

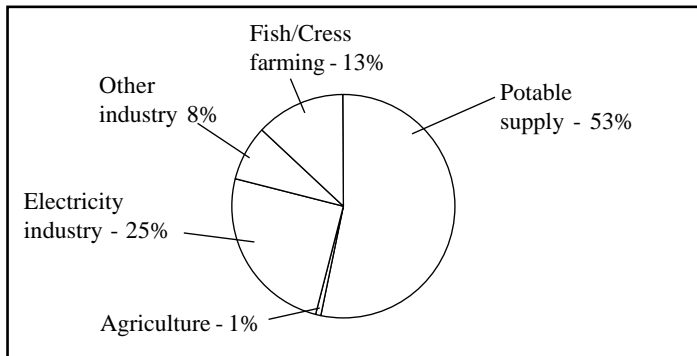


The Pollution of Lakes and Reservoirs

Water supplies in England and Wales

Surface water (lakes, reservoirs and rivers) supply 87% of total abstractions in England and Wales - the rest is obtained from underground aquifers (which are known as **groundwater** supplies). Freshwater in lakes and rivers may be used for drinking water (potable supply), irrigation or other agricultural uses and for industry (Fig 1).

Fig 1. Agricultural and industrial uses for freshwater



The total quantity of water abstracted from freshwater supplies in England and Wales has actually declined over the last 30 years, mainly because of the national decline in demand from power stations and the manufacturing industry. However, reservoirs have been constructed to safeguard supplies, particularly during the summer months when higher temperatures increase evaporation and therefore decrease river flow. Fig 2a and 2b show how reservoir capacity in England and Wales has risen in line with both population and the number of households.

Fig 2a. Population and household trends in England (1860 - 2020)

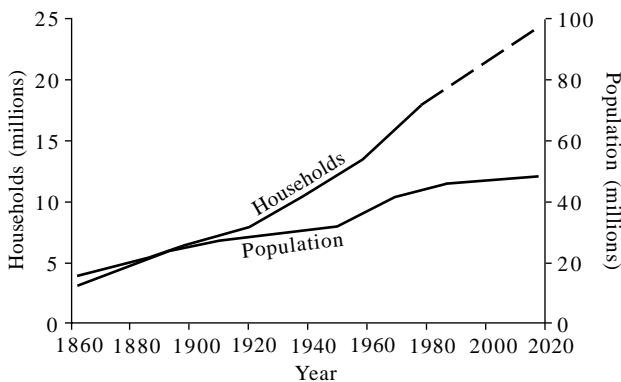
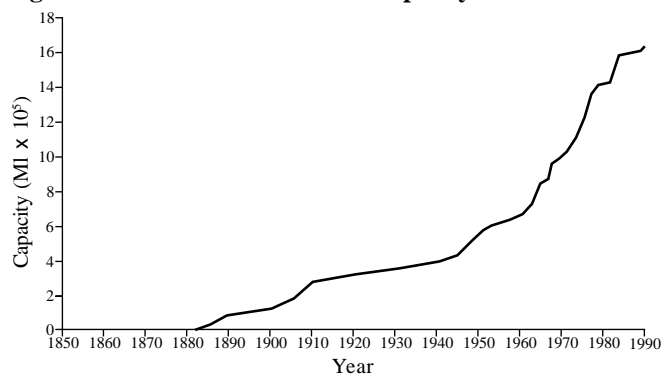


Fig 2b. Increase in total reservoir capacity since 1850

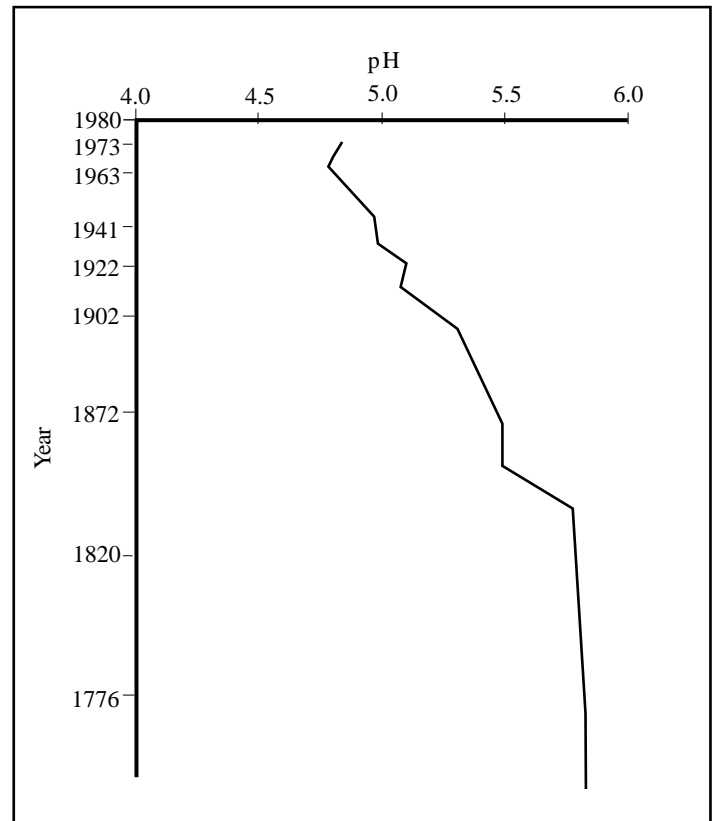


Both lakes and reservoirs may become polluted from **point sources** (e.g. sewage effluent pipes) or from **diffuse** (more widely scattered) sources from a surrounding catchment.

Acidification

Since the start of the Industrial Revolution in the mid 19th Century, the pH of many lakes in Wales, the Scottish Highlands, the Pennines, south-west England and the Lake District has been steadily declining. This increase in acidity is correlated with emissions of sulphur dioxide from coal burning power stations and nitrogen dioxide emissions from vehicles. Fig 3 shows the change in pH of Loch Granoch in Galloway, Scotland over the last 200 years.

Fig 3. pH of Loch Granoch in Scotland



Loch Granoch is situated on granite rocks in south-west Scotland. Micro-organisms known as diatoms have been collected from deep sediment cores taken from the lake. Diatom distribution is known to be very closely correlated with pH - in other words, some species of diatom only occur in water of a particular pH. Thus, by identifying the diatoms which were present at different depths - and by estimating the rate of sediment accumulation - scientists have been able to predict the pH of the lake water over the last 200 years. The estimated pH in 1776 was 5.7, in 1980 it was 4.7 - 10 times more acidic.

Lakes in Norway and Sweden have been devastated by acidification caused by sulphur dioxide released in countries such as Britain, Germany and the Czech Republic; acidic gases may travel thousands of miles in the atmosphere before being deposited. In other words, acid rain is a **transboundary pollutant**.

The effect of land use

Whilst scientists are certain that Scottish lakes and many other upland lakes have become more acidic, it is more difficult to identify the precise causes. Certainly, acid rain is a factor, but land use changes such as afforestation, deforestation and deep ploughing may also have contributed. Afforestation of sensitive catchments (i.e. those with an acidic underlying geology, which is incapable of neutralising the acid) may accelerate the acidification of lakes because the coniferous canopy is an effective filter or 'scavenger' of acidic, airborne pollutants such as sulphur particles. Intercepted rainfall dissolves these and other acidic particles and washes them into lakes.

Conversely, deforestation may also dramatically increase acidification by increasing soil erosion. Such soil may also contain acidic particles but in any case, when it eventually settles on the lake bed, it slows down the re-release into the water of calcium-containing sediments. This reduces any neutralising effect which the lake bed would have had. The biological effects of acidification of a lake which has a normal pH of 7.2 are summarised in Table 1.

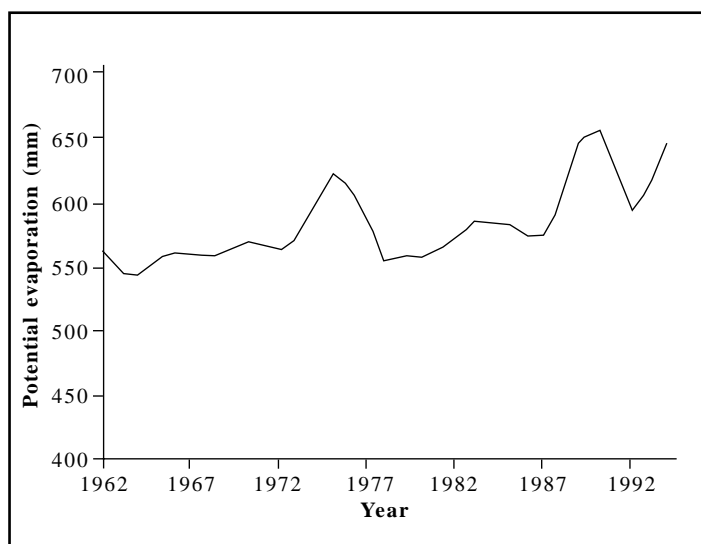
Table 1. The biological effects of acidification of a lake

pH	Effects
6.0 - 6.5	Species numbers and diversity decreases. Acid tolerant species dominate. Plant productivity may decline if phosphate becomes precipitated out in aluminium compounds.
5.5 - 6.0	Species diversity continues to decrease. Acid tolerant prey species of fish dominate. Grazing and filter feeding invertebrates decline.
5.0 - 5.5	Rate of decomposition decreases rapidly. Very few fish species survive. Diatoms decline. Lack of food sources leads to reduced zooplankton.
<5.0	Very few species of plant or animal survive. Water is often clear.

Climate change and pollution

Average air temperatures between 1975 and 1995 have been 0.5°C higher than the preceding 20 year average. As a result, evaporation losses have also risen (Fig 4).

Fig 4. Potential evaporation, 1962-1992 (3-year running mean)



At the same time there has been a tendency for more distinct rainfall differences between summer and winter, with much less rain in summer. In terms of pollution to lakes and reservoirs, these trends have three consequences:

1. Decreasing river inputs mean that any pollutant which enters a lake is less diluted and therefore more harmful to living organisms.
2. As water temperatures increase, the chances of algal blooms and blooms of potentially toxic cyanobacteria also increase.
3. As water temperature increases, oxygen solubility decreases. Thus, in order to obtain a given volume of oxygen, fish have to increase the volume of water which moves past their gills (absorbing more pollutant). Thermal pollution, the release of warm water from a power station cooling plant, for example, would have precisely the same effect.

Toxic 'Algae'

In the summer of 1989, huge and deep blooms of 'toxic algae' caused serious problems in rivers and lakes in several areas of Britain. The 'algae' released substances into the water which killed fish, dogs and in some cases the sheep which ingested the organisms. These chemicals are also toxic to humans.

What are 'toxic algae'?

Firstly, it is worth noting that these toxic algae are not in fact algae but are more accurately known as cyanobacteria. Cyanobacteria grows slowly, so large blooms will only develop in lakes and reservoirs following a long period of stable, favourable weather conditions. Cyanobacteria do not need high concentrations of nutrients such as nitrates or phosphates in order to bloom; an early misconception was that such blooms were always a consequence of eutrophication. However, blooms of cyanobacteria may last longer in lakes and reservoirs which have had high phosphate concentrations because the organisms are highly efficient at storing phosphorus.

**Case Study:
Rutland Water (1989)**

Rutland Water is located in an agricultural area of Leicestershire around Oakham. It is a man-made lake which also serves as a reservoir for 450,000 people and is a very popular centre for watersports and recreational activities such as sailing, fishing and bird watching.

The reservoir contains over a hundred different species of algae and over the course of any one year, there is usually a clear succession of species; during spring, diatoms dominate which give way to unicellular algal species. Finally by midsummer, buoyant cyanobacteria such as *Anabaena* dominate because they out-compete non-buoyant species.

During August 1989, 20 sheep and 15 dogs died. The NRA (National Rivers Authority) carried out detailed water analysis and it was confirmed that the dead animals had ingested *Microcystis aeruginosa*. As a safety precaution, Anglian Water closed both reservoirs for recreational purposes. The blooms were attributed to a combination of favourable conditions; to the mild 1988-89 winter and long periods of stable, high pressure between April and July which brought high and relatively constant temperatures.

Agricultural pollution

Agriculture remains the commonest source of **diffuse** pollution.

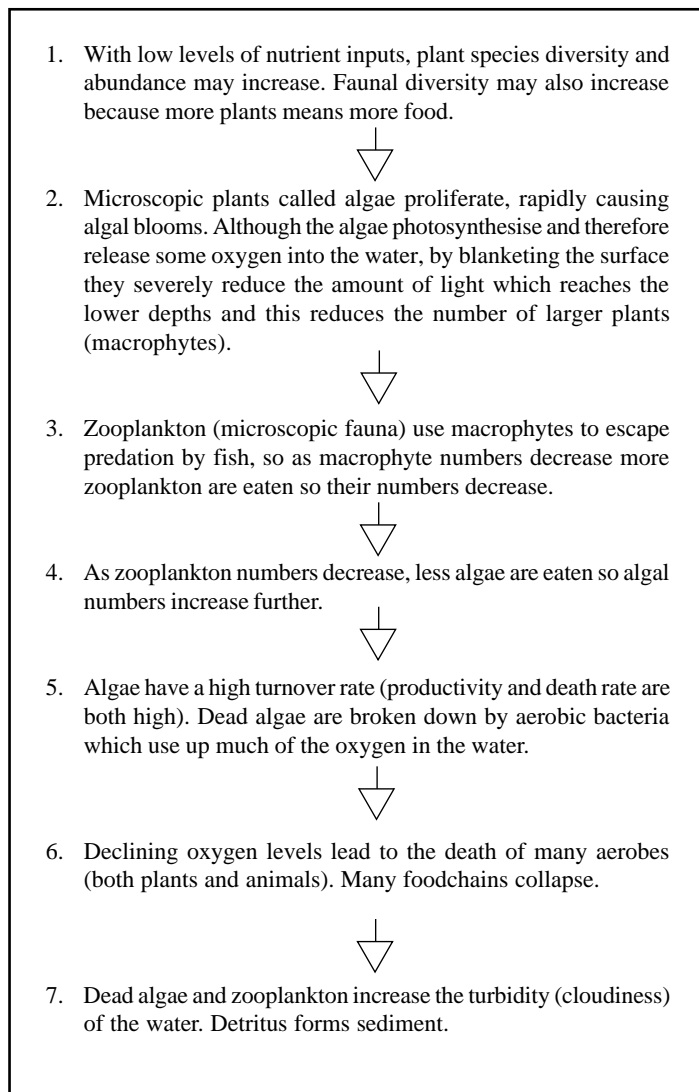
Pesticides

Due to increasing concern about organophosphate pesticides previously used in sheep dips, many have been replaced with pesticides known as synthetic pyrethroids. However, whilst these substances are much less toxic than organophosphates to humans, they are extremely toxic to aquatic life. Such pesticides have found their way into rivers and streams and from there into freshwater lakes. Residues of crop pesticides such as atrazine - although banned in 1993 - are still commonly found in surface waters and are believed to reach lakes and reservoirs by spray-drift, run-off and soil erosion.

Eutrophication

Eutrophication is defined as the excess nutrient enrichment of water. In most cases the excess nutrients are nitrates and phosphates. Eutrophication is a natural process - eventually all lakes become enriched with nutrients such as phosphates as a result of natural weathering and erosion of rock. However, humans have greatly accelerated this process and this is therefore termed **cultural eutrophication**. The ecological effects of such enrichments are shown in Fig 5.

Fig 5. Eutrophication: The process



Case study:

Eutrophication in the Norfolk Broads

Over the last 30 years large sections of the Norfolk Broads have suffered from cultural eutrophication. However, installation of phosphate stripping equipment at sewage treatment works in the Broads has led to dramatic improvements in water quality. For example, by the late 1970s Barton Broad, a shallow lake in the Norfolk Broads was severely eutrophic, turbid and had little animal or plant diversity. Phosphate stripping equipment installed in 1979 quickly reduced phosphate concentrations and algal blooms - as measured by the chlorophyll content of the water (Fig 6). Fig 6 also shows the importance of river flushing of such lakes. The drought in 1991-1992 decreased river flushing and phosphate concentrations and chlorophyll counts both increased as a result.

Fig 6. Levels of phosphate and chlorophyll in Barton Broad

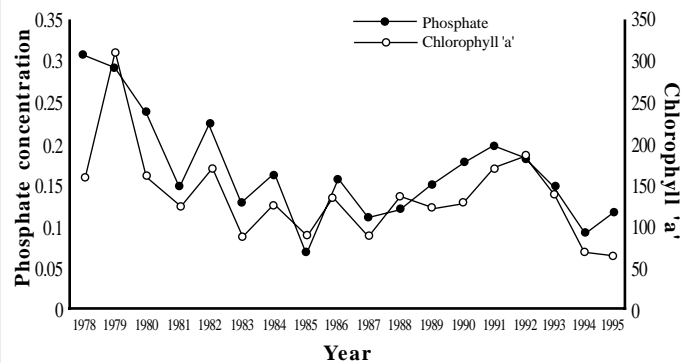
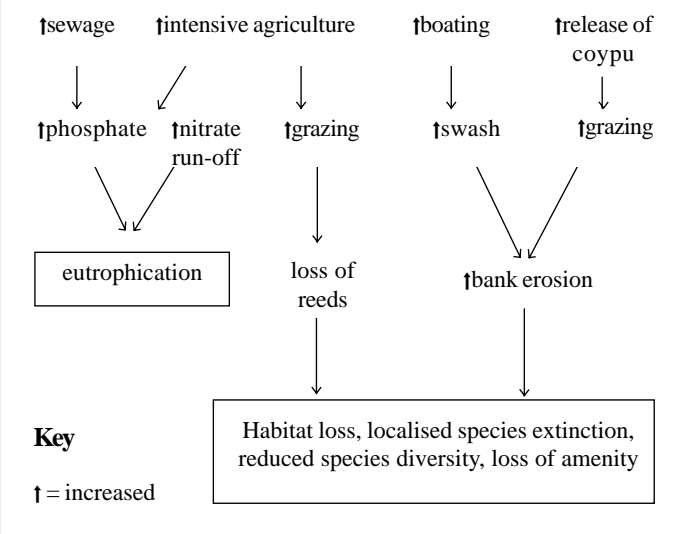


Fig 7 indicates some of the possible means of controlling/ remedying eutrophication; removal of phosphates from detergents, phosphate stripping at sewage treatment works, restriction on usage of nitrates, decreasing grazing pressure and decreasing the number and speed of boats etc. will all help decrease the problem.

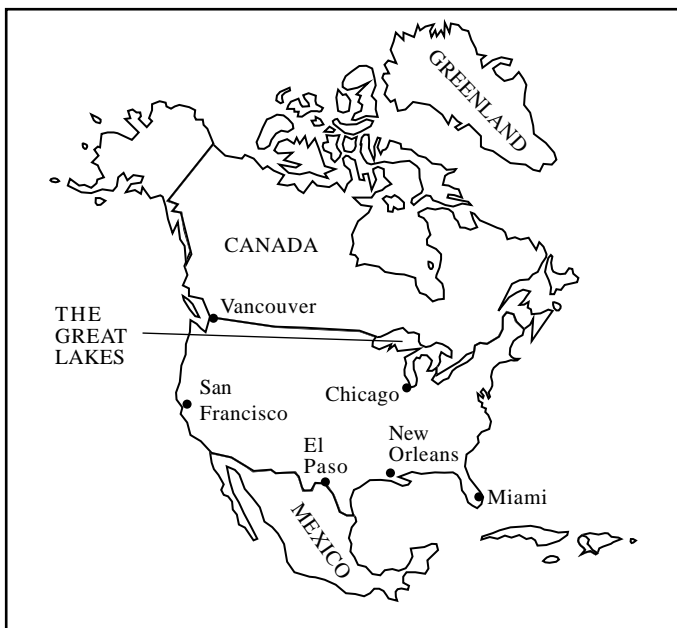
Fig 7. Causes and consequences of eutrophication in the Norfolk Broads



Exam Hint - Candidates often confuse the definition of eutrophication with its consequences. Eutrophication is simply the enrichment of water with excess nutrients. A common **consequence** of eutrophication is an algal bloom.

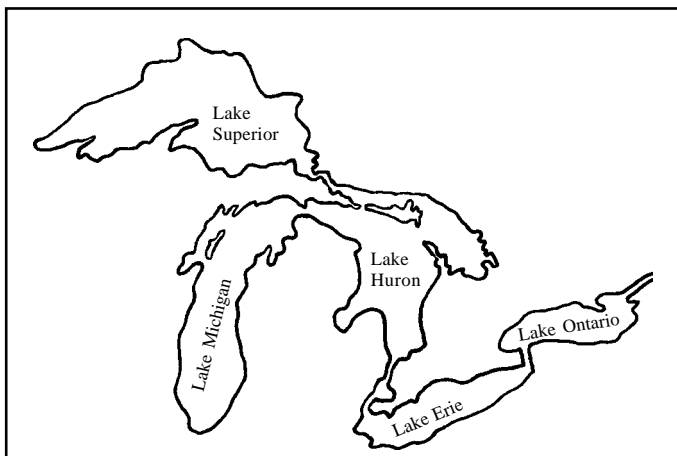
**Case Study:
The Great Lakes**

Fig 8. The Great Lakes



38 million people live within the Basin of the Great Lakes (Fig 8) - Lakes Superior, Huron, Michigan, Erie and Ontario (Fig 9), which became the focus of international concern in the 1970s, when Lakes Erie and Ontario showed severe signs of eutrophication. In 1972, Canada and the United States signed an international agreement to reduce phosphate inputs to these lakes by decreasing the phosphate content of detergents and by establishing tertiary treatment (phosphate stripping) in dozens of sewage treatment works. By 1990, phosphate concentration had fallen by 70%. However, Lake Superior presented more difficult problems. The huge size of Lake Superior and its small inflow means that flush rates are very slow and residence times - the period between a water molecule entering and leaving the lake - has been estimated at 180 years. Any pollution is therefore difficult to remove.

Fig 9. The Great Lakes



The International Joint Commission identified 360 toxic chemicals in the 5 lakes, including dioxins, DDT, lead, mercury and PCBs (polychlorinated biphenyls). PCBs were thought to have leaked from poorly-constructed landfills which have now been re-excavated and moved. Dioxins had been released into the lakes as a result of the breakdown of the herbicide 2,4,5-T. This was banned in the early 1980s and initially dioxin concentrations fell rapidly. Over the same period, concentrations of heavy metals such as lead had decreased, probably due to industrial recession in areas upstream. However, dioxins are persistent i.e. they do not biodegrade quickly and there is increasing evidence that they are accumulating to toxic concentrations in some organisms and that they are becoming biomagnified i.e. increasingly concentrated along the food chain. The International Joint Commission has now shown that dioxins in the Great Lakes have been produced from a wide variety of sources (Table 2).

Table 2. Sources of dioxin in the Great Lakes

Source	%
Medical waste incineration	47.9
Municipal waste incineration	22.3
Iron ore sintering	8.4
Cement kilns burning hazardous waste	7.6
Secondary copper smelting	4.1
Coal combustion	2.6
Wood combustion	2.0
Other cement kilns	2.0
Other	3.1

Furthermore, some dioxins have been transported in the atmosphere from incinerators as far away as California and Florida. Local or even regional pollution control will therefore be ineffective against this long-range pollution.

It is now hoped that this finding will lead to an international agreement - similar to the Montreal Protocol which phased out CFCs - to phase out PCBs and dioxins. Lake Ontario, which receives industrial, agricultural and domestic pollution inflow from all of the upstream lakes, remains the most heavily polluted. Agricultural pollutants such as pesticides and phosphate fertilisers have again begun to increase.

The cost of cleaning up the Great Lakes has been estimated at \$33 billion. However, economists using cost-benefit analysis (CBA) techniques have estimated that the costs incurred and income lost because of the pollutants (lost tourist revenues, for example) far exceed this. In other words it would still make economic sense to try to reduce the pollution level of the Great Lakes.

Acknowledgements;

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