DP IB Environmental Systems & Societies (ESS): SL

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)

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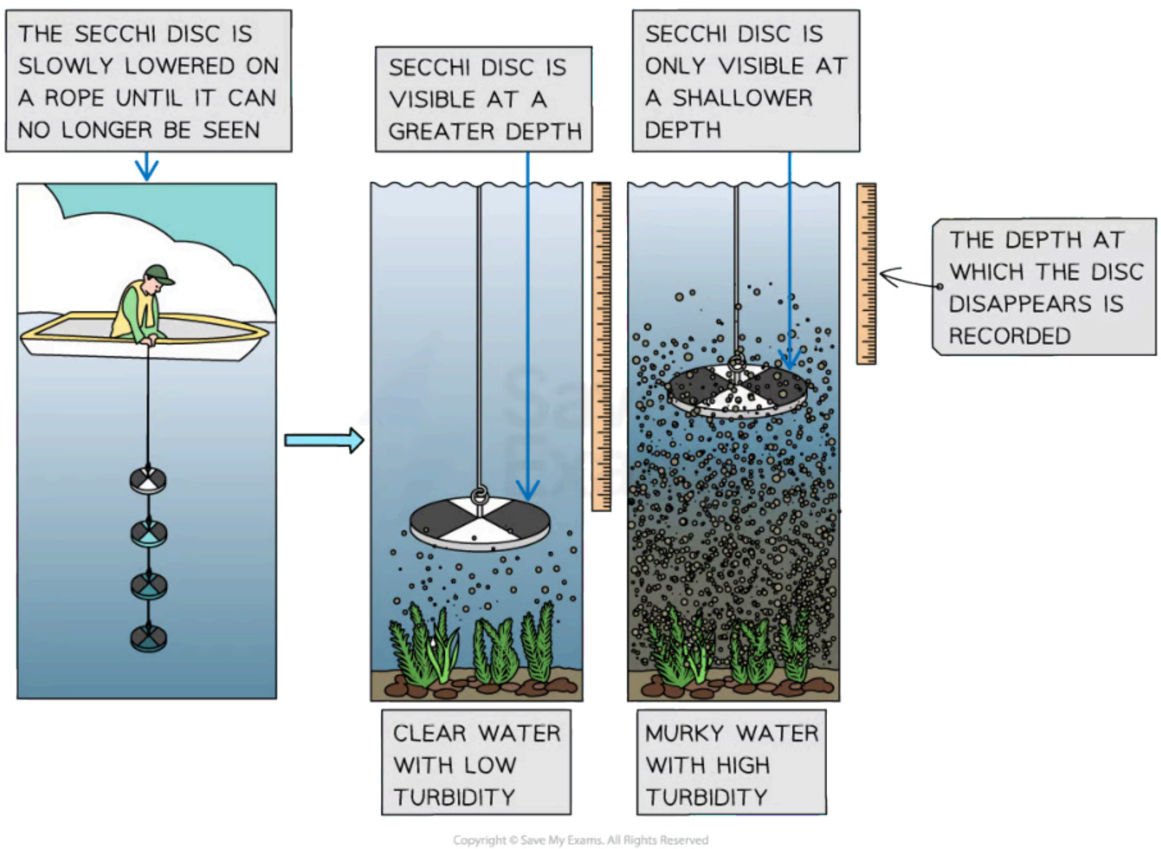
- This reduces photosynthesis in aquatic plants and visibility for predators and prey
- High turbidity can indicate soil erosion or urban, agricultural or industrial run-off

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

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

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

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

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

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

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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

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- 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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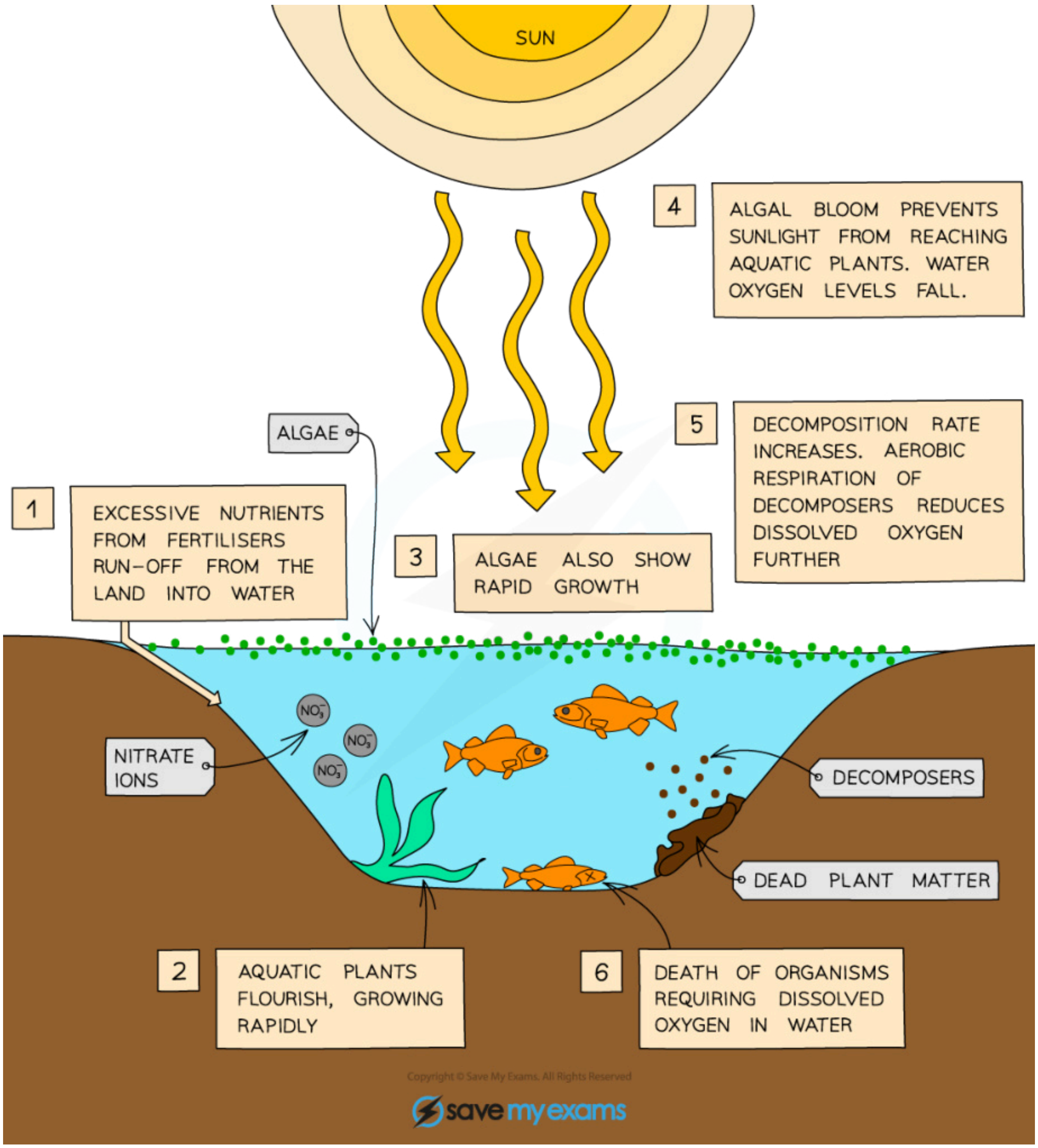

The sequence of events causing eutrophication in lakes, rivers and coastal waters

Positive feedback in eutrophication

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

1. **Increased nutrients**:

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- 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

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

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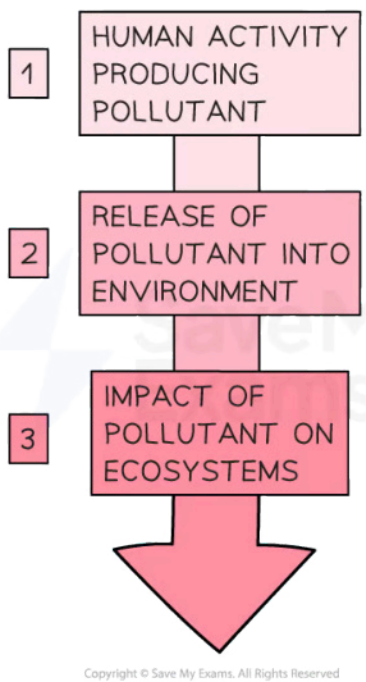
Water Pollution Management Strategies

Water Pollution Management Strategies

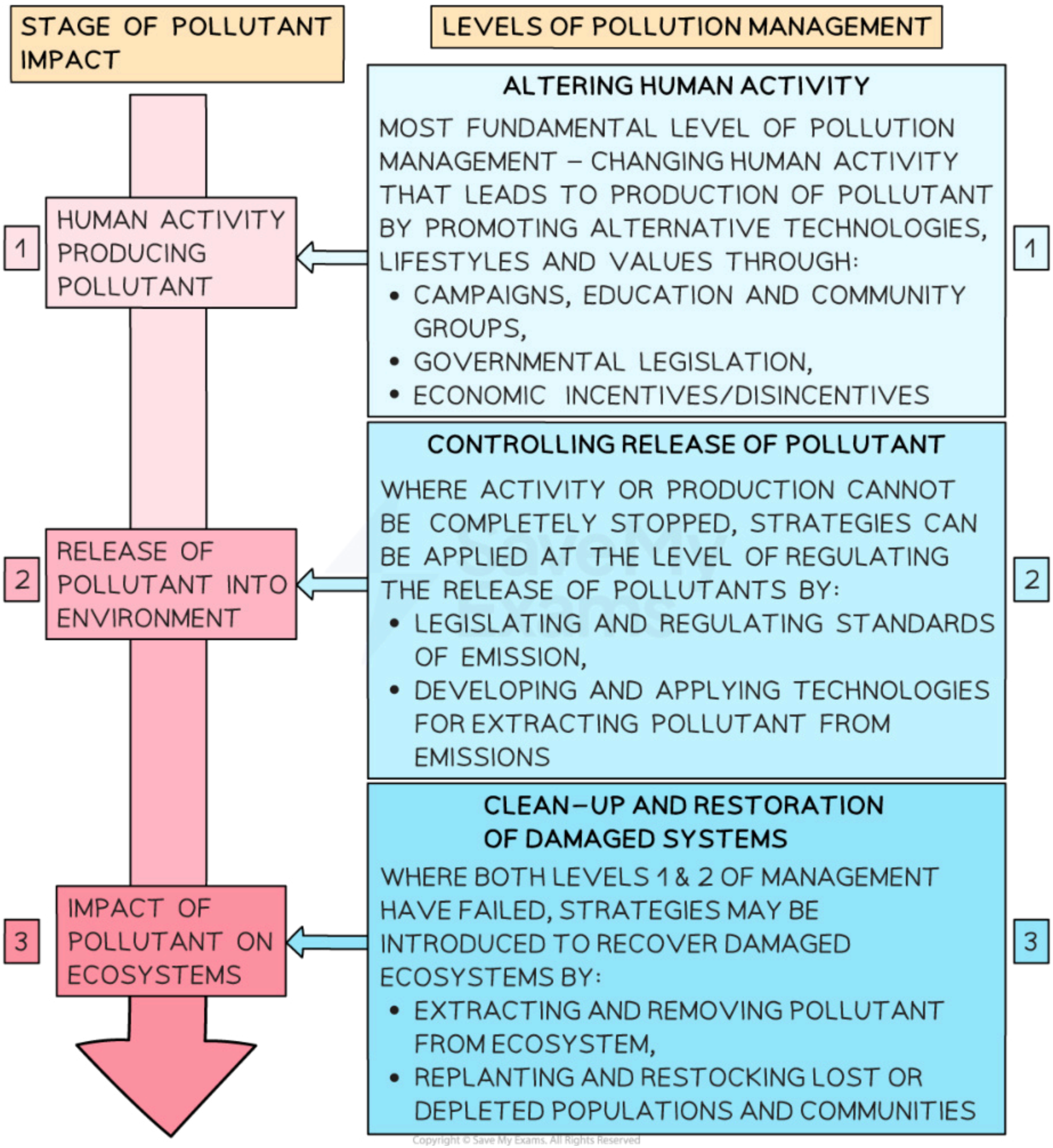
- Human activities, such as farming and industrial practices, urbanisation, development of transport, and energy production, are the major causes of pollution
  - The amount of material released into the environment determines the **impact**
- There are **three main stages** leading to the impact of 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:

- 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

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.

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