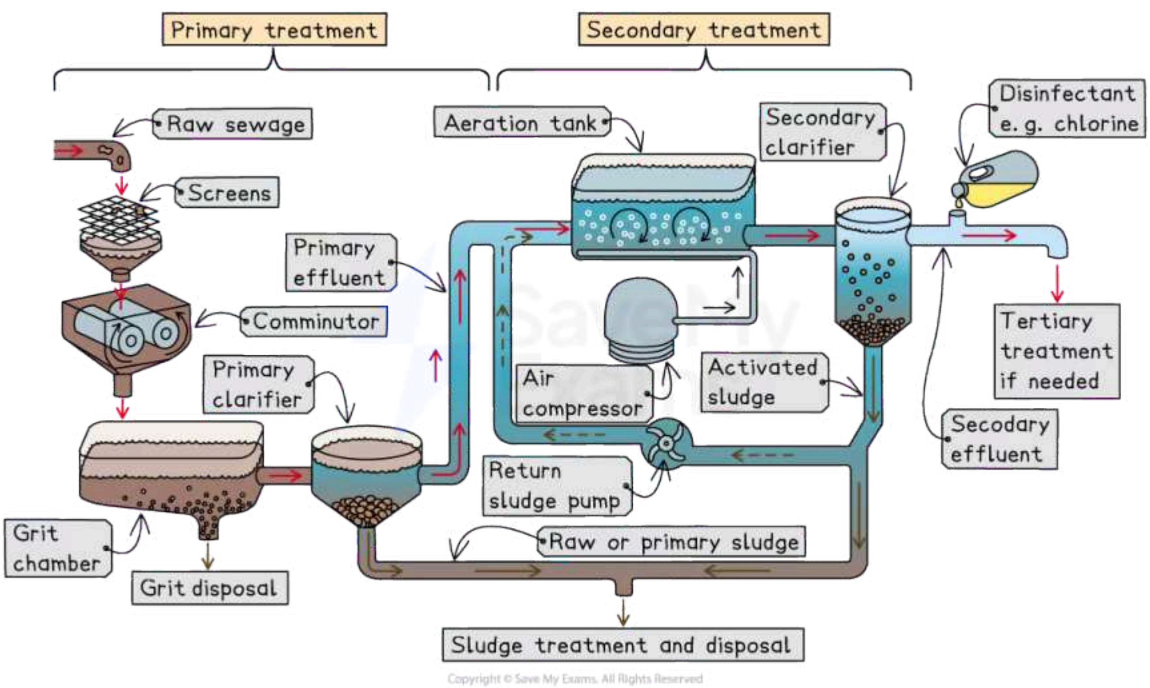
Secondary treatment

- **Purpose**: Breaks down organic matter using biological processes
- **Process**:
  - **Aeration**: Oxygen is pumped into the wastewater to encourage bacteria to break down organic pollutants (e.g. human waste, food)
  - **Biological degradation**: Microorganisms (mainly bacteria) consume the organic waste, converting it into harmless by-products like carbon dioxide, water, and 'activated sludge'
    - Activated sludge contains aerobic bacteria that decompose organic matter

- **Clarification**: Water is again left to settle (in a secondary clarifier) so that any remaining sludge can be removed
  - A portion of this sludge is reused as activated sludge in the aeration tank to continue the process of organic matter decomposition
- **Result**: Water is significantly cleaner but may still contain some nutrients (e.g. nitrates, phosphates) and pathogens

Tertiary treatment

- **Purpose**: Removes remaining nutrients, chemicals, and pathogens for maximum water quality
- **Process**:
  - **Chemical treatment**: Chlorine or ultraviolet light (UV) is used to disinfect the water and kill pathogens
  - **Nutrient removal**: Processes like chemical precipitation are used to remove excess nitrogen and phosphorus, which can cause eutrophication if released into water bodies
  - **Filtration**: Water may be filtered through sand, activated carbon, or other materials to remove any final impurities
- **Result**: Effluent (treated water) is now clean enough to be safely discharged into rivers, lakes, or reused



Primary and secondary water treatment stages

Challenges in implementing sewage treatment

Your notes

High income countries (HICs)

- **Advanced infrastructure**:
  - HICs usually have well-established sewage treatment facilities that cover most urban and rural areas
- **High costs**:
  - Although advanced, maintaining and upgrading sewage treatment plants is expensive
  - Continuous investment is needed to meet stricter environmental regulations and improve efficiency

Low income countries (LICs)

- **Limited infrastructure**:
  - In many LICs, especially in rural or densely populated areas, sewage treatment infrastructure is either insufficient or non-existent
- **Health risks**:
  - Untreated sewage can lead to serious public health problems such as waterborne diseases like cholera, typhoid, and dysentery
- **Cost barriers**:
  - Building and maintaining sewage treatment facilities is costly, and many LICs lack the financial resources to develop this infrastructure
  - This limits access to proper sanitation, especially in rural areas

Social and economic inequality

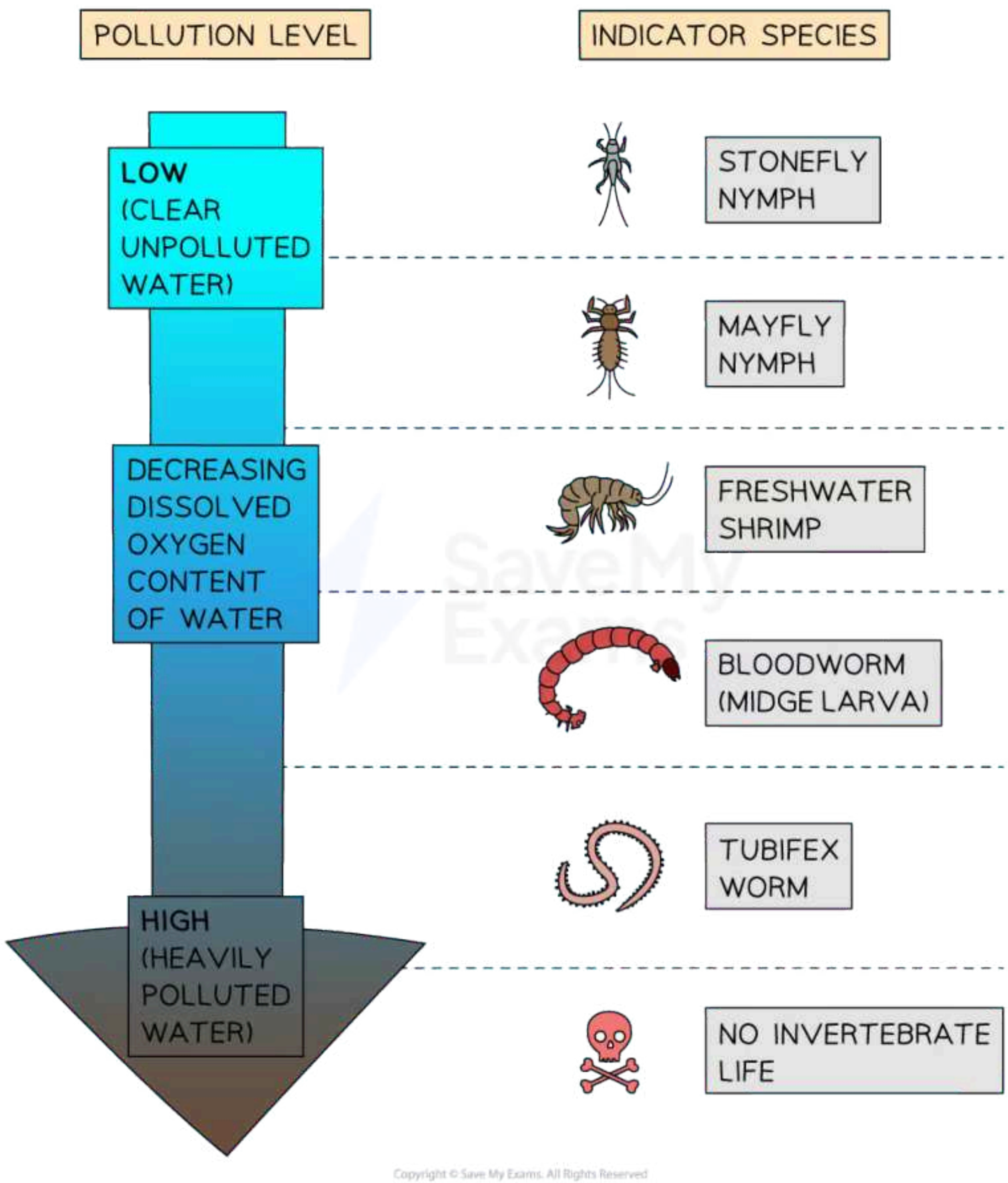
- **Wealth gaps**:
  - In many countries, wealthier communities have access to better sanitation and sewage treatment
  - Poorer or marginalised groups often live without proper facilities
- **International aid and partnerships**:
  - Many LICs rely on international organisations and NGOs to provide funding and expertise to build or improve sewage systems

Indicators of Water Quality (HL)

Your notes

Indicator Species

- Indicator species are organisms that are used to:
  - Assess the **quality of an environment**
  - Indicate the presence of **specific environmental conditions**, including **pollution**
- Different groups of organisms, including invertebrates, plants, and algae, can act as indicator species in **polluted** or **unpolluted** aquatic habitats:



Fresh water pollution invertebrate indicator species

Your notes

Indicators of polluted water

1. Invertebrates

- Bloodworms (the aquatic larvae of midges) are commonly found in polluted waters, especially those contaminated with **organic matter**
  - Their presence indicates low dissolved oxygen levels and high organic pollution

- *Tubifex* worms also thrive in polluted waters with high organic content and low oxygen levels

2. Plants

- The Common Reed is **tolerant** of high nutrient levels, such as nitrates and phosphates, often found in **eutrophic** or **polluted waters**
- Duckweed is a small floating plant that thrives in nutrient-rich waters, including those polluted with agricultural runoff or sewage effluents

3. Algae

- Excessive nutrients, particularly nitrogen and phosphorus, can trigger harmful algal blooms dominated by blue-green algae (cyanobacteria)
  - These blooms are often associated with nutrient pollution and indicate degraded water quality

Indicators of unpolluted water

1. Invertebrates

- Stonefly nymphs are sensitive to water pollution and are often found in well-oxygenated, clean streams and rivers
  - Their presence indicates good water quality
- Mayfly nymphs are also highly sensitive to pollution and require clean, well-oxygenated water

2. Plants

- Water Crowfoot is a plant species commonly found in clean, well-oxygenated freshwater streams and rivers
  - Its presence indicates good water quality and suitable habitat conditions for other aquatic organisms, e.g. fish

3. Algae

- Diatoms are a diverse group of algae, and their presence in high diversity and abundance is often associated with clean, well-oxygenated waters

Using indicator species

- These organisms are just a few examples of indicator species commonly used in **water quality assessments**
- By studying the presence, abundance, and diversity of these organisms, scientists can better understand the **pollution levels** and overall health of aquatic ecosystems

- It is important to note that the selection of indicator species **varies** depending on the **specific region**, **ecosystem**, and **type of pollution** being assessed
- Monitoring the presence or absence of these organisms helps to assess the condition of water bodies
  - This aids in **conservation** and **management efforts** to improve water quality and protect clean, unpolluted waters

Indicator species such as the stonefly nymph can tell you that water is clean, but not how clean (Dave Huth from Allegany County, NY, USA, CC BY 2.0, via Wikimedia Commons)

Limitations of using indicator species

- Although using indicator species is a fairly **simple** and **cost-effective** method of determining whether a habitat is polluted or not, it has some **drawbacks**:
  - It can't give accurate numerical (**quantitative**) figures for exactly how much pollution is present
  - Other factors, such as the presence of predators or disease, can also affect the presence or absence of indicator species
- If more detailed information on pollution levels is required, **non-living indicators** can be used instead
  - For example, dissolved oxygen meters and chemical tests can be used to:
    - Very accurately determine the concentration of dissolved oxygen in the water
    - Show changes in levels of water pollution over time

Biotic Indices

Your notes

- Biotic indices are tools used to assess the overall **health** and **pollution levels** of an aquatic ecosystem
  - Based on the presence, abundance, and diversity of indicator species within a community
- A biotic index provides an **indirect measure** of water pollution by evaluating the impact on different species according to their
  - Pollution tolerance
  - Diversity
  - Relative abundance

Step 1 = selection of indicator species

- Indicator species are selected based on their known **sensitivity** or **tolerance** to water pollution
- These species are representative of **different ecological niches**

Step 2 = sampling and data collection

- Sampling is conducted at **different sites** within the water body
- The presence, abundance, and diversity of indicator species are recorded

Step 3 = calculation of biotic index

- The collected data is used to calculate a **biotic index value**
- This is a **numerical score** or **rating** that reflects the overall quality of the aquatic habitat
- The index is based on factors such as species diversity, tolerance values, and relative abundance

Step 4 = interpretation of biotic index

- The biotic index is then **interpreted** to determine the pollution level of the ecosystem
  - **Higher** biotic index values indicate **cleaner** or **less polluted** waters, whilst **lower** values indicate **higher pollution levels**
- For example, the **Trent Biotic Index** is a widely used biotic index for assessing **freshwater pollution**
  - It focuses on macroinvertebrates (insects, crustaceans, molluscs) as indicator species
  - The index assigns tolerance values to different species based on their known sensitivity to pollution
  - If the Trent Biotic Index score for a particular section of the river is **high**, it suggests a **healthy** and **less polluted** ecosystem

Your notes

Your notes

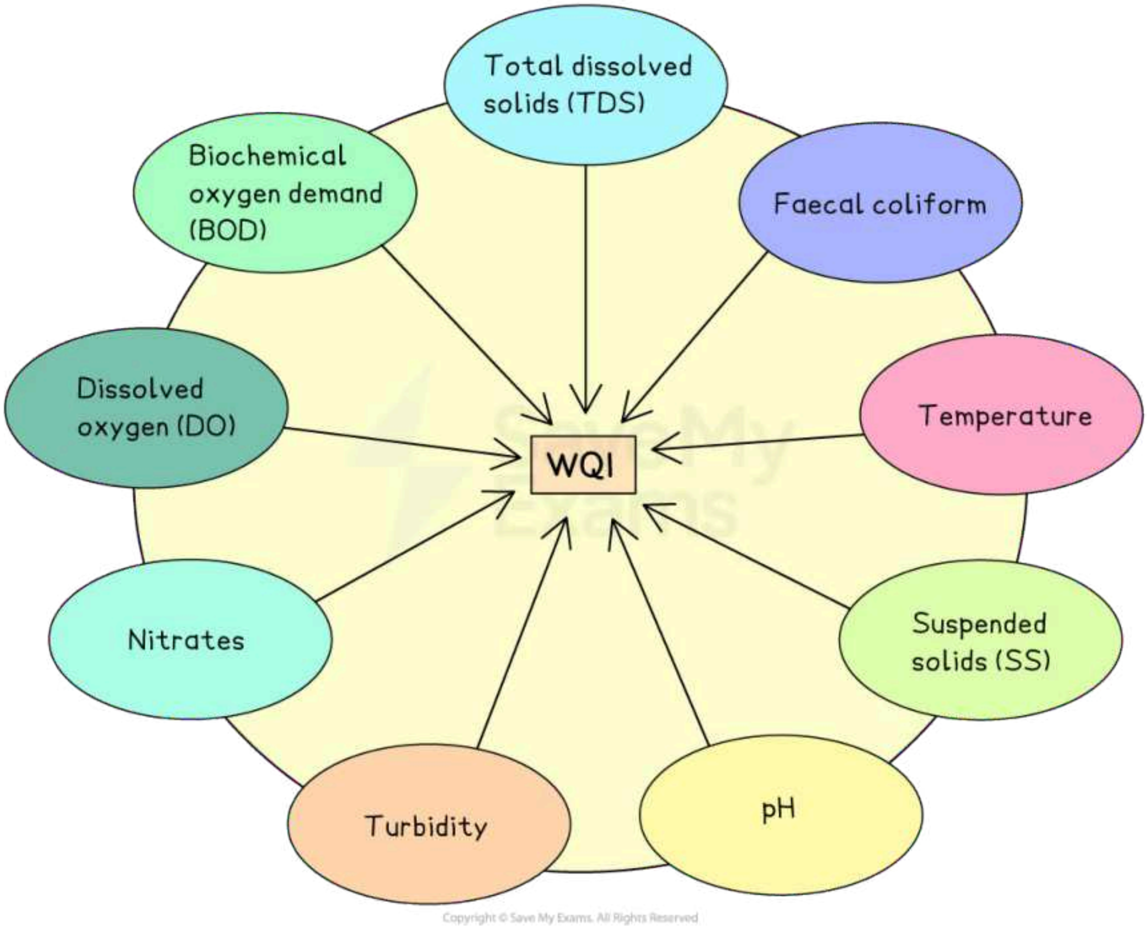
    - This is because it indicates the presence of a **diverse community** of **pollution-sensitive** macroinvertebrates
- Conversely, a **low** Trent Biotic Index score indicates **poor water quality** and **higher pollution** levels
    - In this case, pollution-tolerant species **dominate** the **community**

Water Quality Index (WQI)

- A Water Quality Index (WQI) is a **single number** representing the overall quality of water in a particular area
    - The WQI **simplifies** complex water quality data into one clear score
    - This makes it easier to assess and **compare** water quality **across different locations**
- WQI is calculated by combining results from multiple water quality tests
    - Each of these measures a specific factor or pollutant in the water

How water quality index is calculated

Individual water quality parameters



Commonly used water quality parameters

- Common parameters include:
  - **pH**
  - **Dissolved oxygen**
  - **Biochemical oxygen demand**
  - **Turbidity**
  - **Temperature**
  - **Nitrate levels**
  - **Total dissolved solids**
- Each parameter has its own rating scale, which indicates how contaminated the water sample is

Weighted averaging

- Each parameter is given a **weighting** based on its importance to water quality
  - E.g. dissolved oxygen is often given a high weighting because it is crucial to the survival of fish and certain other aquatic organisms
- The weighted scores for each parameter are **combined** to produce a single WQI score
  - E.g. the WQI score for a sample may range from 0 (poor quality) to 100 (excellent quality)

Vernier's WQI example

- Vernier, a scientific equipment company, provides tools and calculators for measuring WQI using several key water quality parameters
  - Vernier's WQI incorporates parameters like **temperature change**, **faecal coliform**, **BOD**, and **nitrate** levels
  - E.g. a Vernier WQI of 75 might indicate "good" water quality, suitable for most uses, whereas a score of 40 would show poor quality, requiring treatment before use

Your notes

Drinking Water Standards (HL)

Your notes

Drinking Water Standards

- Drinking water standards are **regulations** that define the acceptable quality of water for **human consumption**
  - They aim to ensure that drinking water is safe, clean, and free from harmful contaminants
- There are no globally accepted standards for drinking water
  - Standards **differ by country**
  - They are influenced by local resources, infrastructure, and needs

World Health Organization (WHO) drinking water guidelines

- The World Health Organization (WHO) provides **drinking water quality guidelines**
  - This is to help countries ensure safe drinking water, especially where no national standards exist
  - Countries can adopt these standards or use them as a framework to develop their own standards
- The WHO guidelines outline recommended limits for **contaminants**, including:
  - Bacteria
  - Chemicals (e.g. fluoride, lead, nitrate)
  - Physical properties of water (e.g. pH, turbidity)
- While WHO guidelines are **not enforceable**, they are often used as a baseline in developing countries or where governments aim to improve water safety

National drinking water standards

Developed countries

- Developed countries like the UK, USA, and Australia have statutory drinking water standards based on the WHO guidelines, often with additional requirements
  - For example, the UK follows regulations that specify limits on contaminants such as lead and pesticides to ensure safe drinking water across the country
  - Water suppliers are regularly monitored to ensure compliance
  - Failure to meet standards can result in fines or shutdowns

Developing countries

Your notes

- In developing countries, setting and enforcing drinking water standards is more challenging due to limited resources and infrastructure
    - Many countries adopt WHO guidelines as they may lack the resources to conduct their own extensive testing

International business and environmental assessments

Environmental Impact Assessments (EIA)

- EIAs are studies that assess the **potential environmental effects** of proposed projects (e.g. road construction or mining operations)
    - Drinking water standards play an important role in EIAs
    - They help evaluate the impact on **local water sources**
    - This helps to ensure safe water for surrounding communities

International business agreements

- When private companies operate **abroad**, especially when using local resources like water, they need to follow **local standards** to protect the environment and the health of the local community
- Companies are required to meet the local water quality standards of the country they operate in
    - For example, a drinks company building a bottling plant must ensure its water use meets local standards to avoid **depleting** or **polluting community water**
- Many companies use WHO standards as a **minimum**, even if local laws are less strict
- This helps **avoid environmental harm** and **maintains a positive reputation**
    - For example, Coca-Cola faced concerns over water use at its bottling plants in India
    - To address this, the company followed both WHO and local guidelines to protect community water sources and **avoid controversy**
- Other examples include:
    - International mining companies often follow stricter global water quality standards to prevent pollution in local rivers and lakes

Examiner Tips and Tricks

Remember, WHO provides **guidelines**, while individual countries set **enforceable standards**.

Reducing Water Pollution (HL)

Your notes

Reducing Water Pollution

- Water pollution is the introduction of **harmful contaminants** into water bodies, making the water **unsafe** for humans, wildlife, and ecosystems
- Reducing water pollution is essential for:
  - **Protecting drinking water sources**
  - Conserving biodiversity
  - Supporting overall ecosystem health.
- Both **individual actions** and organised **group efforts** can make a significant impact on reducing water pollution

Actions individuals can take

Reducing consumption and waste disposal

- **Conserving water**:
  - Reducing water use decreases the amount of wastewater generated
  - This reduces the volume that needs treatment and helps to keep water sources cleaner
  - E.g. taking shorter showers, turning off taps while brushing teeth, and using water-efficient appliances can reduce household water waste
- **Disposing of waste properly**:
  - Proper disposal of chemicals, oils, paints, and medicines prevents these pollutants from entering water systems
  - Hazardous household waste should be disposed of at designated recycling or waste facilities
  - When dumped down sinks or drains, these substances can contaminate both **local water sources** and **groundwater**
- **Minimising use of harsh chemicals**:
  - Avoiding strong chemicals in daily use, like certain **detergents** and **cleaners**, helps prevent these harmful compounds from entering the water system

Using eco-friendly products

- **Choosing cleaning products**:

Your notes

- Using eco-friendly products that are **biodegradable** ensures that fewer harmful chemicals end up in water sources
- Many green products are made from **natural ingredients** that break down easily, reducing the risk to aquatic life
- **Reducing plastic use**:
  - Reducing single-use plastics decreases the chances of plastic waste ending up in rivers, lakes, and oceans

Actions by groups and citizen activists

Peaceful citizen protest

- **Raising awareness**:
  - Peaceful protest can draw public attention to water pollution issues and encourage **companies** or **governments** to **take action**
  - Protests can make both **policymakers** and the **public** more aware of potential environmental risks
  - This can sometimes lead to **stricter regulations** or **new laws** to protect water
- **Organising community clean-ups**:
  - By organising local clean-up events, groups can help directly remove pollutants like litter and plastics from rivers, lakes, and beaches.
  - Community clean-ups also educate members of the community on the importance of keeping water sources free from waste

Data collection and research

- **Community science projects**:
  - Community-led data collection efforts, often called community or **citizen science**
    - E.g. this could involve local residents monitoring water quality by measuring factors like pH, turbidity, and levels of certain pollutants
  - Community data can provide valuable information about **water pollution trends** and help identify specific **sources of pollution**
- **Reporting pollution**:
  - Individuals and groups can help by reporting visible pollution or notable changes in water quality to local authorities
  - This can help authorities take action before pollution spreads further, making it easier to **contain** and **treat**

Forming legal teams and lobbying lawmakers

Your notes

- **Legal action against polluters**:
  - Environmental legal teams often help communities **hold polluters accountable** by filing lawsuits if laws protecting water quality are violated
  - Legal action can lead to **financial penalties** for companies or stricter operational requirements
  - This helps to prevent further pollution.
- **Lobbying for stronger water laws**:
  - Groups and organisations may work to **influence local or national lawmakers** to create or strengthen regulations protecting water quality.
  - Lobbying efforts can lead to:
    - **New policies** that restrict pollution
    - **Increase penalties** for violations
    - **Require improved treatment** of industrial and agricultural wastewater