EUTROPHICATION of FRESHWATERS

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This review is one of a series of 'reviews of current knowledge (ROCKs) produced by FWR. They focus on topics related to water supply, wastewater disposal and water environments, which may be the subject of debate and inquiry. The objective of each review is to produce concise, independent scientific and technical information on the subject to facilitate a wider understanding of the issues involved and to promote informed opinion.

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Contents

1 Introduction

Aquatic eutrophication (from the Greek 'eutrophia', meaning 'well nourish') refers to the enrichment of natural waters with plant nutrients, which stimulates an array of symptomatic changes. These include the increased growth of algae and other aquatic plants affecting the quality of the water and disturbing the balance of organisms present within it. Such changes can destroy wildlife habitats and interfere with a range of water uses from recreation to the production of drinking water.

The concentration and availability of plant nutrients in a water body is determined by its catchment, which in turn is influenced by the geology. Thus waters vary in their nutrient status. Some waters are naturally eutrophic. However enrichment and accelerated consequential impacts can occur because of human activities, and it is this artificial eutrophication which warrants attention and is the subject of this review.

In the UK, eutrophication as a water quality issue has had a high profile since the late-1980s, when the widespread occurrence of blue-green algal blooms in standing and slow-flowing freshwaters gave rise to considerable interest and concern by the public, the media and within the water industry. From 1989 to 1997, algal blooms have affected some 3000 different freshwater bodies in England and Wales (Ref. 1). Eutrophication occurs in both non-saline waters (freshwater lakes, reservoirs and rivers) and in saline waters (seawater and tidal estuaries). In the UK freshwaters are currently of greatest concern. Hence this review is primarily concerned with freshwater eutrophication.

2 What causes eutrophication?

The growth of plants in aquatic systems is influenced by a number of factors including the supply of nutrients, light, temperature, water flow, turbidity, zooplankton grazing and toxic substances. The properties of the catchment and the water body and the impact of human activities affect these factors.

While it is important to understand the role of all these factors, it is widely accepted that the principal factor ultimately controlling the growth of algae and plants in natural waters is the supply of nutrients.

In temperate freshwater systems, phosphorus is generally the key limiting nutrient. It may occur as soluble inorganic compounds such as phosphate (PO_4^{2-}) or as soluble organic compounds such as proteins and lipids. Both the inorganic and organic compounds may bind to mineral surfaces such as clays, and therefore be transported with fine particulates in the water. Chemical and microbial processes in the soil, water and sediments can transform the phosphorus from one compound to another, and affect its availability as a nutrient. Hence concentrations of phosphorus are normally reported as the element P rather than say the concentration of the phosphate ion (PO_4^{2-}). However, phosphate, either dissolved or bound to particulate matter is normally the phosphorus compound directly responsible for the majority of eutrophication events in freshwaters.

There are exceptions. In some freshwaters silicon may limit blooms of diatoms in spring. In areas where phosphate levels are naturally high because of the underlying geology, water bodies may be limited by nitrate (NO_3^-), e.g. the meres of Shropshire and Cheshire. Estuaries may be limited by phosphorus at their freshwater extreme, grading through to nitrogen-limitation at their seaward end. However, the common occurrence of suspended sediments and consequential turbidity in estuaries often means that light limits algal growth. Where nutrients are the limiting factor in coastal waters, nitrogen as nitrate is generally believed to be the key nutrient.

Water bodies can be categorised in relation to the process of eutrophication. This is termed the trophic status and is typically based on the concentration of chlorophyll (the major photosynthetic component of algae and plants), the transparency of the water and the mean concentration of total phosphorus associated with such conditions. **For standing waters** the most common classification scheme is that proposed by the Organisation of Economic Co-operation and Development (OECD Ref. 2). This is presented in Table 1.

Trophic status	Total P	Chlorophyll a		Transparency Secchi disc depth	
µg =microgram	Mean µg /litre	Mean µg /litre	Maximum µg /litre	Mean metres	Minimum metres
Ultra-oligotrophic	< 4	< 1.0	< 2.5	> 12	> 6
Oligotrophic	< 10	< 2.5	< 8	> 6	> 3
Mesotrophic	10 - 35	2.5 - 8.0	8.25	6 – 3	3 – 1.5
Eutrophic	35 - 100	8.25	25 – 75	3 – 1.5	1.5 – 0.7
Hypertrophic	> 100	> 25	> 75	< 1.5	< 0.7

Table 1 OECD criteria for trophic status of lakes

The scheme has three main trophic classes: oligotrophic for nutrient poor waters, mesotrophic for waters slightly to moderately enriched with nutrients and eutrophic for waters excessively enriched with nutrients. There are also two boundary classes: ultra-oligotrophic for extreme nutrient deficiency and hypertrophic for extreme eutrophication.

For flowing waters classifying waters in terms of their trophic status using phosphorus concentrations remains questionable and methods are being developed based on surveys of visible plants (macrophytes). However, UK guidance relating to the European Community Urban Waste Water Treatment (UWWT) Directive (Ref. 3 and see later for details of relevant legislation) suggests that a river is excessively enriched if the mean concentration of **soluble phosphates** is greater than 100µg per litre as P.

3 What are the nutrient sources?

Nutrient sources are often broadly segregated into two categories: readily identifiable point sources such as sewage effluents, and diffuse sources such as the run-off from agricultural land, with the relative contribution of each varying between catchments.

Point sources include sewage treatment works effluents, industrial effluents and fish farms.

Diffuse sources include fertiliser, livestock manure and sludge applied to both arable land and pasture.

Raw domestic sewage in the UK typically contains between 5 and 20 mg/litre of phosphorus, about 40% of which is due to sodium tripolyphosphate, a component of many detergents. It is possible to reduce these concentrations to below 2 mg/litre of phosphorus using certain sewage treatment processes.

Inorganic fertilisers include superphosphate (about 9% P) and triple superphosphate (20% P). Sewage sludge may also be used as a fertiliser/conditioner and contains 1 - 2% of phosphorus on a dry solids basis. However about fifty times more animal waste than sewage sludge is applied to the land and this contains variable quantities of phosphorus according to source. Typical values are 0.5% and 1.8% in cow and poultry manure respectively. Certain industrial wastes may also be recycled to land. The combined total of sewage, industrial and agricultural waste applied to land in the UK has been estimated as 22 million tonnes dry solids per annum. However sewage sludge is a small proportion of the total. The relative proportions of these three types of waste are as follows (Ref. 14).

- Sewage Sludge 2%
- Industrial Waste 4%
- Agricultural Waste 94%

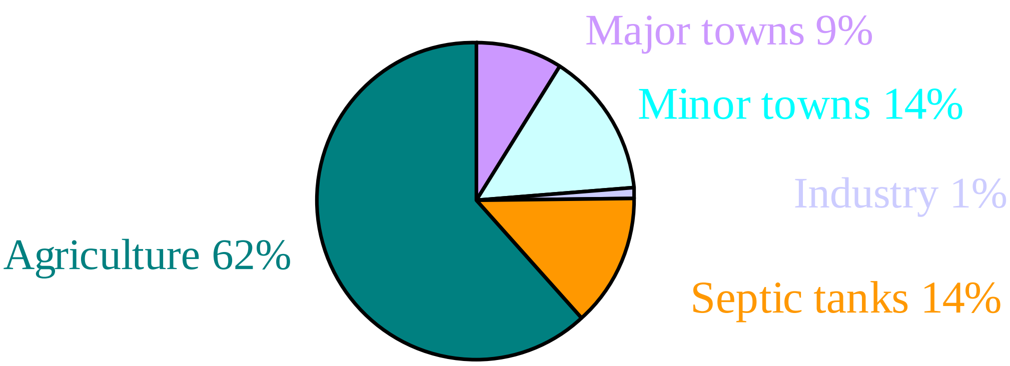
Contributions from all possible diffuse and point sources will change with time, both in the short-term, in response to land management and climatic variation, and in the longer-term in response to technological advances, national and international regulations and voluntary codes of practice. There are also differences between urban and rural areas: sewage effluents are more likely to be the major contributor of P to urban water bodies whereas agriculture is more likely to be the major contributor to rural waters. In general terms the percentage contributions of the main sources of phosphorus entering surface waters in the UK have been estimated (Ref. 4) as: -

Agricultural	43%
Human and household waste including detergents	43%
Industry	8%
Background sources	6%

The actual contributions in any given catchment will depend on the nature of the catchment and the human activities within it. A good example is Lough Neagh in Northern Ireland, which is the UK's largest lake, a multi-purpose resource and a major source of drinking water.

Lough Neagh is also one of the most eutrophic lakes in the world due to high phosphorus inputs. During the 1970's these inputs were quantified and ascribed to sources (Ref. 5). Phosphorus from sewage works was shown to account for almost half the amount entering the lake. To curtail this source, P reduction treatment was introduced by 1981 at the ten major sewage disposal works in the Lough Neagh catchment. This was the first time P reduction treatment had been employed in the UK and it led to a reduction in P loading and improved water quality in the lake. Lough Neagh and its tributaries have been sampled at least fortnightly since 1969. The unbroken record of nutrient inputs and water quality in the lake shows that in the early 1990's, the effects of sewage P reduction were overtaken by increasing diffuse P loads from agriculture as shown in Figure 1.

Figure 1 Sources of phosphorus in Lough Neagh



For nitrogen, inputs to fresh waters in Europe come principally from diffuse sources, particularly agriculture, although point sources (usually urban wastewater) also contribute significantly in many regions. In England and Wales 70% of the total input of nitrogen to inland surface waters is estimated to come from diffuse sources (agriculture, precipitation and urban run-off, in order of decreasing importance). The remaining 30% comes from sewage effluent and industrial discharges. As for P, the actual contributions in any given catchment will depend on the nature of the catchment and the human activities within it.

4 What are the trends in nutrient pollution of freshwaters?

For P, there is evidence of a reduction of loadings to surface waters from sewage treatment works (STWs) during the early 1990's. This is attributable mainly to the reduced use of phosphate in detergents as shown in Figure 2.

Furthermore, the Urban Waste Water Treatment Directive (Ref. 3) requires the UK (and other members of the EU) to identify areas sensitive to eutrophication (see section 6). Any sewage going to into these sensitive areas must be treated to very high standards to minimise P concentrations (nitrates for seas and estuaries). In England and Wales 119 water bodies have been designated as areas sensitive to eutrophication. This number includes rivers, lakes and estuaries. The designations are reviewed every four years.

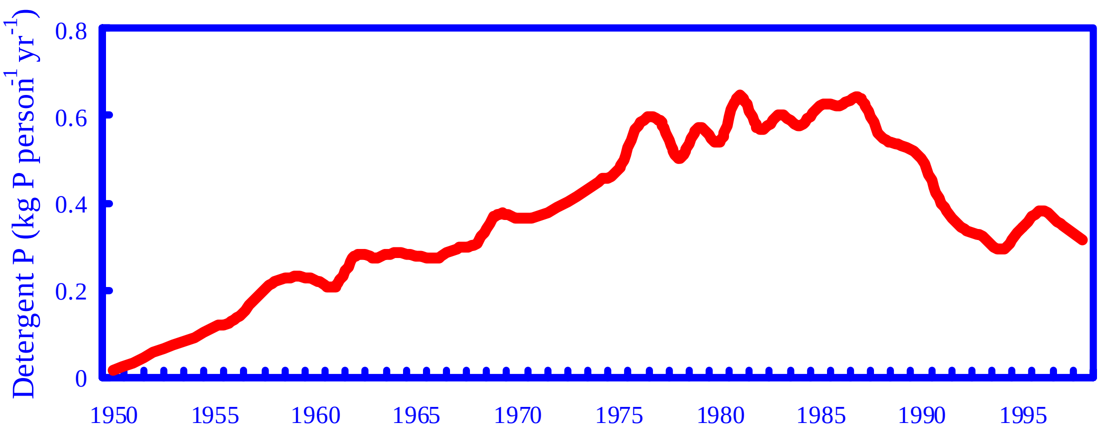


Figure 2 UK detergent P consumption 1950-1998

With regard to agriculturally derived phosphorus, UK usage of phosphorus fertilisers has fallen slightly in the 1990's, while livestock numbers increased slightly from 1970 to the early 1990's. However, the contribution to eutrophication of agricultural losses of P has become increasingly important, as shown in the case of Lough Neagh described above. Small losses in agronomic terms can have significant effects on aquatic ecosystems. Most UK farms, particularly those with livestock, operate with an annual import of phosphorus (as fertiliser and animal feed) exceeding that exported as produce. This is common agricultural practice in other European countries (Ref. 6) and generates a steady accumulation of excess phosphorus in soils. There is growing evidence that phosphorus is being transported to water from diffuse agricultural sources at rates which are increasing under modern farming methods (Ref. 7). Even where these phosphorus surpluses are eliminated, soils could contribute to elevated phosphorus concentrations in receiving waters for many years.

The net effect of these changes will vary from catchment to catchment. However, for rivers in England and Wales, there appears to have been no general improvement when judged by the criterion that a river with a high concentration of phosphate is one where the average value is greater than 0.1 mg/l as P. In 2005, 51% of rivers had such high concentrations compared with 50% in 1995.

Concentrations of nitrate in the rivers and lakes of England & Wales are high in common with other western European countries. Before the mid-1970's, nitrate concentrations had risen significantly since the 1930's in a number of catchments, reflecting changing agricultural practices. However, since the 1970's there have been no general changes in river nitrate levels, although there may be marked changes in specific catchments.

In 2005, 28% of rivers had high concentrations of nitrate (average values greater than 30 mg/l), compared with 32% in 2000 and 30% in 1995. Nitrate concentrations fluctuate from year to year and there is no clear overall trend.

5 What are the impacts of eutrophication?

Eutrophication can have both temporary and irreversible effects on aquatic ecosystems. Significant fluctuations in dissolved oxygen concentrations between day and night can occur in waters where there is increased plant or algal growth. This can cause problems in the early morning when plant respiration can cause low oxygen levels which may lead to the death of invertebrates and fish. This process can be compounded when algal blooms, through their decay, further reduce the oxygen content of water.

Certain algal species in fresh and marine waters, including blue-green algae (cyanobacteria), can produce toxins that may seriously affect the health of mammals (including humans), fish and birds. This occurs either through the food chain, or through contact with, or ingestion of, the algae. Algal species also cause fish deaths, for example by physically clogging or damaging gills, causing asphyxiation. The toxins produced by blue-green algae include neurotoxins that cause paralysis of the skeletal and respiratory muscles, and hepatotoxins that cause severe liver damage. Those water supply sources that are at risk from 'blooms' of blue-green algae are now regularly monitored and alternative supply strategies are adopted if at risk. Treatment processes are also available to provide added security (Ref. 8). However, humans and other mammals are still at risk if they consume fish from contaminated waters or consume affected raw water, especially where an obvious surface scum or film is evident. Further information about these toxins is available in another FWR ‘ROCK’ entitled *Cyanobacterial Toxins in the Water Environment* (Ref. 19).

Eutrophication can give rise to undesirable aesthetic impacts in the form of increased turbidity, discolouration, unpleasant odours, slimes, and foam formation. Eutrophication ultimately detracts from biodiversity, through the proliferation and dominance of nutrient-tolerant plants and algal species.

These tend to displace more sensitive species of higher conservation value, changing the structure of ecological communities.

Eutrophication can also adversely affect a wide variety of water uses such as water supply (e.g. algae clogging filters in treatment works, palatability affected by taste and odours compounds), livestock watering, irrigation, fisheries, navigation, water sports, angling and nature conservation.

Unfortunately it is not possible to determine national trends for the above ecological and use-related impacts. This is due to difficulties in determining the influence of factors such as the weather, and to a lack of long-term records. There are some notable exceptions where historic data are available for specific waters such as the Lake District and the Norfolk Broads.

Where eutrophication exists, a range of preventative or remedial measures may be used to control or remove excessive growths of algae or other aquatic plants. These include the corralling and removal of algal scums, destratification of lakes, weed-cutting and removal, barley straw application and biomanipulation techniques which alter the fish community. The effects of these measures are often temporary and reversible. Long-term solutions normally require the direct control of external nutrient sources. This is addressed in the next section.

6 What is being done about eutrophication?

Several long standing **EC Directives** contain legislation that affects the control of eutrophication.

The **EC Urban Waste Water Treatment (UWWT) Directive** (Ref. 3) sets minimum standards for the provision of sewage collection and treatment, and for effluent discharges, depending on the population equivalent (pe) served and the nature of the receiving water. A component of this Directive states that discharges of greater than 10,000 population equivalent to waters identified by Member States as sensitive to eutrophication, termed 'Sensitive Areas (Eutrophic)', must comply with specified standards for phosphorus and/or nitrogen (depending on the situation), in addition to a requirement for secondary sewage treatment. Sensitive areas may be fresh or saline waters which are eutrophic, or which may become so in the near future if protective action is not taken. The nutrient removal requirements are enforced by the environmental regulators through discharge consenting procedures.

The designation of sensitive areas is the responsibility of ministers with the advice of environmental regulators. Sensitive areas must be reviewed at least every four years, with a seven year lead-in time for bringing newly identified qualifying discharges to the required standard. A shortcoming of the Directive, as a general tool for eutrophication control, is the pe threshold of 10,000. Discharges from treatment works serving smaller populations are a significant source of phosphorus in some catchments.

The **EC Nitrate Directive** (Ref. 10) has an objective to "reduce water pollution by nitrates from agricultural sources, and to prevent further such pollution". A water body is identified as "polluted" if it shows signs of eutrophication (induced by excess nitrates), or if it is used for drinking water abstraction and has elevated concentrations of nitrate. The catchment for the water body is then designated a Nitrate Vulnerable Zone (NVZ), within which farmers must comply with mandatory restrictions aimed at reducing nitrate leaching. The Directive has obvious limitations when applied to eutrophication control as it only applies to waters which are eutrophic due to nitrate, primarily saline water situations.

The **Habitats Directive** (Ref. 12) enables the designation of Special Areas of Conservation (SACs), in which rare and endangered habitats and species must be protected. If eutrophication threatens the conservation status of SACs, there may be a need to impose nutrient control requirements on discharges, where appropriate. The environment regulators have a duty to review discharge consents to ensure that the designated sites are adequately protected. Sites designated as Special Protection Areas (SPAs) under the EC Wild Birds Directive (Ref. 13) will receive the same protection.

In England and Wales the Environment Agency developed a strategy for managing eutrophication in both freshwaters and coastal waters (Ref. 1). A similar approach was adopted by the Environment and Heritage Service in Northern Ireland (Ref. 9). A key element of both strategies was the need for a partnership approach to the management of eutrophication. This is because the control of nutrient inputs, particularly from diffuse sources, is generally beyond the remit of any one regulatory body.

These strategies have now been surpassed by the requirements of the **Water Framework Directive** (Ref. 11). This Directive provides a co-ordinated approach to sustainable water management through river-basin management plans containing programmes of measures to achieve **good ecological status**. The definition of good ecological status does not permit eutrophication problems. The measures will comprise those required by existing Directives (as above), supplemented by whatever additional measures are needed to control pollution sources, point or diffuse, to achieve the stated objective. The environmental regulators in the UK are the Environment Agency (England & Wales), the Scottish Environment Protection Agency and the Environment & Heritage Service Northern Ireland. They are responsible for the formulation of the programmes of measures by December 2009.

The identification and control of diffuse agricultural sources of nutrients present the greatest challenges. There are increasing pressures on the agricultural industry to develop more environmentally sustainable farming methods. In England and Wales this is being implemented through agri-environment schemes where grants are offered for farming in a more environmentally sympathetic manner.

Catchment sensitive farming is an initiative aimed at encouraging farmers to adopt voluntary measures to reduce nutrient losses. Methods are provided in Codes of Good Agricultural Practice (Ref. 15), free advisory visits or soil analysis (Ref. 16), and the dissemination of leaflets; for example, on erosion control (Ref. 17). The Code of Good Agricultural Practice (Ref. 15) recommends application rates of organic manures and P fertiliser based on soil analysis results. The advice is a long-term strategic measure to prevent the accumulation of surplus P in the soil and hence limit the transfer of P to water by erosion and leaching. The identification and adoption of effective voluntary approaches to controlling P losses from agriculture depends on good science and good communication. A review of this topic and examples of current approaches are provided in a recent publication (Ref. 18).

In the longer term the reform of the EU Common Agricultural Policy has the potential to bring about the adoption of more environmentally sustainable practices. It is evident that better management of the application of nutrients to agricultural land is required. The ultimate objective is the control of nutrient application to land, from both organic and inorganic fertilisers, such that the critical soil concentration is maintained in accord with soil and type of crop.

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