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omists in order to describe precisely the result of drainage operations. Without a greater appreciation of the findings, methods and techniques of these other disciplines and professions, there can be little precision in answering the question 'how does a specific form of drainage, applied at a specific point in time, in a specific place, on a certain soil type, affect a particular kind of plant or animal life?'

iii. To acquire and compare a greater range of base-line data, derived from the past and present, from a wide range of wetland systems in order to monitor future trends more rigorously. We need to demonstrate the considerable variety of conditions prevailing within each wetland area, and the bearing this variety has on such questions as 'are the effects of contemporary agricultural change unprecedented in that area?' and 'how far do the drainage techniques being applied in one area have a similar impact on wildlife to those in another?'

iv. To obtain more detailed knowledge of the autecology of the species affected by drainage and land use change, and, especially, of the ecological processes that can affect the rate and character of species displacement and colonization.

*5 Summary*

In order to assess the extent to which wildlife communities may be affected by land drainage, a greater knowledge is required of the chronology and extent of drainage in the past, changes in land use and management, and changes in wildlife. The methodology used by ITE in a study of grazing marsh vegetation is described. Priorities for research in monitoring and predicting trends include obtaining comparable knowledge of changes in birds, mammals and invertebrates, collaboration with agricultural scientists, collection of more base-line data from a wider range of habitats, and autecological studies of species liable to displacement or to become colonizers.

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# The effects of eutrophication on aquatic wildlife

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*1 Introduction*

This paper reviews the eutrophication process, and in particular the effect of so-called 'cultural' eutrophication on lakes. Appropriate case histories relevant to agriculture are presented, and current and potential research is reviewed in relation to ameliorating the worst ecological effects of excessive nutrient input.

Biological productivity in fresh waters throughout the world has been the focus of many recent research projects, especially those initiated during the International Biological Programme. Over the last 2 decades, there has been an increasing awareness of problems associated with excessive growth of algae and higher aquatic plants, particularly in lakes, and to a lesser extent in rivers and estuaries.

Normally, as lakes age they undergo change, and a natural process of maturation takes place. Precipitation and natural catchment drainage contribute nutrients which support and enhance the growth of algae and macrophytic vegetation. However, the activities of man in agriculture, urbanization, and the discharge of sewage and industrial wastes increase the amounts of organic and inorganic sediments and the nutrient input to lakes. In these ways, the natural processes of enrichment and sedimentation are accelerated, and the quality of the water changes materially, often at a relatively rapid rate.

There is no simple relationship between the process of eutrophication and the actual amounts of nutrients present or entering the waters concerned. Rawson

(1955) emphasized the complex interrelationships of climatic, physical, chemical and biological factors affecting the productivity of lakes. The basin morphology, catchment geology, temperature, nutrients and other variables all influence the trophic nature of a water body.

## 2 Eutrophication

### 2.1 Eutrophication process

The view that all lakes originate as oligotrophic systems, gradually become more eutrophic, and then fill in completely is actually too simplistic. Many lakes lose nutrients from the watershed as they increase in age, and change from eutrophic to oligotrophic systems. However, most lakes do gradually become richer; in particular, lakes in areas affected by man's activities may receive unnaturally large amounts of nutrients which increase lake productivity. The nutrients are mainly from agricultural fertilizers, industrial wastes and sewage effluents. Their impact on the lake is to make it change rapidly from oligotrophic to eutrophic, and this acceleration is sometimes referred to simply as eutrophication or often as cultural eutrophication. Detailed accounts of this process have been given by Hasler (1947), Beeton (1965), Sawyer (1966), and others. The nutrients specifically involved in the eutrophication process are nitrates and phosphates, which in nature are frequently present in small (and therefore limiting) amounts. Other less important nutrients include magnesium, potassium, sulphates, trace elements and organic growth factors (Vollenweider 1968).

One of the major effects of eutrophication is the excessive growth of algae. In waters used for domestic and industrial purposes, for example, the excessive growth may result in massive and expensive filtration problems. Algal blooms are frequently aesthetically unpleasant, resulting in slimy floating green masses of objectional odour. Many algae impart unpleasant tastes and odours to water, and some release toxic substances. Extensive growths of phytoplankton may also result in turbid waters through which light cannot penetrate and which have high oxygen demand. In many eutrophic waters, there are extensive growths of macrophytes which interfere with swimming, boating, fishing and other recreation. Macrophytes also play an important role in the eventual extinction of lake basins. Linked with these changes in the plant communities, there are changes in fauna. Usually the invertebrate community becomes much less diverse, although the species which remain may become very abundant. A significant change usually takes place in the composition of the fish fauna, with salmonid species being replaced by coarse fish. In extreme eutrophication, primary production is so high that subsequent decomposition of organic matter and respiration at night completely deoxygenate the water, and fish may be eliminated altogether.

With increasing land use and the significant movement of particulate and dissolved material from catchments to their water courses, numerous water bodies have undergone serious ecological deterioration over the last few decades. Considerable attention was given in the past to domestic and industrial sewage outflows, but many other land use activities such as agriculture, tourism and recreation also contribute significantly to a reduction of water quality in lakes and rivers. In particular, high rates of fertilization and increased stocking density of grazing animals have added significantly to the amounts of major nutrients (especially phosphorus and nitrogen) passing into fresh waters. Unfortunately, the diffuse character of these sources makes their study much more difficult than that of point sources (eg a domestic sewage outfall), especially as the chemical make-up of agricultural fertilizers may also change in time.

Nitrogen, which is much more abundant than phosphorus in most fresh waters, rarely limits primary production, whilst increased amounts of phosphorus can lead to excessive algal growth, depletion of oxygen, and subsequent fish deaths. Phosphorus is frequently designated as the most important limiting nutrient. One of the most important sources of phosphorus is domestic sewage, but significant amounts of phosphorus are also carried into fresh waters from agricultural land during heavy rainfall. Most nitrogen passing into watercourses appears to come from adjacent soils, and intensively fertilized farmland represents the main source of nitrogen to fresh waters draining from agricultural areas. Several studies have indicated that some 10-25% of nitrogen applied as fertilizers runs off into adjacent running waters. Apart from eutrophication problems, high levels of nitrate become a health hazard when they reach concentrations greater than 11 mg per litre.

Within the water bodies themselves, various biological indicators can be used to quantify the changes which take place during cultural eutrophication. In general, plant and animal communities become much less diverse, and many sensitive species are lost. In the phytoplankton, blue-green algae often become predominant, and form the basis of periodic massive blooms. Some species of macrophytes grow extremely well initially, though they may die back later. Zooplankton and zoobenthos communities always become much simpler with the loss of many sensitive species. A number of indices has been developed based on community structure and species diversity which indicate the direction of change. Studies of lake sediments can also provide extremely useful information on the trophic history of a lake.

### 2.2 Origin of nutrients

#### *2.2.1 Natural sources*

The main contribution of natural nutrients to surface waters is through the normal runoff from soil. Soluble chemicals in the soil are removed through erosion and solution and pass into adjacent watercourses. The ratios of nutrients coming from surface runoff compared to those from groundwater vary in each catchment according to local soils and geology. The levels of nutrients in runoff water depend likewise on the type of soil involved. Massey *et al.* (1950) found that the enrichment ratio (concentration in eroded material divided by concentration in soil) for phosphorus, nitrogen, organic matter and exchangeable potassium was always more than one. The enrichment ratio usually increases as erosion decreases. Loss of organic matter from the soil is considered a serious aspect of soil erosion and usually necessitates large amounts of artificial fertilizer to replace the loss.

Sylvester (1961) showed that, although relatively clean streams draining afforested ground contain low concentrations of nutrients (similar to the concentrations in a eutrophic lake), very small increases in soluble phosphate are all that are necessary to increase production significantly. The inputs of various nutrients from atmospheric precipitation have been studied less than most other sources. However, in some cases they can be an important additional source and should always be taken into account when preparing nutrient budgets. In some areas, contributions from dust or rainfall can be significant.

Many of the nutrients in standing waters are derived from sediments. This is especially true in shallow waters where sediments are more easily disturbed by wind action. Several studies have shown that significant fractions of nutrients from the sediments enter the water column under reducing conditions (Mortimer 1942).

*2.2.2 Artificial sources*

Most of the nutrients derived from artificial sources originate in agricultural drainage, industrial waste and domestic sewage. The importance of these sources varies in different catchments, and relevant data are available from numerous studies. Rohlich and Lea (1949) examined the sources of nutrients entering Lake Mendota. In one year, 7936 kg of soluble phosphorus entered the lake. The greatest single contributor was Six Mile Creek, which supplied about 40% of the nutrients although it made up only 20% of the flow. The total amount of inorganic nitrogen entering the lake was 111 000 kg, mostly in the form of nitrates. Allochthonous contributions of soluble phosphorus and inorganic nitrogen were thought to be low.

Engelbrecht and Morgan (1961) stated that the amount of phosphate varied according to the nature and amount of phosphates in the soil, mode of drainage, topography, intensity and distribution of rainfall, rates of infiltration and percolation, and other features. Sylvester (1961) found nitrates to be twice as high in sub-surface drainage and the ratio of nitrogen to phosphorus to be 2.5 times that in surface drainage water. The greatest concentrations of total phosphorus were found in surface irrigation drains, of soluble phosphorus and nitrogen in sub-surface drains, and of total nitrogen in urban street drains.

In characterizing the Chickamauga Reservoir in Tennessee, Stream Sanitation Staff (1964) noted that there were many local point sources of pollution. Fortunately, the relatively rapid flushing of such reservoirs prevented their rapid eutrophication. Ohle (1955) found that nutrients in north German lakes were derived mainly from the increased activities of man. Organic sewage and kitchen wastes were major contributors and brought about significant changes in Plon Lake from 1926-29. The rapid eutrophication of such lakes is distinguished from normal eutrophication by the enormous production of plankton, as well as the speed of enrichment. The contribution of nutrients from artificial sources was greater than that from natural drainage waters. Moreover, the increased flow of nutrients into oligotrophic lakes was felt by Ambuhl (1962) to be much more important than the input to eutrophic lakes (see Maitland 1981).

2.3 Case histories relevant to agriculture

Much of the important evidence concerning the eutrophication of fresh waters has come from a study of case histories, from which it has been possible to determine the onset and gradual eutrophication of many bodies of water. Insight may also be gained into the problems of eutrophication. However, extremely detailed and long-term studies are rare, even from some of the most important lakes in the world. Usually, though these lakes have been the subject of extensive research, it has not been directed to the study of eutrophication. Many of the case histories do not concern nutrients directly, but other indices used to interpret the changes taking place.

*2.3.1 North America*

Whiteside (1965) described the eutrophication of Potato Lake, Arizona, on the basis of palaeoecological evidence from sediment cores. The loss on ignition (equivalent to the organic matter) at different levels in the sediments was also studied. An interesting feature of the cores from this lake was the sudden variation in organic matter near the mud-water interface. Whiteside attributed this variation to recent changes brought about by man's activities within the catchment, especially agriculture and logging.

The Great Lakes of North America are among the largest bodies of fresh waters in the world. Following the collapse of a major fishery in 1925, Wright and Tidd (1933) investigated Lake Erie. After an analysis of its water chemistry, they concluded that pollution from human sources had increased plankton to such an extent that there had been a significant reduction of oxygen in the water. Beeton (1963) described changes in Lake Erie and in some of the other Great Lakes. He pointed out significant changes in the zoobenthos of Lake Erie after the summer of 1953, when oxygen depletion caused a massive mortality of mayfly larvae. The number of caddis fly larvae also decreased, but there were increases in midge larvae and worms. In subsequent surveys, Beeton (1965) verified that large areas of Lake Erie still had low oxygen values. He classified Lakes Huron, Michigan and Superior as oligotrophic, Lake Ontario as morphometrically oligotrophic or mesotrophic, and Lake Erie as eutrophic. All of the Great Lakes were considered to show progressive increases in various ions and total dissolved solids, with the exception of Lake Superior.

*2.3.2 Europe*

The Bodensee is one of the clearest examples of lake eutrophication. Kliffmuller (1962) showed that, in 1935, when the first recorded measurements were made, no measurable phosphate was present. In 1950, 2-3 mg/m$^3$ were found, and in 1954, 2-4 mg/m$^3$. By 1959, the amount of phosphate had increased to 7-9.5 mg/m$^3$. Based on the phosphate content only, the lake probably changed from oligotrophic to eutrophic between 1935 and 1962. Numann (1964) reported that, as a consequence of enrichment, the growth of whitefish had increased so much that they were being caught prior to maturity by gill nets, resulting in a decrease in the fishery. In addition to the accelerated growth, various other changes in the lake caused changes in the breeding areas of fish present, which meant that 4 previously isolated whitefish were able to inter-breed. Isolation mechanisms present before enrichment had been minimized.

Loch Leven in Scotland has shown numerous changes in its flora and fauna over the last century which have been attributed to eutrophication. Species associated with oligotrophic conditions such as charr and desmids have declined or disappeared, and prolonged algal blooms have been a feature of recent years. Much of the macrophytic vegetation has disappeared, and there have been major changes in the composition of zooplankton and zoobenthos. These changes have been associated with, and are probably due to, artificial enrichment of the lake by fertilizers draining from farm land and sewage from the townships of Kinross and Milnathort. Holden and Caines (1974) recorded large quantities of nitrate nitrogen carried into the loch, equivalent to 250 tonnes of nitrogen in 1969. The use of nitrogenous fertilizers in the catchment increased about 3 times from 1952-68.

*2.3.3 Australasia*

Lake Haruna in Japan is the site of one of the earliest studies of eutrophication in Asia. Yoshimura (1933) showed that there were gradual changes in the water transparency over a period of 24 years, decreasing from 9.5 m in 1906 to 2.3 m in 1932. Nutrients were assumed to have entered the lake from the areas of grassland in its catchment, and the decreasing values of transparency along with the more recent appearances of blue-green algae were regarded as a definite indication of enrichment.

As part of a review of the eutrophication of 3 lakes in New Zealand (Lake Okataina, Lake Ngapouri and Lake Okaro), Fish (1963) examined the performance (especially the growth rates) of trout. The fish in Lake Okataina grew significantly faster and seemed healthier in other ways than those in the other 2 lakes, both of which had higher primary production and lower dissolved oxygen levels than Lake Okataina, largely because of eutrophication. The main cause was believed to be the development of agriculture in the catchments of Lakes Ngapouri and Okaro, which resulted in poorer conditions for trout in the lakes.

2.4 Rehabilitation

The causes of the degradation of lake ecosystems by eutrophication are now fairly clear, and appear to be associated largely with the increased inflow of material from the catchment. Methods for rehabilitating such lakes have been reviewed by Bjork (1980) and include sediment removal, manipulation of bottom sediment, aeration of the hypolimnion, manipulation of biological components in the ecosystem, and, of course, the control of nutrient input. Though the treatment of industrial discharges varies considerably for each industry, standard methods are now available for the efficient treatment of domestic sewage. Over the last few years, there has been a considerable decrease in the discharge of organic matter and phosphorus.

*2.4.1 Sediment removal*

Lake Trummen in Sweden is one of the classical cases of lake restoration by sediment removal. The history of its development, degradation and restoration has been described by Bjork (1972), Andersson *et al.* (1975) and others. This shallow lake received sewage and industrial discharges for about 30 years, and changed rapidly from an oligotrophic to a eutrophic system. The extensive layers of rich sediment which were deposited during eutrophication were so great that, although the sewage was eventually diverted, the lake showed no recovery during the following decade. Because of this, the sediments which had accumulated during the period of sewage discharge were suction dredged during the summers of 1970 and 1971, and altogether about 300 000 m$^3$ of sediment was pumped out. Following this action, the concentration of nutrients decreased considerably and the oxygen conditions improved. Blooms of blue-green algae disappeared and transparency increased in summer. The sediment which was removed has been used to improve the nutrient-poor soils of the area, and the lake is now used for sport fishing and swimming.

*2.4.2 Sediment manipulation*

Because of the difficulties in some districts of finding suitable areas on which to deposit lake sediment, the manipulation of sediments *in situ* was considered desirable. The first feasibility trial was carried out on Lake Lillesjon (Ripl 1978) into which sewage had been discharged for many years. When sewage was finally diverted in 1971, the lake was in a very poor state with total oxygen deficiency and luxuriant growth of duckweed, sometimes covering most of the water surface. The upper layers of sediment were black and extremely rich in phosphorus.

The method involves oxidizing the top sediment layer by adding nitrate and precipitating the phosphorus by adding an iron salt. Because of the rapid denitrification, the nitrogen leaves the ecosystem as a gas. In Lake Lillesjon, iron chloride was added resulting in a decrease of pH to 3. Under these conditions, hydrogen sulphide evolved, but 2 weeks after the first treatment the transparency increased from 2.3 m to more than 4.2 m. The water of the lake is fully oxygenated all the year round, and the superficial layers of sediment now act as a trap for phosphorus. Phytoplankton crops are not extensive, and the lake is used for swimming and sport fishing.

*2.4.3 Hypolimnion aeration*

The use of compressed air has been developed by Hasler (1957) and others to increase the circulation in lakes. The objective was to prevent the deoxygenation of the hypolimnion during summer, and the killing of fish during winter. Ambuhl (1962) experimented with the artificial mixing of water in Lake Pfaffiker in Switzerland. Compressed air was pumped into the centre of the lake for extensive periods. Both the total heat content of the lake and the amount of oxygen increased.

*2.4.4 Biological manipulation*

Apart from chemical treatment such as the use of copper sulphate to reduce algal blooms, other attempts have been made to manipulate the biology of eutrophic systems. The regular removal of large amounts of macrophytes by cutting and dredging has been attempted in some lakes, but is generally considered to be an expensive process. In other lakes, the removal of large numbers of fish has been considered as a way of depleting the total nutrients. However, although probably effective in very nutrient-poor arctic systems, it has been relatively unsuccessful in eutrophic waters.

*2.4.5 Nutrient reduction*

In many lakes, phosphorus appears to be the main factor limiting primary production. The addition of phosphorus is often mainly via the discharge of sewage effluents, and if these can be diverted around the lake then significant improvements can be expected. The eutrophication of Lake Washington from 1933-55 has been described by Edmondson (1966). Typically, blue-green algae started to dominate the phytoplankton and oxygen deficits occurred in the hypolimnion. Eventually, plans were developed to divert all of the sewage from the city of Seattle from Lake Washington to Puget Sound. Following this diversion, there was a rapid parallel drop in the levels of phosphorus and phytoplankton, while nitrate dropped less rapidly. This reversal of eutrophication is regarded as being one of the classical examples of artificial oligotrophication.

*3 Current research*

Current research on eutrophication has changed considerably over the last few years. Much less effort is now directed towards describing the eutrophication process, and rather more to the ways of diverting it or reducing its harmful effects. The zoning of land use is of major importance, if natural aquatic systems are to be protected from the worst effects of eutrophication. Good farming practices are being developed which provide benefits not only for the farmer, but also for other inhabitants of the catchment. Proper planning of sewage schemes in urban areas can help to alleviate the overloading of sewage systems. Methods for the prevention of eutrophication of drinking water reservoirs have been developed. These include the exclusion of animals and man from reservoir catchments, the development of adequate sewage systems where exclusion is impracticable, strip cropping and contour farming.

The intensive research on biological production and eutrophication which was carried out during the International Biological Programme has been replaced by a new series of projects under the aegis of the UNESCO Man and the Biosphere (MAB) programme. Many of the research activities in this programme relate to land use impacts on inland waters, and there is active participation in this field by Austria, Bulgaria, Czechoslovakia, Federal Republic of Germany, German Democratic Republic, The Netherlands, Poland, Spain, Sweden, Switzerland, and the United States of America. There are no MAB research projects in the United Kingdom or special MAB funding within this particular field.

However, recent work in the UK parallels that being carried out elsewhere in Europe. It includes the typology, trophic state and hydrobiological regime of important lakes, and the results provide a basis for recommendations to the Government about future exploitation and management. Rivers are being classified in terms of water quality in relation to their biology, and attention has been given to improving the position of biological methods of analysis. The possibility of managing lakes by controlling their nutrient cycling is also being investigated. The main aim here is to find out just how the nutrient loading of these systems can be reduced in order to control algal growth under given nutrient loadings. Much of this type of research involves monitoring the release of nutrients from watersheds and following their impact as loads on the aquatic biota.

*4 Future research*

The literature concerning eutrophication shows that systematic measurements of variables over a reasonable time period are rare. It is often difficult to prove that changes have actually taken place in the lake. Unless background data on nutrients, transparency, algae, production, zooplankton, zoobenthos and sediments are available, then statements concerning the eutrophication of a water body may be doubtful. It is important, therefore, that, as well as new, stimulating projects in this field, a reasonable amount of effort should be devoted to systematic surveys of important waters, to establish base-line data and obtain information from which trends can be noted.

The variables to be measured and the frequency of recording are often difficult to identify where resources are limited. Temperature, oxygen and transparency are certainly valuable parameters to record. To be of maximum value, such studies should extend over several years because of the influence of climate. Modern techniques of remote sensing are being developed rapidly at the moment, but their value in surveillance programmes is not yet clear.

Basing their conclusions on the results of recent symposia, Duncan and Rzoska (1980) have specified a minimum monitoring programme for quantifying the effects of land use in a watershed on its waters. The prerequisites for such a programme are as follows.

i. An inter-calibration centre for ensuring compatibility of results by testing analytical methods.

ii. A workshop on methods of raw data analysis for purposes of comparison. This should establish a common terminology and computational procedures for deriving quantities such as nutrient loadings from raw monitoring data.

iii. Criteria for the selection of research catchments should include area, representativeness of regional characteristics and land use. Land use should be defined in some detail and intensity of usage should be quantified.

iv. A detailed description of the main characteristics of the watershed and its main water bodies: regional relief and geology; soils; available water resources; natural soil drainage and erosion hazard; hydrographical network, including permanent/temporary discharge; natural terrestrial vegetation and its level of biological productivity; characteristics of the major rivers and lakes, including their trophic status and previous lake history from sediment core analysis.

It is also noted that the following considerations relate to the parameters to be monitored.

i. Frequency of measurement will depend on the main growing season, timing of hydrological events and nature of measurement, but both a time sequence throughout the year and mean annual or seasonal quantities are required.

ii. Ideally, parameters should be measured in absolute concentrations of weight per unit volume.

iii. Overall watershed parameters required for possible correlation with quantities measured within the watershed include the levels and seasonal patterns of precipitation and evaporation, discharge and inputs of airborne materials. Local measurements should include precipitation, surface and sub-surface runoff and percolation to the groundwater, together with their chemical content.

iv. Water quality parameters of watercourses and recipient water bodies should include nitrogen, phosphorus and carbon; other elements, eg calcium, magnesium, etc; biocytes; suspended matter; physico-chemical parameters (eg dissolved oxygen, pH, conductivity and temperature); and biological parameters. The latter could include a wide variety of measurements, including BOD, chlorophyll, phytoplankton, zooplankton and zoobenthos, and fish.

v. Collation, presentation, interpretation and publication of results.

vi. Development of a model of the land use impact on lakes and reservoirs in the watershed.

In addition to the above recommendations, the following specific studies have been suggested for MAB projects on the mechanisms of land use impacts on inland waters. These include, first, whole watershed studies of different types.

i. Long-term monitoring of small watersheds subjected to various levels of fertilization.

ii. Long-term monitoring of water bodies in small watersheds before and after changed land use. The measurements should include all the recipient waters in the catchment.

iii. Long-term development of models encompassing the whole watershed and its terrestrial and aquatic components and including the submodels, the hydrodynamic, physico-chemical and biological aspects.

Second, there are a number of particular topics.

iv. Detoxification processes in aquatic sediments and the role of bacteria.

v. Transfer mechanisms of the elements and fertilizers and pollutants from soil to underground water, and consequent biological changes.

vi. Inputs of airborne material into watersheds.

vii. The role of littoral macrophytes as biological filters for nutrients.

viii. The contamination of groundwater and its biological consequences.

Several projects encompassing some of the above topics are already in progress in the United Kingdom and elsewhere. However, there is still considerable scope for progress in many areas, particularly in quantifying the transfer of nutrients from one part of the system to another. The present controversy over the effects of acid precipitation on freshwater ecosystems in Great Britain has effectively demonstrated our ignorance about many of the processes that take place between materials landing on the soil and their transfer to neighbouring watercourses.

## *5 Discussion*

Fernald (1980) has emphasized that proper land use planning is the key to the mitigation of negative impacts on water quality. Land use planners and other public decision-makers often do not understand the data available from the scientific community. At the operational level, the public decision-maker must play a major role in the control of eutrophication and many other harmful processes affecting our environment. Fernald assumes that the land use decision-making process is a sequence of rational steps which can be applied at any level of planning. The elements in his process include formulation of land use objectives; the identification of future land use needs; the gathering and analysis of the upland data; the evaluation of land use laws, policies and regulations; the identification and evaluation of policy influences; the evaluation of land use change methodology; and implementation of land use decisions.

Although, as outlined above, there are still a number of relevant areas for current and future research concerning the effects of eutrophication on aquatic wildlife, sufficient is already known about the impact of eutrophication to mean that the control of the problem lies mainly in the hands of planners and decision-makers, rather than with the scientific community. Excessive quantities of nutrients from various sources lead to a destabilizing of natural aquatic systems, with consequent loss of sensitive species, and massive increases of tolerant ones. Periodic massive deaths of algae and macrophytes lead to de-oxygenation and fish kills. In theory, the remedies are often simple; in practice, they may be rarely carried out. Until sensible long-term planning of land use overtakes the short-term gains of various forms of land mis-management, eutrophication will continue to be a problem.

## *6 Summary*


6.1 Eutrophication is a natural process whereby freshwater ecosystems age and enrich with time. Most lakes are eventually doomed to extinction.

6.2 The process is accelerated because of cultural eutrophication, in which several of man's activities (notably agriculture, industry and urbanization) add significantly to the load of nutrients and other materials entering lakes and rivers. The phenomenon is world-wide.

6.3 The most obvious effects of such eutrophication are the production of unstable plant and animal communities in fresh waters, with periodic massive algal blooms and fish kills. Contamination of water supplies and objectionable odours are usually associated with such changes.

6.4 The subject has been extensively researched and control measures are now feasible in many situations. Point sources of eutrophication are easier to deal with than diffuse ones. In addition, many rehabilitation methods have now been developed to reverse the process.

6.5 The major controls now lie in the hands of land use planners and politicians. Nonetheless, we are still ignorant about many of the processes that take place between materials landing on the soil and their transfer to neighbouring watercourses.


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# The effects of flood alleviation and land drainage on birds of wet grasslands

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## *1 The habitat*

This paper largely concerns lowland neutral grasslands below 600 ft (183 m) which are subject to freshwater flooding or waterlogging. It therefore includes flood plain grasslands, washlands, coastal grazing marshes, and more open areas of flood plain mire which grade into base-rich marshes and fens with beds of common reed in the absence of grazing (Ratcliffe 1977). It excludes salt marshes and the uplands. Embanked washlands (or ings) are a feature of the low-lying regions of eastern England. They tend to be flooded more frequently in winter than most other flood plain grasslands and, because of their flood relief function, water is allowed to lie on the fields for longer in the spring. The traditional use of washland in summer is grazing by cattle, though in more accessible areas a hay crop is taken first (Thomas *et al.* 1981).

## *2 Loss of habitat*

Until the mid-17th century, there were about 3380 km$^2$ of wetland in the fens of Cambridgeshire (including Huntingdonshire) and adjacent Lincolnshire and Norfolk; 98% was drained before 1939, and a further 4000 ha during or just after the Second World War. Only 1% now remains as a fragmented relict and much of this area is in a drier state than formerly. Of the 6094 ha of washland, 49% is now arable (Thomas *et al.* 1981). Even in Cambridgeshire, little over 4000 ha of damp or wet grassland still exist, and 62% is represented by the Ouse Washes (1860 ha) and Nene Washes (604 ha); most of the other 30 damp grassland sites are less than 50 ha in size.

The Survey of Breeding Waders of Wet Meadows, carried out in 1982 by the British Trust for Ornithology (BTO), the Royal Society for the Protection of Birds (RSPB) and the Nature Conservancy Council (NCC), covered a substantial proportion of the damp grassland sites in England and Wales and showed how restricted the habitat had become (Smith 1983a). In many counties, there is little land left to drain except by refinements to existing drainage. Few extensive areas remain. The largest is the Somerset Moors (c.12 000 ha) but, since 1958, a series of pump drainage schemes has reduced the frequency, duration and depth of winter flooding over much of the area.

The RSPB's survey of reed beds in 1979 and 1980 located only 109 in excess of 2 ha in England and Wales; 70% were less than 20 ha, and half of the total area of reed (2169 ha) was restricted to 15 sites. Over one third of the reed beds were largely dry and the majority showed signs of degeneration as a result of a lowering of the water table. With an abandonment of reed cutting and grazing, hydroseral development is no longer arrested and carr had developed at 70 sites (Bibby & Lunn 1982).