DP IB Environmental Systems & Societies (ESS): SL

Your notes

Water Pollution

Contents

Sources of Fresh Water & Marine Pollution

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Sources of Fresh Water & Marine Pollution

Causes of Water Pollution

- There are a variety of freshwater and marine pollution sources
- Types of aquatic pollutants include:
  - Organic material
  - Inorganic nutrients (nitrates and phosphates)
  - Toxic metals
  - Synthetic compounds
  - Suspended solids
  - Hot water
  - Oil
  - Radioactive pollution
  - Pathogens
  - Light
  - Noise
  - Invasive species

Water Pollution Effects

Pollutant	Description	Effect
Organic material	Pollution caused by excessive organic matter such as untreated human **sewage**, animal waste, or decaying plant material	Excessive organic material can lead to **oxygen depletion**, harmful **algal blooms**, and **eutrophication** in water bodies

Inorganic nutrients	Pollution from excess **nitrates** and **phosphates** primarily originating from agricultural runoff, sewage, and fertilisers	Elevated levels of these nutrients can cause nutrient enrichment, leading to **algal overgrowth** and water quality degradation
Toxic metals	Pollution caused by heavy metals such as mercury, lead and arsenic, often originating from industrial activities, mining, or improper waste disposal	These metals can **accumulate** in aquatic organisms, leading to toxic effects and posing risks to human health and ecosystems
Synthetic compounds	Pollution resulting from **human-made chemicals**, including pesticides, herbicides, pharmaceuticals, and industrial pollutants	These compounds can enter water bodies through runoff, discharges, or improper disposal, potentially harming aquatic life and human health
Suspended solids	Pollution caused by the presence of solid particles in water, typically **sediment, silt, or fine particles** from erosion, construction, or dredging activities	High concentrations of suspended solids can impair water clarity, clog fish gills, smother **benthic** habitats, and impact aquatic organisms such as invertebrates and their larvae
Hot water	Pollution from the release of heated water into aquatic systems, often associated with industrial processes or power generation	Elevated water temperatures can disrupt aquatic ecosystems, **reduce oxygen levels**, and negatively impact fish and other organisms (e.g. disrupting migration patterns or natural breeding cycles)
Oil	Pollution resulting from oil spills, leaks, or discharges from shipping, oil exploration, or industrial activities	Oil can coat the water surface, affecting marine and freshwater ecosystems, harming aquatic life such as seabirds, and leading to long-term environmental damage
Radioactive pollution	Pollution caused by the release of radioactive substances, often associated with nuclear accidents, mining, or waste disposal	Radioactive pollution can have severe ecological and human health impacts, with **prolonged exposure** potentially leading to **genetic mutations** and **cancer**
Pathogens	Pollution from the presence of disease-causing microorganisms, including bacteria,	Pathogens can contaminate water sources, leading to **waterborne diseases**

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	viruses, and parasites, often originating from **sewage** or **animal waste**	(such as cholera) and posing risks to human and animal health
Light	Pollution resulting from **excessive artificial lighting**, particularly in coastal areas	Light pollution can disrupt natural light cycles, affecting **nocturnal marine species** and disrupting reproduction, navigation, and feeding patterns of marine organisms
Noise	Pollution caused by anthropogenic noise from activities such as shipping, sonar, construction, or offshore energy production	Excessive noise can **disrupt** communication, feeding, and migration patterns of marine species (such as whales), leading to ecological disturbances
Invasive species	Pollution resulting from the 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)	Invasive species can 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)

- It is important for countries, governments, industries and the general public to try and prevent and mitigate these forms of aquatic pollution through proper waste management, wastewater treatment, responsible industrial practices, and the implementation of environmental regulations and policies

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Measuring Water Quality

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Measuring Water Quality

- To directly test the quality of aquatic ecosystems, various **parameters** can be measured and analysed.

Water testing is conveniently carried out in the field using digital probes

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

1. pH

- 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

2. Temperature

- 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 harm aquatic life

3. Dissolved Oxygen (DO)

- Dissolved oxygen measures the amount of oxygen dissolved in water
- Adequate oxygen levels are crucial for the survival of aquatic organisms
- Low dissolved oxygen can lead to **hypoxia**, suffocating or killing aquatic life

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4. Suspended Solids (Turbidity)

- Turbidity refers to the level of suspended solids, such as sediment, organic matter, or algae, in water
- High turbidity reduces water clarity, **light penetration**, and can disrupt aquatic habitats
- Turbidity measurements provide insights into **sedimentation, erosion**, and overall water quality

5. Metals

- Testing for metals, such as mercury, lead, cadmium, or arsenic, assesses contamination levels
- Metals can **accumulate** in aquatic organisms, posing risks to their health and ecosystem integrity
- Monitoring metal concentrations helps identify pollution sources and evaluate potential ecological impacts

6. Nitrates and Phosphates

- Measuring nitrates and phosphates assesses nutrient pollution in water
- High nutrient levels can lead to **eutrophication**, harmful algal blooms, and **oxygen depletion**
- Monitoring nutrient concentrations helps manage **nutrient inputs** and prevent water quality degradation
- These parameters provide valuable information about the health and condition of aquatic ecosystems
    - Most of these parameters can be measured using standard water testing kits
    - The measurements obtained using these kits can be compared to standardised charts, colour charts, or tables that feature known samples
    - For example, when analysing water for nitrates, uncontaminated water typically contains less than 5 mg dm^{-3}, whilst polluted water may contain 5–15 mg dm^{-3}
    - 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

Photo by Tarek Badr on Unsplash

Measuring water pollution parameters near factory outlets is vital to assessing the impact on ecosystems

- Monitoring and analysing these parameters at **regular intervals** help scientists, environmental agencies, and policymakers understand the overall water quality, identify potential issues, and implement appropriate management strategies to protect and restore aquatic ecosystems

Biodegradation of Organic Material

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Biodegradation of Organic Material

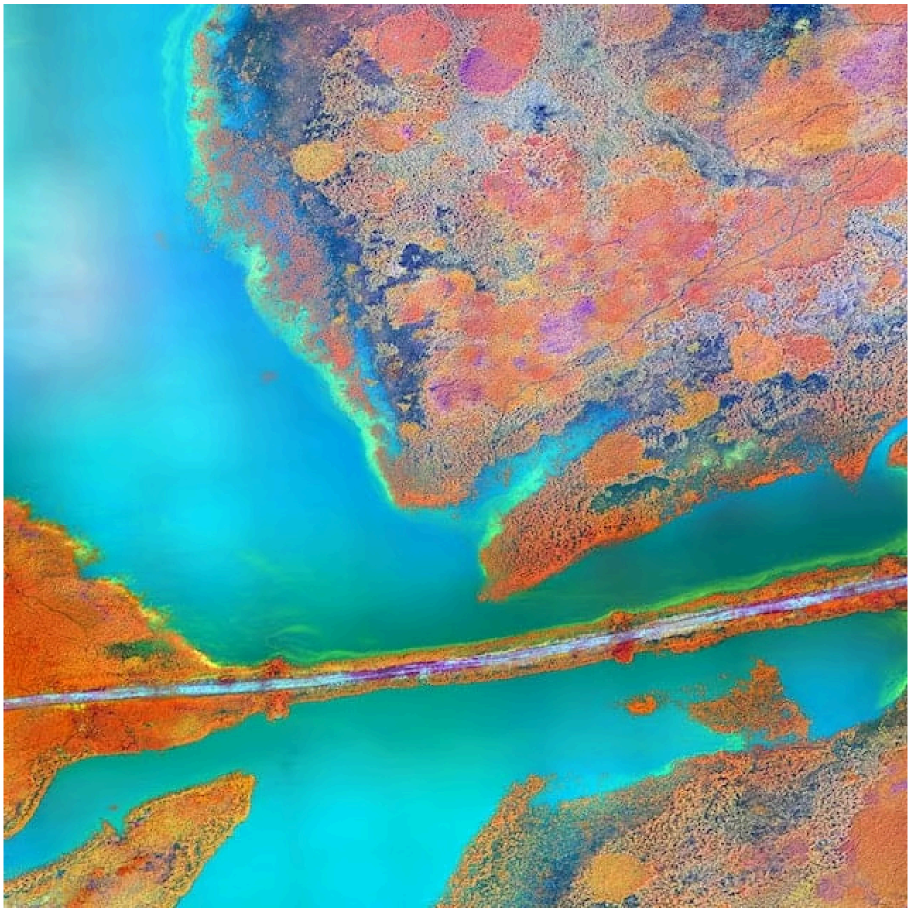

Photo by USGS on Unsplash

Algal booms on Milford Lake in Kansas are an example of excessive biodegradation of organic material

- Biodegradation of organic material refers to the **natural process** where microorganisms **break down organic substances** into simpler compounds
  - During biodegradation, microorganisms utilise oxygen for the breakdown of organic matter
  - High levels of organic material can lead to increased microbial activity and oxygen consumption in water bodies

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- Excessive biodegradation of organic material can **deplete dissolved oxygen levels**, leading to **anoxic** conditions (low oxygen) in the water
  - In anoxic conditions, **anaerobic decomposition** occurs, carried out by bacteria that do not require oxygen
- Anaerobic decomposition results in the production of gases such as **methane** (CH_4), **hydrogen sulphide** (H_2S), and **ammonia** (NH_3)
  - Methane is a **powerful greenhouse gas** and contributes to climate change when released into the atmosphere
  - Hydrogen sulphide is **highly toxic** and can harm aquatic organisms
  - Ammonia, in high concentrations, can be toxic to aquatic life and contribute to **nutrient pollution**, causing **eutrophication** and **algal blooms**
- The presence of these toxic gases can have detrimental effects on water quality, aquatic ecosystems, and the organisms that rely on them
- It is important to manage organic waste properly, promote adequate oxygen levels in water bodies, and prevent the buildup of excessive organic material in order to minimise the occurrence of anoxic conditions and the subsequent formation of toxic gases

Biochemical Oxygen Demand

- 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 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 **elevated 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

Matthias Tilly, CC BY 3.0,via Wikimedia Commons

Tubifex worms are able to withstand quite polluted water

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

- High BOD values indicate a larger amount of organic matter present in the water sample, as 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 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 and measuring the dissolved oxygen concentration initially and after a specific incubation period (often 5 days) at a **constant temperature**
- For example, if a water sample has an initial dissolved oxygen concentration of 8 mg/L and 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

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- As the dissolved oxygen levels have decreased substantially, this indicates that the sample has a **relatively high organic load**

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Indicator Species

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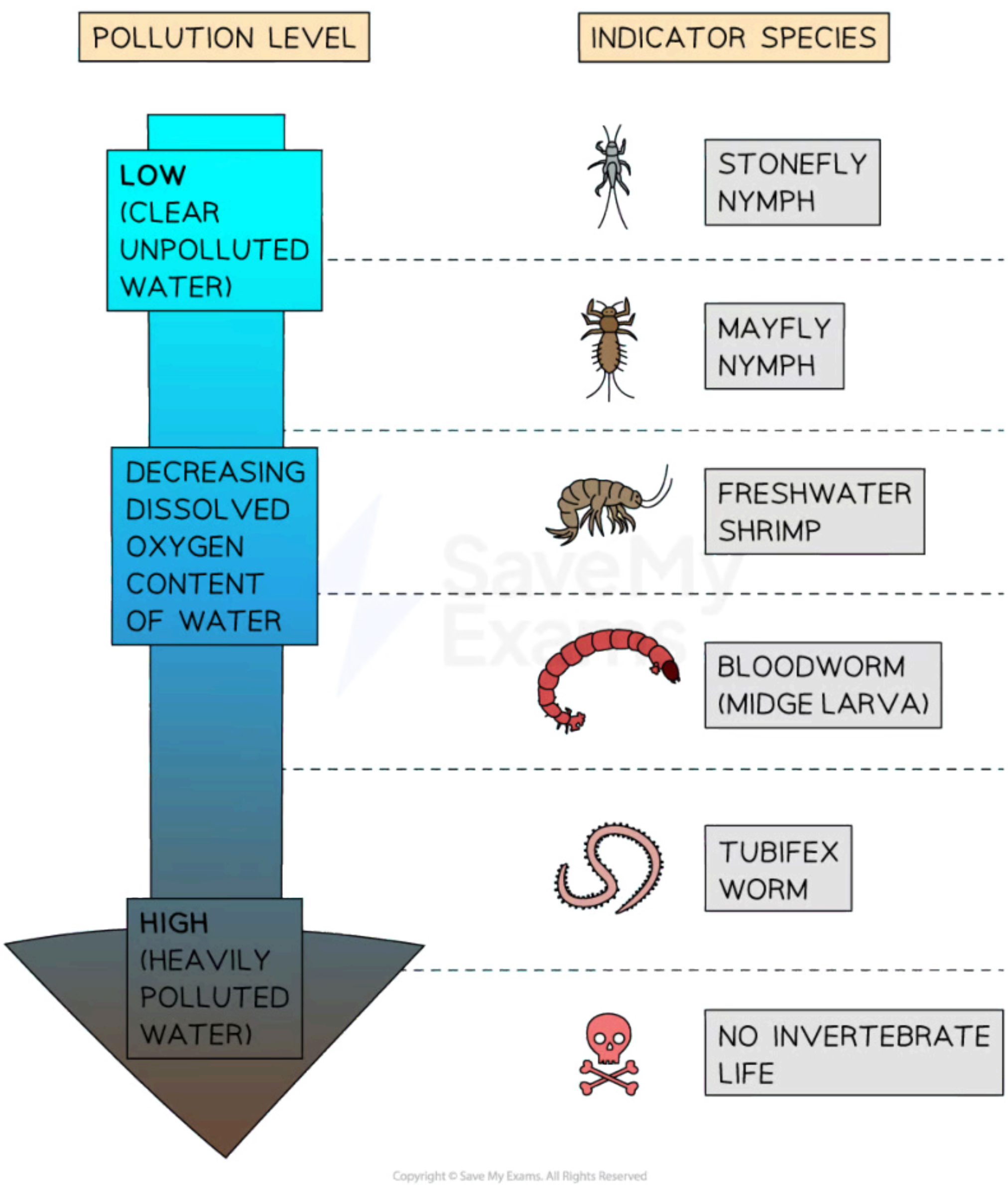
Indicator Species

- Indicator species are organisms that are used to assess the **quality of an environment** or indicate the presence of **specific environmental conditions**, including pollution
- Different groups of organisms, including invertebrates, plants, and algae, can serve as indicator species in **polluted waters**:



Fresh water pollution invertebrate indicator species

1. Invertebrates

- Bloodworms (*Chironomidae*): bloodworm (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: *tubifex* worms also thrive in polluted waters with high organic content and low oxygen levels - their abundance suggests degraded water quality

2. Plants

- Common Reed (*Phragmites australis*): this tall perennial grass is **tolerant** of high nutrient levels, such as nitrates and phosphates, often found in **eutrophic or polluted waters**
- Duckweed (*Lemnaceae* family): duckweed is a small floating plant that thrives in nutrient-rich waters, including those polluted with agricultural runoff or sewage effluents

3. Algae

- Blue-green Algae (Cyanobacteria): excessive nutrients, particularly nitrogen and phosphorus, can trigger harmful algal blooms dominated by blue-green algae - these blooms are often associated with nutrient pollution and indicate degraded water quality
- Indicator species in aquatic ecosystems can also provide valuable insights into **unpolluted** or **clean** waters - examples include:

1. Invertebrates

- Stonefly nymphs (*Plecoptera*): stoneflies are sensitive to water pollution and are often found in well-oxygenated, clean streams and rivers - their presence indicates good water quality
- Mayfly nymphs (*Ephemeroptera*): mayflies are also highly sensitive to pollution and require clean, well-oxygenated water - their presence is indicative of unpolluted aquatic habitats

2. Plants

- Water Crowfoot (*Ranunculus spp.*): 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 such as fish

3. Algae

- Diatoms: diatoms are a diverse group of algae, and their presence in high diversity and abundance is often associated with clean, well-oxygenated waters
- These are just a few examples of indicator species commonly used in **water quality assessments**

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- By studying the presence, abundance, and diversity of these organisms, scientists and environmental professionals can gain insights into the **pollution levels** and overall health of aquatic ecosystems
    - It is important to note that the selection of indicator species may vary 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 and **aids in conservation and management efforts** to improve water quality and protect clean, unpolluted waters

Dave Huth from Allegany County, NY, USA, CC BY 2.0, via Wikimedia Commons

Indicator species such as the stonefly nymph can tell you that water is clean, but not how clean

Potential 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**
    - For example, it can't give accurate numerical (**quantitative**) figures for exactly how much pollution is present
    - In addition, the presence or absence of indicator species can also be affected by factors other than pollution (e.g. the presence of predators or disease)
- 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 and can be used to show changes in

levels of water pollution over time

Biotic Indices

- A biotic index is a tool used to assess the overall **health** and **pollution levels** of an ecosystem based on the presence, abundance, and diversity of indicator species within a community
- It provides an indirect measure of pollution by evaluating the impact on different species according to their tolerance, diversity, and relative abundance

Photo by Jonny Gios on Unsplash

A biotic index allows environmental scientists to assess the health of an ecosystem

Step 1 = Selection of Indicator Species

- Indicator species are selected based on their known **sensitivity** or **tolerance** to pollution
- These species are representative of **different ecological niches** and are used to evaluate the impact of pollution on the ecosystem

Step 2 = Sampling and Data Collection

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- Sampling is conducted at **different sites** within the water body being assessed
- 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**, which is a **numerical score** or **rating** that reflects the overall quality of the ecosystem
- 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
  - By sampling macroinvertebrate communities at various sites in a river, the relative abundance and diversity of pollution-sensitive and pollution-tolerant species are determined
  - These data are then used to calculate the Trent Biotic Index score, which provides an assessment of water quality and pollution levels in the river
  - If the Trent Biotic Index score for a particular section of the river is **high**, it suggests a **healthy** and **less polluted** ecosystem, as 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, as pollution-tolerant species **dominate** the **community**
- There are many different types of biotic indices that can be calculated to study different types of water pollution
  - For example, the **Fine Sediment Sensitivity Index** can be calculated to help identify occurences of sediment pollution in freshwater systems
- These biotic indices provide a valuable means to evaluate and **monitor** the impact of pollution on aquatic ecosystems, aiding in **conservation efforts** and guiding **water management strategies**

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What is Eutrophication?

Eutrophication

- When lakes, rivers, estuaries and coastal waters receive **artificially large inputs** of **nutrients** (such as nitrates and phosphates), this results in **excess growth** of plants and phytoplankton
  - 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**
- This algal bloom can completely block out sunlight and stop it from penetrating below the water surface, so aquatic plants below the surface of the water start to **die** as they can **no longer photosynthesise**
  - The algae also start to die when **competition** for nutrients becomes too intense
- As aquatic plants and algae die in increasing numbers, **decomposing bacteria** feed on the dead organic matter and also increase in number
  - As they respire **aerobically**, these bacteria use up the **dissolved oxygen** in the water
- As a result, 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

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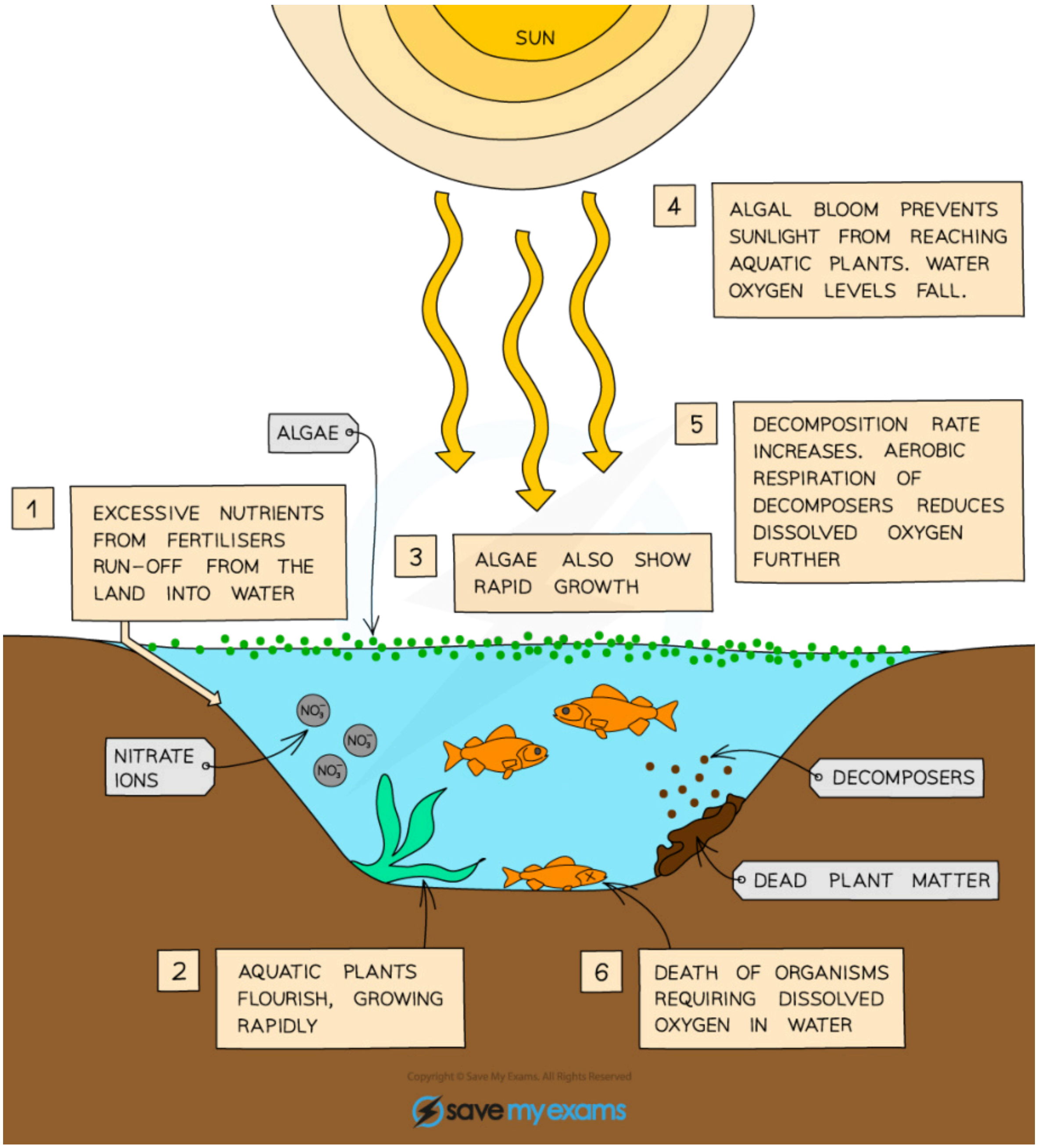

Sequence of events causing eutrophication in lakes, rivers and coastal waters

Water Pollution Management Strategies

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Water Pollution Management Strategies

- There are three levels of pollution management:
  - Changing human activity
  - Regulating and reducing quantities of pollutants released at the point of emission
  - Cleaning up the pollutant and restoring the ecosystem after pollution has occurred

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The three levels of pollution management strategies can be applied to the management of water pollution in aquatic ecosystems

1. Reducing human activities that produce pollutants

- Implementation of alternative practices and technologies:

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- Identifying and adopting **alternatives** to current fertilisers and detergents that have less harmful environmental impacts
- For example, promoting the use of **organic fertilisers** and **eco-friendly detergents** can reduce the release of pollutants into water bodies

- Public awareness and education:
  - Educating the public about the environmental consequences of certain human activities and **encouraging behaviour changes**
  - This includes promoting sustainable agricultural practices, responsible waste management, and water conservation

2. Reducing the release of pollution into the environment

- Waste water treatment:
  - Implementing effective **waste water treatment systems** to remove pollutants, such as nitrates and phosphates, before the water is discharged back into the environment
  - This includes processes like biological treatment, chemical precipitation, and advanced filtration techniques
- Industrial regulations:
  - Enforcing **strict regulations** and **standards** for industries to control and reduce the release of pollutants into water bodies
  - This can include effluent discharge limits, mandatory pollution control measures, and **regular monitoring** and **reporting** of pollution levels

3. Removing pollutants from the environment and restoring ecosystems

- Remediation and restoration projects:
  - Implementing strategies to **remove pollutants** from **contaminated sites** and restore ecosystems
  - This can involve techniques like **dredging** to remove accumulated sediment, using activated carbon or other absorbents to **capture pollutants**, and **re-establishing native vegetation** and aquatic species
- Ecosystem management:
  - Adopting holistic approaches to manage ecosystems and their water quality
  - This includes implementing integrated watershed management plans (sometimes known as the Catchment Based Approach), promoting **natural filtration systems** (e.g. constructed wetlands), and **restoring riparian buffers** to minimise pollution runoff
- These three levels of pollution management strategies can be used **together** to address water pollution using a combined approach

- By reducing the production of pollutants, minimising their release into the environment, and actively removing pollutants and restoring ecosystems, the goal is to prevent further degradation, improve water quality, and preserve the health of aquatic ecosystems