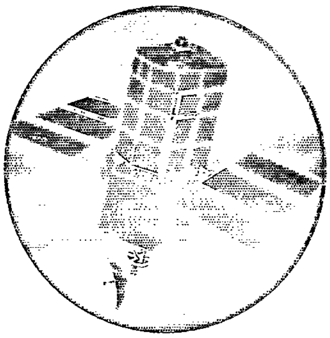
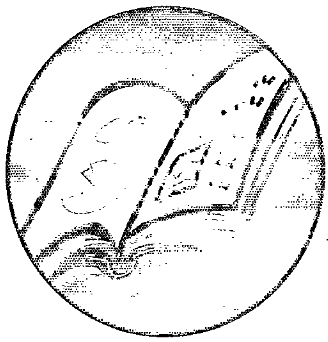
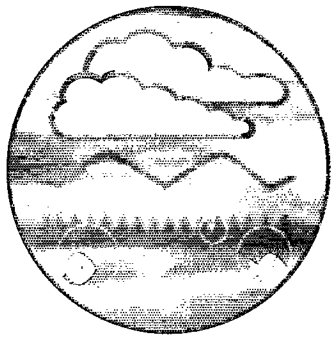
Determining the Causes of "Apparent Eutrophication" Effects







Research and Development

Technical Report
P203

ENVIRONMENT AGENCY

Determining the Causes of "Apparent Eutrophication" Effects

Technical Report P203

J Hilton and G P Irons

Research Contractor:
Institute of Freshwater Ecology

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Statement of use

This report is intended for use by Environment Agency staff involved in the management of "apparent eutrophication" in inland freshwaters. It provides a systematic approach to identifying potential sources of nutrients, and/or other processes, which can trigger observable effects of eutrophication in situations which can normally absorb current nutrient loads. The recommendations are being considered for implementation by the Agency.

Research contractor

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1. EXECUTIVE SUMMARY

When the symptoms of eutrophication are observed in a river the common assumption is that excess nutrients from sewage treatment works upstream are the cause and that the appropriate response is to remove phosphorus from the effluent. However there are many other causes which can result in the changes to aquatic systems which resemble the effects of eutrophication. The possibility that one of these effects is a cause needs to be considered, and discounted, at an early stage, before proceeding to consider P control from point or diffuse sources.

In this document the factors which control plant growth have been listed. On the basis of these factors and following wide consultation amongst agency staff, a list of potential causes of eutrophic effects has been derived. A simple checklist scheme is proposed to assess the likelihood that any of these alternative causes may be driving the observed effects. Since, at this stage, the effects have not been confirmed as eutrophication, i.e. excessive growth of aquatic plants due to the presence of excess nutrients introduced from anthropogenic sources, the stage has been termed "Apparent Eutrophication".

It is recommended that the ease of use and completeness of the list of potential causes of effects be assessed regularly.

2. INTRODUCTION

When the symptoms of eutrophication are observed in a river system, the simplest management response is to identify sewage treatment works in the contributing catchment and insist that the local water company reduces the phosphorus in the effluent. Since this is a very expensive exercise it can be particularly embarrassing for the Agency if such an action does not result in the desired changes to the river system. In order to reduce the likelihood of this occurring, a systematic approach is required to identify a) additional potential sources of nutrients, and/or b) other processes, which can trigger observable effects of eutrophication in situations which can normally absorb current nutrient loads. This check will need to be carried out at a very early stage in the assessment of the problem. Because, at this stage of the investigation, eutrophication has not been formally identified as the cause of problems, the effects can be termed "Apparent Eutrophication". The IFE has been commissioned to review the factors, particularly physical ones, which could contribute to "apparent eutrophication" and devise an approach to assist in identifying its cause(s) at a given site.

3. APPROACH

IFE staff (Prof J Hilton and Dr G P Irons) met with Mr P Buckland, the Environment Agency project manager, on 1 December 1997 at IFE, East Stoke, to discuss the overall development of the project. Dr M Everard (Environment Agency), the original project instigator, was contacted to ascertain his interpretation of the problem.

Three workshops were held to elicit input from a wide range of Environment Agency staff from a number of the regions (Appendix 1) The meetings were held at different venues: 17 December 1997 IFE East Stoke; 3 March 1998 at IFE, Windermere and 3 April 1998 at Environment Agency, Blandford Forum. A total of 20 individuals from 7 regions of the Environment Agency + HQ were involved in the consultation exercise. The meetings, generally, took the form of a presentation of current thinking on aspects of project development, followed by workshop discussions to elicit Environment Agency staff responses. Ms S McNally, an economist with ITE, attended the last workshop, which concentrated, on controlling diffuse sources and the economics thereof.

4. WHAT IS "APPARENT EUTROPHICATION"

A general definition of "apparent eutrophication" could be:

"The occurrence of observable effects of eutrophication in a stretch of river with no identified cause."

The term "eutrophication" was originally defined qualitatively for lakes. Work by Vollenweider and others has established a reasonably objective, quantitative, biologically based definition for lakes, where an excess of planktonic algae is usually the observed effect. However, in rivers it remains poorly defined because of a) the wider range of effects which are attributed to eutrophication and b) the lack of good models which link P concentrations in waters or sediments with planktonic or macrophyte growth rates/biomass. In rivers it is usually interpreted to mean one or more of the following:

a. excessive growth of planktonic (suspended) algae.

b. excessive growth of benthic and filamentous algae

c. excessive growth of aquatic macrophytes. Used as a definition particularly by flood defence engineers.

d. reductions in the number of species of macrophytes present.

e. a move from macrophyte to benthic, filamentous or planktonic algal dominance.

Hence, apparent eutrophication must be the observation of one or more of these biological effects in a situation that has not been investigated sufficiently thoroughly for their cause(s) to be accurately identified.

In order to help in following through a procedure more efficiently, operationally, the occurrence of apparent eutrophication can be considered to split into three types:

a. effects which continue after a management programme, usually P reduction, has been carried out.

b. long term observation of the effects of (apparent) eutrophication.

c. recent occurrence of the effects of (apparent) eutrophication.

This approach will then be used to highlight, in the first case, the effectiveness of the P removal processes, the philosophy underlying the target setting and the assumption that P was the limiting nutrient; in the second case, the potential sources of P in the catchment and thirdly temporal changes in the catchment or river which could trigger the effects of eutrophication.

5. FACTORS WHICH CONTROL THE GROWTH OF PLANTS

Eutrophication exhibits itself as changes from the expected norm in the relative dominance of macrophytes, planktonic algae, and benthic algae, ie:

a. in oligotrophic systems: an increase, from a low base level, of benthic/epilithic algae changing to macrophyte dominance.

b. in shallow mesotrophic/eutrophic systems: a change from macrophytes to heavy benthic or filamentous algae.

c. in deep slow flowing systems: from macrophytes to planktonic algae.

d. in very productive systems, as reduced diversity in macrophyte communities.

Hence, in considering the causes of eutrophication only those factors which control aquatic plant growth (either algal or macrophyte) need to be considered:

1. changes in the amount of light reaching the plant's surfaces.

2. changes in the amount of nutrients from point industrial sources or diffuse agricultural (arable or livestock) sources.

3. changes in the amount of nutrients from sources, other than point industrial sources or diffuse agricultural (arable or livestock) sources.

4. changes in the flow rate which change dilution rates of nutrients.

5. changes in retention time which will tend to flush out planktonic algae.

6. changes in water velocity which will change plant species by selectively pulling out rootstocks, etc.

7. changes in the amount of innoculum available at the start of the growing season.

8. changes in the concentration of toxic substances which affect plants either directly, eg herbicides, or indirectly by removing species further up the food chain.

9. changes in substrate after management, particularly dredging and resectioning resulting in no suitable habitat for macrophytes.

An additional factor which affects macrophytes detrimentally is mechanical abrasion.

These factors can be translated into a number of potential causes of eutrophication which are listed in Table 1.

Table 1. Possible Causes of "Apparent Eutrophication"

Names and affiliations in brackets after some descriptions refer to known examples of this effect.

Factor	Cause of Change	Short Description
Nutrients	Local geology	Natural phosphate rich rocks can dominate, eg Shropshire Meres.
	Septic tanks	Although septic tanks do reduce the P output by allowing P to sorb to soils, long term use can saturate the soil with P and hydraulic overload can allow overland flow. The effect will vary with distance from the watercourse. A technique is available to identify these but needs specialist assistance (Bassenthwaite, L May, IFE)
	Excessive wild bird populations	Excreta from large water bird populations (roosts) can cause localised problems and can contribute a significant proportion of the P load to a small lake. Data exist in the literature concerning P output from different birds. (Chew Valley, J Hilton, IFE)
	Fish farming	Although the excreta from large numbers of fish can be a problem the main effect is through the presence of excess food on the bed. This is a particular problem in cage systems in small lakes. (Esthwaite water, G Hall, IFE)
	Groundwater inputs	Theoretical source. No examples known
	Heavy ground baiting due to angling pressure.	Areas which are used regularly, particularly for match fishing, can receive large amounts of bait which has a significant P content. (R&D Note 470, p.32)
	Storm sewer overflows	Intermittent discharges dependant on the capacity of the sewers to contain the effects of rainfall
	Run-off from old road systems	New road systems have some form of soak-away treatment of run-off. Old roads do not
	Seasonal discharges from industry	Industries, such as food canning can have very high nutrient discharges during the season but no discharge outside this period. Sampling programmes outside the season will miss the contribution to p load. (R Ant, G Phillips, EA, Anglian)

Factor	Cause of Change	Short Description
	Poor control of separate sewer connections.	There are reports of many new housing estates having separate fouls and surface water drainage systems. Often contractors are not monitored closely enough to check that connections are made to the foul system. (Anglian EA)
	Water transfers	(Including canal overflows) can increase P load in the receiving river
Internal recycling of nutrients	Sediment release	If sediments have a high organic content they will become anaerobic. This will increase the dissolved P in the interstitial water and if the sediment is resuspended into the water column, than a proportion of this, and other sorbed phosphorus, will be released into the water column. Resuspension can be caused by wind, particularly in canals (and shallow lakes), storm flow, but often washed out very quickly, boat traffic – but uptake may be limited by light (see below) (Chew Valley, J Hilton, IFE)
	Bioturbation	The term given to disturbance of the sediment by animals, eg carp or bream (bottom feeding fish) or macroinvertebrates (more important in estuaries and US where the invertebrates are much larger).
	Dredging	Removes plant roots/tubers and recycles nutrients from the sediment.
Light	Tree removal/planting	River sections running through closed canopy tree cover are generally devoid of aquatic plants, including algae as a result of shading. Addition or removal of trees on the banks will change the light climate and affect the observation of eutrophic effects. (F H Dawson, IFE)
	Weed cutting	Excessive weed cutting can tip the production into algal dominance. (Somerset levels, encouraged filamentous algae. A Hicklin, South West)
	Resuspension of sediments by storms or boats	Sediment in suspension increases turbidity and reduces light penetration which will limit macrophyte and algal growth. (The Broads, G Phillips, EA, Anglian)
	Heavy growth of epiphitic algae on submerged leaves of macrophytes	High nutrient concentrations can result in heavy algal growths on plants. These growths reduce the light reaching the macrophyte leaves and reduce macrophyte productivity, often leading to population decline. (The Broads, G Phillips, EA, Anglian)

Factor	Cause of Change	Short Description
Flow rate	Abstraction	Abstraction can reduce the flow rate/ pattern. This can have a multiple effect of increasing nutrient concentrations because of the reduced dilution and increasing retention times allowing planktonic algae more time to utilise resources and increase biomass
	Drought	Will reduce dilution, increase retention times and increase siltation, which can result in benthic algal blooms. Effects may only last for a year or two and then recover. (Upland rivers, R F Prigg, North West)
	Impoundment	Increase in retention time allowing planktonic algae time to increase their biomass
	Flow regulation	Causing intermittent, reduced or constant flows
Innoculum	Swans eating spring growth	Large swan populations can reduce early spring biomass of submerged plants to almost nothing which seriously reduces the plants' ability to grow later in the season
	Livestock poaching on banks	Unfenced banks allow cattle to obtain access to the river where they trample and uproot macrophytes. In some circumstances livestock can also contribute a significant amount of P load through excreta on the banks, which is washed into the river during heavy rainfall events
	Upstream lakes	With high planktonic algal populations can cause problems downstream due to high innoculum, which can utilise any nutrients
	Canal discharges	See upstream lakes
	Water transfers	See upstream lakes
Toxic substances	Herbicide pollution	Acute pollution will kill macrophytes allowing benthic algae to gain dominance. Chronic pollution can reduce growth rates so that when reductions in toxic substance occur, eutrophication appears to increase

Factor	Cause of Change	Short Description
	Insecticide pollution	a. killing herbivorous aquatic macro-invertebrates allowing plants to grow unchecked. (R Derwent, epilithic algal bloom following sheep dip spill. R.F Prigg, North West) b. killing carnivorous aquatic macro-invertebrates, allowing herbivores to increase unchecked and reduce the macrophyte biomass allowing algae to dominate. (R Seiont, large chladophora increase; R J Hemsworth, Welsh)
Habitat loss		a. Resulting from dredging b. Changes in substrate type c. Settlement of fines d. Reduced flow resulting from abstraction or re-sectioning (over-widening)
Mechanical effects	Boat damage	Repeated over-running with propellers will macerate macrophytes and stunt growth allowing planktonic and benthic algae to gain dominance
	High flows	Can differentially affecting growth by pulling out the roots of plants with a high resistance to flow, allowing less resistant species to gain dominance
	Swan damage	See swans above
	Livestock damage	See livestock poaching above
	Wind blown concentration	The production from a large surface area can be concentrated into a small area by the wind, making the small area appear very eutrophic (duck weed behind sluice gates, A Hicklin, South West)

This list is fairly extensive. However, it is derived from a knowledge of the underlying physiology of plant growth and, although many causes have specific examples known to the authors, some are only suggested by theory and the authors know of no actual examples, to date. As time progresses the list will, no doubt, increase in size as other causes are identified at specific sites.

6. A SIMPLE SCHEME TO AID IN THE MOVE FROM "APPARENT EUTROPHICATION" TO IDENTIFYING CAUSE

Given the list of possible causes from table 1, a potential scheme for identifying the source of the eutrophication is given below;

Section 1 – General Questions

1.1 Have the symptoms continued after control of some P sources in the catchment?

- Y Go to section 2, Ineffective Management Plan
- N Continue

1.2 Have the symptoms existed in their present form for several years?

- Y Go to 1.3.
- N They have appeared in the recent past. Probably a recent change in load, flow, light or toxicity. Go to section 4.

1.3 Is the problem replacement of macrophytes by algal dominance?

- Y Go to question 1.4.
- N Probably a result of excess phosphate inputs. Go to section 3.

1.4 Is the water very salty due to saline intrusion?

- Y Poor, habitat for macrophytes resulting in algal dominance. P reduction is unlikely to have a major effect.
- N Continue.

1.5 Is the water very acid or polluted as a result of mine water drainage?

- Y Poor habitat for macrophytes resulting in algal dominance. P reduction is unlikely to have a major effect.
- N Continue.

1.6 Has the channel been over widened in the past?

- Y Poor habitat for macrophytes. Resection channel to deepen.
- N Go to section 3.

Section 2 – Ineffective Management Plan

2.1 Has the in-river phosphorus concentration reduced to below the target level?

Y Check the basis of setting the target and reassess (return to 2.1).

N Continue.

2.2 Is the removal process working consistently?

Y Go to 2.3.

N Contact discharger to solve the problem.

2.3 Is the problem particularly visible for a short distance downstream of the recently controlled P sources and at low flows?

Y Sediments may contain high concentrations of available P, which will take some time to reduce. Get the assistance of an expert (Dr W A House, IFE) to assess the problem. If P loaded sediments are the problem, it will resolve itself given a few years.

N There was an incorrect assumption made in the original assessment. Revisit the calculations to identify extra sources needing reductions to meet the target. Go to section 3 - P sources.

Section 3 – Alternative P Sources

3.1 Does the local geology include phosphate-bearing rocks (eg. Shropshire Meres)?

Y System is naturally eutrophic. P controls are likely to be ineffective.

N Continue.

3.2 Do the identified point sources contribute most of the P in the river?

Y P removal from selected point sources may be a sensible option.

N Try to identify other sources. Continue.

3.3 Do diffuse sources and identified point sources contribute the majority of P in the river?

Y A proportional decrease in both sources may be appropriate.

N Try to identify other sources. Continue.

3.4 Is there a sudden decrease in phosphate concentration in the river at a point upstream?

Y Probably an unsuspected point source. Look particularly for storm sewers and/or run- off from old roads and/or farms.

N Continue.

3.5 Are there any seasonal industries in the catchment?

Y Go to question 3.6.

N Continue to question 3.7.

3.6 Did the sampling regime for the estimates in 3.2 and/or 3.3 above realistically account for their contribution?

Y Continue to question 3.7.

N Try to obtain a better assessment of the seasonal inputs and return to question 3.2, above.

3.7 Are there a large number of unsewered houses in the catchment?

Y You may have a significant contribution from septic tanks, go to question 3.8.

N Continue to question 3.10.

3.8 Have you included the likely maximum P contribution of septic tanks in your assessment of the sources contribution to the P load at 3.3 above?

Y Continue to question 3.10.

N Estimate the maximum contribution using an average per capita P discharge rate.

3.9 Is the maximum septic tank P contribution a significant proportion of the total load in the river?

Y Reduce your load estimate by a proportion to allow for losses during passage through the soil and return to question 3.3 above.

N Continue.

3.10 Are there any separate sewer systems in the catchment?

Y Go to question 3.11.

N Continue to question 3.13.

3.11 Have you monitored the discharges through some storm periods to check for significant numbers of misconnections of foul drains to storm water sewers?

Y Go to question 3.12.

N Organise a monitoring programme and return to question 3.11.

3.12 Is the storm water drain P load significant compared with other sources in questions 3.2 and 3.3?

Y Contact developer to trace and correct misconnections.

N Continue

3.13 Are there any fish farms upstream, particularly cage systems?

Y Go to question 3.14

N Go to question 3.15

3.14 Is the fish farm P load significant compared with other sources in question 3.2 and 3.3?

Y Incorporate the fish farm P load into your management options.

N Continue

3.15 Are there any large populations of water birds on any stretch of the river?

Y Go to question 3.16

N Go to question 3.17

3.16 Is the P load from water bird droppings significant compared with other sources in question 3.2 and 3.3?

Y Incorporate the water bird P load into your management options.

N Continue

3.17 Probably results from internal phosphorus sources - call in a specialist (Dr W A House, IFE) but consider the other possible causes of observed effects of eutrophication.

Section 4 – Recent Appearance of Effects of Eutrophication

4.1 Are there any known point source increases in the catchment?

Y Go to section 3, question 2.

N Continue

4.2 Have there been any recent, major changes in land use in the catchment?

Y Go to section 3, question 3.

N Continue

4.3 Has abstraction increased in the upstream catchment over the period of interest?

Y Go to question 4.4.

N Go to question 4.5.

4.4 Has the reduction in dilution been sufficient to raise P concentrations significantly?

Y Consider a combined P reduction/flow increase management plan.

N Continue.

4.5 Has there been a drought covering the period of interest?

Y Go to question 4.6.

N Go to question 4.7.

4.6 Is the reduction in dilution sufficient to raise P concentrations significantly?

Y An early warning of potential problems in the future. Check to see recovery in following non-drought years.

N Continue.

4.7 Is the eutrophication problem due to increased phytoplankton levels?

Y Go to question 4.8.

N Go to question 4.11.

4.8 Has a new impoundment structure been introduced over the period of change.

Y Go to question 4.9.

N Go to question 4.10.

4.9 Has the retention time increased significantly (total changed by a few days) above the places where the effects of eutrophication are observed?

Y Need to either reduce the retention time by several days (potential reduction by factor of 2 for each 2-day reduction in retention time) or reduce P.

N Go to question 4.10

4.10 Has the flow rate changed due to either drought or abstraction?

Y If you have reconsidered the retention time in the light of flow rate changes go to 4.11 other wise go to question 4.9.

N Continue

4.11 Is the problem a reduction in macrophyte growth?

Y Go to question 4.12.

N Go to question 4.13.

4.12 Has the turbidity in the river increased significantly recently due to, say, increased boat traffic or increased soil erosion?

Y Turbidity may be shading out light.

N Continue.

4.13 Has there been a herbicide discharge upstream?

Y Identify the cause and make sure the discharge has ceased.

N Continue

4.14 Has there been an insecticide (sheep dip?) discharge upstream?

Y Can selectively kill carnivorous macro-invertebrates which allow herbivores to increase and strip macrophytes. Confirm absence of carnivores. Identify the cause and make sure discharge has ceased.

N Continue.

4.15 Are there a significant number of swans feeding in the area?

Y Swans may be cropping of macrophytes before they can establish.

N Continue.

4.16 Are cattle poaching along the banks?

Y Cattle may be controlling macrophyte growth by feeding on/trampling. Fence off the banks.

N Continue.

4.17 Is the problem too many macrophytes?

Y Go to question 4.18.

N Go to section 3.

4.18 Have trees on the bank been felled/pruned recently?

Y The plants may have been light limited due to shading which has been removed. Either replace the trees or introduce P management.

N Continue.

4.19. Has there been an insecticide (sheep dip?) discharge upstream?

Y Can selectively kill herbivores allowing macrophytes to grow to excess. Confirm absence of herbivores. Identify the cause and make sure discharge has ceased.

N Continue.

4.20 Have the banks recently been fenced?

Y Cattle may have been poaching the river and feeding on/trampling aquatic macrophytes, controlling their growth.

N Continue.

4.21 Are there trees growing on the bank where the effects are showing themselves.

Y The trees may be shading the macrophytes whereas before hand the canopy cover was insufficient to cause light limitation. Try pruning back the trees a little.

N Go to section 3.

7. CONCLUSIONS AND RECOMMENDATIONS

1. A simple question and answer scheme has been developed to try and make sure that a wide range of possible causes of eutrophication are considered at an early stage in the consideration of remedial management.

2. The authors acknowledge that the basis of the key is a combination of basic theory and practical experience. As such it will continue to develop and we recommend the creation of an official route both to add previously unrecognised causes and to modify the present text.

3. The authors recommend that the question and answer scheme is either:

   a. pilot tested in a few areas before redesigning and approving for general use; or

   b. the scheme is approved for general use but a questionnaire reply form is included which is filled in by users and returned to a central office.

The questionnaire should include questions on the ease of use, the efficiency and effectiveness of a) rapidly disposing of a large number of options which are not relevant in the given situation and b) reliably identifying the most likely causes of eutrophication which will require management. The responses should be assessed on a regular basis (5 yearly?) and the scheme amended accordingly.

4. The authors have identified a simple method which, for the majority of cases, could rapidly identify catchments where point sources dominate and those where diffuse sources dominate. We recommend that this method is tested with a view to incorporating it into the diagnostic key.

Appendix 1

List of Attendees at the IFE/Environment Agency Workshops

Date and Location	Name	Region	Comment
17 December 1997 IFE, East Stoke	D Harvey	Southern	Low attendance- snow.
3 March 1998	J McEvoy	Thames	
IFE, Windermere	J R Haines	Thames	
	S Brierley	Anglian	
	J Pitt	Anglian	
	R J Hemsworth	Welsh	
	H Millband	Welsh	
	A Hicklin	South-West	
	P Mitchell	South-West	
	P Bryson	South-West	
	D C McIlroy	Midlands	
	D Foster	HQ	
	R F Prigg	North-West	
	P Wittred	North-West	
	S Jones	North-West	
	I Dunhill	North-West	
3 April 1998	R Huggins	South-West	
Environment Agency,	P Bison	South-West	
Blandford Forum	R Robinson	South-West	
	P Mandeville	Southern	
	S McNally	ITE	

P Buckland (EA); J Hilton (IFE) and G P Irons (IFE) in attendance at all three.