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CEEP
Centre Européen d'Etudes des Polyphosphates

cefic

Regulatory

Europe

European Commission maintains pressure for sewage treatment implementation

The EU Commission is maintaining the active pressure on Member States to implement European legislation on water quality and sewage treatment*. 9 Member States have received final written warnings for failure to correctly transpose into national legislation the Water Framework Directive 2000/60 and 7 for failing to meet a December 2000 deadline for installing proper sewage treatment in cities and towns with more than 15,000 equivalent inhabitants (Urban Wastewater Treatment Directive 91/271): France, Greece, Ireland, Italy, Portugal, Spain, the United Kingdom.

** this to date concerns only the pre-2004 EU15 Member States, as the ten new Members have delays as follows for implementation of the EU Waste Water Treatment Directive: Cyprus 2012, Czech Republic 2010, Estonia 2010, Hungary 2015, Latvia 2015, Lithuania 2009, Malta 2007, Poland 2015, Slovakia 2015, Slovenia 2015*

This follows **actions already engaged in 2003 against 6 Member States for failure to implement the wastewater treatment Directive 91/271** (see Scope Newsletter n°52) and the EU Commission's third implementation report addressing this Directive in 2004 (Scope Newsletter n°55). This implementation report showed that nutrient removal was only in place (at 1.1.2002) for 42% of sewage from agglomerations discharging into "sensitive areas" (the Directive deadline for implementation was December 1998).

At the same time, the NGO European Environment Bureau (*www.eeb.org*) has published a survey showing that **European environment associations give their governments a negative rating on water management**, and inciting NGOs to launch complaints in national courts and to the European Commission regarding bad water management practice.

The European Court has also produced a judgement on one of the previous actions brought by the European Commission, **condemning France for inadequate designation of eutrophication "Sensitive Areas".**

Inadequate waste water treatment

The European Commission published a press release (IP/05/30 dated 12-1-2005) indicating that final written warning (termed a "Reasoned Opinion") has been sent to **the UK concerning inadequate sewage treatment** (absence or insufficient of secondary = biological treatment) for 14 agglomerations. These are, in Northern Ireland : Bangor, Carrickfergus, Coleraine, Londonderry, Larne, Newtownabbey, Omagh, Portrush and Donaghdee; in England: Broadstair, Brighton, Bideford/Northam ; in Scotland: Lerwick. This sewage treatment should have been in place by end 2000.

At the same time, **the UK Government has admitted that some 30-40 million tonnes of untreated sewage are discharged to the Thames** tidal river downstream of London every year (34 million tonnes in 11 months in 2004, 41 million tonnes in 2003). House of Commons "*Written Answers*" 15/12/2004.

Italy has been referred to the European Court of Justice by the EU Commission for the **lack of wastewater treatment for an agglomeration in the Varese province**, resulting in significant pollution of the Olona river which contributes to nutrient input to the eutrophication-sensitive Adriatic Sea (press release IP/05/56, dated 18-1-2005).

Ireland has received final written warnings concerning inadequate sewage treatment for the towns of Bray, Shanganagh, Howth, Letterkenny, Slido and Tramore (secondary treatment: deadline was end 2000), as well as concerning the prevention of malodours from municipal waste water treatment plants. The EU Commission has also sent a final warning to Ireland asking the State to comply with the March 2004 European Court judgement concerning the Nitrates Directive 1991/676 (failure to designate nitrate "Vulnerable Zones", failure to establish a nitrate action plan), emphasising that

Member States can face substantial fines if they do not comply with European Court Judgements.

Portugal has received final written warnings concerning failure to install "tertiary" treatment (nutrient removal) in waste water plants serving 18 different agglomerations discharging into eutrophication "Sensitive Areas" (press release IP/05/45, dated 14-1-2005). Nutrient removal at sewage works discharging into such areas should have been in place by end 1998.

Final written warnings have also been sent to France, Greece and Spain concerning inadequate secondary sewage treatment in cities and towns over more than 15,000 population equivalent.

Vanishing sewage

Greece has also been condemned by the European Court of Justice for **failing to collect and treat sewage from the large agglomeration of Thriasio Pedio in Attica**, currently discharged into the "sensitive area" of the Gulf of Elefsina. Greece claimed that the sewage was collected by road tanker. Because the agglomeration, with some 80,000 population equivalent, produces 3,000 tonnes of sewage per day, the Court concluded that this was not logistically credible (European Court of Justice case number C-119/02)

Defining eutrophication "sensitive areas"

Following an EU Commission complaint that **France has inadequately designated eutrophication "sensitive areas",** the European Court judged on 23 September 2004 that France should indeed tighten its designations. The Court based its judgement on the definition of eutrophication given in the text of the EU Wastewater Treatment Directive 1991/271:

> *"eutrophication means the enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance of the balance of organisms present in the water and to the quality of the water concerned"*

The Directive specifies that sewage shall be collected and treated, with nutrient removal (phosphorus and/or nitrogen removal), for all villages or groups of villages with a population equivalent of 10,000 or above (generally approx. 6,000 persons population, when discharges from restaurants, offices, small factories etc. are also taken into account), wherever discharge is into a eutrophication "sensitive area". Such areas are specified as being :

> *"natural freshwater lakes, other freshwater bodies, estuaries and coastal waters which are found to be eutrophic or which in the near future may become eutrophic if protective action is not taken."*

The Directive also specifies that "appropriate" sewage treatment shall be ensured for villages with lower population equivalents.

The Court's judgement interprets the definition of eutrophication as meaning **an accelerated growth of algae or plants leading to any undesirable effects (not only ecosystem unbalance or deterioration, but also any other nuisance** such as water colour, taste, tourism, fishing, drinking water or cooling water extraction, or). The Court further considered that the presence of algal blooms is sufficient to designate a water body as "eutrophication sensitive", even without proof of a causal link between nutrient inputs and these blooms.

The Court consequently ruled that **a number of specific water bodies had been wrongly considered as not "Sensitive Areas" by the French State**, and should be designated (the Andelle, the Artois-Picardy coast, Brittany Coast - Vilaine Bay, Lorient, Elorn Estuary, Douarnenez Bay, Concarneau Bay, Gulf of Morbihan, Vistre river, Thau coastal lagoon) and consequently that tertiary treatment (nutrient removal) should be installed in sewage works serving some 98 cities discharging into these (including Montpellier).

UK House of Commons "Written Answers"
www.publications.parliament.uk

EU Commission press releases
http://europa.eu.int/comm/press_room/index.htm

EU Commission waste water legislation implementation http://europa.eu.int/comm/environment/water/water-urbanwaste/index_en.html

European Environment Bureau (EEB) / WWF report, press release "Survey shows gaps in EU water directive implementation", and call for NGOs to lodge complaints on non-implementation with the EU Commission http://www.eeb.org/press/pr_water_protection_at_stake_survey_100305.htm

European Court Judgement EU Commission vs. Greece, judgement of 24 June 2004, refs. C-119/02 at http://www.curia.eu.int

European Court Judgement EU Commission vs. France, judgement of 23 September 2004, refs. C-208/02 at http://www.curia.eu.int

Northern Ireland

Proposal to limit agricultural phosphorus inputs

The Northern Ireland Executive has proposed that the whole province be designated a "Nitrate Vulnerable Zone" under the EU Nitrates Directive 1991/676 and an "Action Programme" to address nitrate pollution, and also to address agricultural phosphorus emissions. This follows European Court of Justice decisions condemning the UK for inadequate designation of Nitrate Vulnerable Zones (case C-69/99, 1999) and France for not taking into account nitrates contribution to freshwater eutrophication (case C-258/00, 2002, see Scope Newsletter n° 46).

The European Court's judgement of 2002 underlined that hat in all waters "**nitrogen is a nutrient of prime importance in fostering eutrophication and must be controlled as preventive measure**" and that nitrogen must be taken into account and managed, as well as phosphorus. The Court therefore judged that France must classify as "Nitrate Vulnerable Zones".

The Action Programme proposed for Northern Ireland (published for consultation), by addressing both agricultural nitrates and agricultural phosphorus over the whole territory, will initiate action towards achieving the "Good Ecological Status" which all surface waters must achieve by 2015 under the terms of the EU Water Framework Directive 2000/60.

Agricultural phosphorus surplus

The Executive's consultation paper estimates as 15 kilos/hectare/year the surplus of phosphorus inputs over crop needs (outputs), and proposes to set a surplus ceiling of 10 kg/ha/year in 2010 moving down to 6 kg/ha/year in 2012.

The inclusion of curbs on agricultural phosphorus as well as nitrogen in an action programme addressing the Nitrates Directive (Nitrate Vulnerable Zones) goes beyond the Directive's explicit requirements, but corresponds clearly to scientific logic (**the fact that both agricultural nitrates and phosphorus are contributing to surface water eutrophication in these areas**). It will set a clear precedent for introducing agricultural phosphorus limits or controls in Nitrate Vulnerable Zones both in the rest of the United Kingdom and in other EU Member States.

Northern Ireland Executive Nitrates Directive "Action Programme" consultation paper, February 2005: http://www.doeni.gov.uk/foi/search/details.asp?docid=2571

Report on the environmental aspects of the nitrates Directive in Northern Ireland: http://www.ehsni.gov.uk/pubs/publications/DARDDOE23OCT02.pdf

European Court decision concerning inadequate implementation of EU Nitrates Directive by the UK (inadequate designation of Nitrate Vulnerable Zones), 1999 case C-69/99 http://curia.eu.int

European Court decision concerning inadequate implementation of EU Nitrates Directive by France (necessity to take account of agricultural phosphorus), 2002, case C258/00 http://curia.eu.int

European Commission Nitrates Directive 91/676 page http://europa.eu.int/comm/environment/water/water-nitrates/index_en.html

Nutrients and ecosystems

Water Framework Directive
Defining and implementing Good Ecological Quality

A wide range of projects are underway, both at the national level, and in many cases at the trans-national or EU level, looking at criteria for implementation of the EU Water Framework Directive (WFD)'s requirements to bring surface waters across Europe to "Good Ecological Status" by 2015 (apart from "heavily modified" water bodies which can be exceptionally excluded from this requirement, but whose ecological condition must nonetheless be improved). Ecological Status is not defined in the Directive by "fixed" parameters, but as a situation where the ecosystem is not significantly detrimentally modified from natural conditions. For this reason, considerable work is necessary to develop models, benchmarks and guidelines for defining this ecological quality locally (at the catchment level), whilst ensuring coherence in requirements across Europe.

For nutrients, "Good Ecological Status" is defined as such that:

> *"Nutrient concentrations do not exceed the levels established so as to ensure the functioning of the ecosystem and the achievement of the values specified above for the biological quality elements".*

That is:

> *"There are slight changes in the composition and abundance of planktonic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of algae resulting in undesirable disturbance to the balance of organisms present in the water body or to the physico-chemical quality of the water or sediment. A slight increase in the frequency and intensity of the type specific planktonic blooms may occur."*

The European Commission has put together documents presenting research or demonstration projects underway which contribute to Water Framework Directive implementation and funded either by the EU's Research budget (5th and 6th Framework RTD Programmes), document dated 2002, or the Environment budget (LIFE), document dated 2004. These documents are not publicly accessible, but can be available if you sign up to and are admitted to the European Commission's "CIRCA" system http://forum.europa.eu.int/Public/irc/env/Home/main?index

An **EU working group on common implementation** of the Water Framework Directive and monitoring methodologies, ECOSTAT, has produced documents including:

> "Common Implementation Strategy, Guidance Document n°13: Overall Approach to the Classification of Ecological Status and Ecological Potential", 2005 http://www.eeb.org/activities/water/Guidance-No13-Classification-of-Ecological-Status-WGA.pdf)

and

> "Conceptual Framework for eutrophication assessment in the context of European water policies." (draft, 2004) http://cwss.www.de/workshops/wfd-ref/Eut%20SG%20guidance%20%20v3.0%2027%20Aug%2004.doc

The former summarises the general Water Framework Directive approach to Ecological Status, the second provides an overview of the approach to eutrophication in different existing EU Directives, including the WFD, confirming that under the WFD: "High nutrient concentrations without any corresponding biological impacts will not result in down grading Ecological Status. Thus assessments of eutrophication consistent with the WFD must focus on the biological effects resulting from elevated nutrient levels."

Defining WFD "Ecological Status"

A central area for benchmarking research is that of identifying or defining **criteria for classifying the Ecological Quality of waters**. The principal EU funded projects are:

ECOFRAME – Ecological Quality and functioning of shallow lakes - http://www.limnol.lu.se/limnologen/publikationer/31.pdf

AQEM – development of an assessment system for Ecological Quality of streams and rivers, based on benthic macro-invertebrates www.aqem.de

PAEQANN – development of models to predict the structure and diversity of diatoms, micro-invertebrates and fish (using "artificial neural networks") http://aquaeco.ups-tlse.fr/

STAR – Standardisation of River Classifications – framework method for calibrating biological survey results against ecological quality classifications http://www.eu-star.at/

FAME – Fish-based Assessment Method for ecological status of European rivers http://fame.boku.ac.at/

REFCOND - Identification of reference conditions, and boundaries between high, good and moderate status http://www-nrciws.slu.se/REFCOND/index.html

RIVPACS - approach to river bioassessment - http://www.dorset.ceh.ac.uk/River_Ecology/River_Communities/Rivpacs_2003/rivpacs_europe.htm

Modelling

The following projects address integration of different water quality models at the catchment level (see also the CATCHMOD cluster of projects at http://www.harmonit.org/links/catchmod.htm):

- modelling tools for integrated basin management "HarmoniCA" www.harmoni-ca.info

- integrating different thematic models (open modelling interface) "HarmonIT" www.harmonit.org

- generic water management modelling methodology "HarmoniQua" http://harmoniqua.wau.nl/

- benchmarking of integrated models "BMW" http://www.environment.fi/default.asp?node=11687&lan=en

- tools for assessing uncertainty in data used for river basin management "HarmoniRib" www.harmonirib.com

- tools to gauge local functional status within freshwater ecosystems "Target" http://www.oieau.fr/5pcrd/projets/TARGET.htm

- US soil and water assessment tool (publicly available model) SWAT http://www.brc.tamus.edu/swat/index.html

- US EPA model linking water quality and aquatic life – AQUATOX http://www.epa.gov/ost/models/aquatox/

Implementing WFD nutrient requirements

A number of projects specifically address nutrient management within the context of the Water Framework Directive and the definition and identification of nutrient Quality compatible with Good Ecological Quality:

REBECCA - Relationships between ecological and chemical status of surface waters http://www.ymparisto.fi/?contentid=65545&lan=EN

DANUBS - Nutrient management in the Danube basin and its impact on the Black Sea http://danubs.tuwien.ac.at/ See summary of conclusions of this project in Scope Newsletter n°58 at www.ceep-phospahtes.org

STREAMES – addresses how human nutrient inputs affect nutrient cycling http://www.streames.org/

EUROHARP – Towards harmonised procedures for quantification of nutrient losses at the catchment scale http://euroharp.org/index.htm

INCA - Integrated Nitrogen Model for European Catchments http://www.rdg.ac.uk/INCA/

NICOLAS – Nitrogen control by landscape structure in agricultural environments - http://www.qest.demon.co.uk/nicolas/nicolas.htm

BUFFER - key nutrient transport mechanisms for the prediction of nutrient and phytoplankton concentrations http://www.buffers.info/

SWIFT – Screening methods for water data information for the Water Framework Directive - www.swift-wfd.com (mainly concerns toxicity and "priority substances")

ECOFRAME

This project aimed to develop a practicable, pan-European typology and classification system for shallow lakes, as a support tool for defining the Ecological Status (high, medium, low) of lakes for different lake ecotypes, in a cost-effective way. The method was developed by 12 partner research institutes across Europe, through a combination of expert workshops and field analyses at more than 100 shallow lakes, initially starting from the large data sets accumulated by the Denmark National Environment Research Institute (NERI www.dmu.dk).

Lakes are classified into 48 ecotypes depending on simple variables: climate (temperature), lake size (10.000 ha considered as a threshold for wind mixing effects), catchment soil/rock type, conductivity.

Ecological status is then classified using 28 easily measured variables. Variables were chosen to not require high levels of specialist expertise (eg. taxonomic classification expertise) and to require a minimum number of site visits to establish data (in some cases, only one visit is necessary):

- pH
- total phosphorus
- total nitrogen
- Secchi depth (transparency)
- phytoplankton chlorophyll$_{a}$
- phytoplankton community, limited to the distinctions: multi-species community/monospecies, presence or not of surface blue-green blooms
- plant and phytobenthos communities: six readily recognisable community categories, presence/absence of invasive species, plant diversity, plant abundance
- zooplankton ratios - two simple ratios: large/small zooplankton, crustacean zooplanktons/phytoplankton
- macro-invertebtrates: three simple variables regarding communities in emergent plants and soft sediments
- fish community: objectives and criteria to be specified locally
- fish biomass
- fish: piscivorous fish/zooplanktivorous fish ratio
- water flow and residence time
- connection to groundwater
- lake depth profile: variation in depth over the lake area
- quantity, structure, substrate of lake bed
- structure of lake shore
- water temperature
- oxygen
- salinity
- pollution by WFD priority substances
- pollution by other substances

The published paper: http://www.limnol.lu.se/limnologen/publikationer/31.pdf provides details of each of these data definitions, data sets for the 66 shallow lakes on which the scheme was tested, and tables indicating how to derive the Ecological Status classification from collected data for each of the 48 lake ecotypes. A second paper (K. Irvine, 2004) emphasises the need for monitoring to take into account natural variability.

REBECCA

The EU-funded *REBECCA* project, launched 2003, aims to examine the links between chemical conditions in surface waters and their Ecological Status, to provide a basis for water management decisions. A paper published December 2004 provides a first report on "*Existing methods and relationships linking pressures, chemistry and biology in rivers*" (available for download only via inscription at the EU's CIRCA website, see below).

Regarding nutrients, this assessment is based on around 230 literature articles, selected from 1,115 initially identified, in which data are given relating in rivers nutrient enrichment to biological elements (phytoplankton, periphyton, macrophytes, macro-invertebrates, fish). The analysis shows that although much information is available, further understanding is needed on the role of river bed sediments, water plants and phytobenthos, and on the relative roles of phosphorus and nitrogen.

The report looks at the difficulties in identifying and quantifying the impacts of nutrients on macrophytes and on phytoplankton, given the combined impacts of other factors such as light, temperature, flow rate, and the related wide seasonal variability in response to nutrient enrichments. A table summarises relationships found between algal development (chlorophyll$_a$) and silicate, ammonia, nitrate, total nitrogen, soluble phosphorus, total phosphorus, N/P ratio. A large amount of qualitative knowledge exists, but quantitative information is more variable. Few available papers consider nutrients in sediments, whereas macrophytes can uptake nutrients from this source. Little work has been done on phytoplankton communities (assemblages).

In all cases, the effects of nutrient enrichment depend on the initial nutrient concentrations in the water.

The general assumption that phosphorus is the limiting nutrient in freshwater "*has to be reconsidered due to the number of cases where nitrogen has been found limiting*".

The authors also conclude that distinguishing between inorganic nutrients and organic pollution is fundamental in determining management actions necessary to achieve Good Ecological Status, as well as further studies on river ecosystem recovery following reductions in nutrient inputs.

"The determination of ecological status in shallow lakes – a tested system (ECOFRAME) for implementation of the European Water Framework Directive", Aquatic Conservation: Marine and Freshwater Ecosystems, 13: pages 507-459, 2003 www.interscience-wiley.com *DOI: 10.1002/aqc.592 Available for public download at:* http://www.limnol.lu.se/limnologen/publikationer/31.pdf

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"Classifying ecological status under the European Water Framework Directive: the need for monitoring to account for natural variability", Aquatic Conservation: Marine and Freshwater Ecosystems, 14, pages 107-112, 2004 www.interscience-wiley.com *DOI: 10.1002/aqc.622 Available for public download at:* http://www.limnol.lu.se/limnologen/publikationer/31.pdf

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EU Commission summaries of relevant EU-funded projects, available only via registration at: http://forum.europa.eu.int/Public/irc/env/Home/main?index

** DG Research funded projects, document dated April 19th 2002: "DG RTD I/3 "Sustainable management and quality of water. Potential contribution of past and on-going EU-funded research projects for supporting the activities of the Working Groups and Expert Advisory Fora instituted in the framework of the implementation strategy of the Water Framework Directive"*

** DE Environment funded projects, document dated January 20th 2004: "The Contribution of LIFE Projects to the Implementation of Water Policy in the EU" (version 1.0)*

EU Commission "implementation of the Water Framework Directive" pages: http://europa.eu.int/comm/environment/water/water-framework/implementation.html *and Guidance documents:* http://europa.eu.int/comm/environment/water/water-framework/guidance_documents.html

Many documents are only available via inscription at the European Commission's "CIRCA" system http://forum.europa.eu.int/Public/irc/env/Home/main?index

Morphoedaphic index

Estimating "natural" phosphorus concentrations for lakes

A key issue for water body management is to estimate natural or "background" levels of nutrients, as actions on loadings can aim to bring water concentrations down to this level but cannot be expected to achieve reductions beyond that. This paper, for 53 reasonably unpolluted lakes, compares the morphoedaphic index (MEI = mean alkalinity/mean depth or mean conductivity/mean depth) with mean water total phosphorus concentrations. The 53 lakes were selected as having "negligible phosphorus load due to human activities" and such that data for mean depth, conductivity, alkalinity and total phosphors concentrations were available in literature.

Previous authors have shown that ratios between lake mean depth and alkalinity, conductivity and or total suspended solids (TDS) can be used to estimate lake potential fish yields (Rawson 1951, 1952, 1955, Northcote and Larkin 1956, Ryder 1961, 1974). Oglesby (1977) further showed that MEI (conductivity/depth) was correlated to the standing phytoplankton crop.

This paper aims to take this relationship one step further, and to **establish whether a relationship can be established between MEI and (total) phosphorus concentrations in unpolluted lakes, which could then serve to guide lake management** by enabling evaluation (in lakes subject to anthropogenic phosphorus inputs) of the proportion of phosphorus due to natural sources. That is, an indicator of the "natural" phosphorus status of the lake.

Alkalinity

The data used came from 53 Northern Hemisphere lakes with average depths of 2 – 313 metres: 10 from Italy, two from Germany (Lake Constance 1925-1936 data, Feldsee), 7 from the USA and the remainder from Canada. Alkalinity values were in the range 0.04 – 2.86 mequiv/l and conductivity 3.4 – 285 µS.

It was noted that there is a linear relationship ($p<0.01$) between conductivity and alkalinity in these lakes. Alkalinity, on the other hand, is considerably less affected by anthropogenic pollution than is conductivity: Chiaudani *et al.* 1983, for example, showed no significant variation of mean alkalinity values in a number of Italian lakes over 15 years, whereas slight changes in conductivity and TDS were observed.

The authors examine both MEI-alkalinity and MEI-conductivity for the 53 lakes, with both showing a clear log-log regression ($p<0.01$). Covariance analysis shows that there is no significant difference between the European and North American lakes.

The authors conclude that the log-log correlation equations relating MEI-alkalinity and MEI-conductivity to mean total phosphorus concentration can be considered valid for general use, independent of the geographical location of lakes, and that MEI-alkalinity (mean alkalinity/mean depth) is the most useful management parameter.

Management application

The derived ratios were "tested" by application to two USA lakes for which mean phosphorus concentrations before and after diversion of all point sources has been reported (Lake Washington 1978, Lake Minnetonka 1981). In both cases, the lakes' mean total phosphorus levels returned, after point source diversion, to **levels close to the "natural" concentration estimated from the MEI-alkalinity ratio**. In Lake Washington, this "natural" concentration corresponds to an oligotrophic situation (around 10 µgP-total/l) and in Lake Minnetonka to an eutrophic status (around 30 µgP-total/l).

"A simple method to estimate lake phosphorus concentrations resulting from natural background loadings", Water Res., vol. 19, n°8, pages 987-991, 1985. http://www.sciencedirect.com/science/journal/00431354

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UK lakes

Nitrogen limitation of upland lakes

30 small upland lakes were studied in Scotland, Northern Ireland, Wales and North West England, with three visits between April and August 2000. Water chemistry parameters were measured, water samples taken for use in laboratory phytoplankton growth assays, and in situ periphyton growth experiments were carried out.

The 30 lakes were situated at altitudes of 125-528 m and were of areas 1.2-35 ha. The lakes were generally of low pH (4.39 – 7.14) with low nutrient concentrations (average total phosphorus 0.15 – 1.52 mmol/m^3, total dissolved phosphorus 0.04 – 0.75 mmol/m^3, total dissolved nitrogen 9-36 mmol/m^3).

For each lake, three series of laboratory phytoplankton growth assays were carried out using water samples collected from just below the lake water surface, approx. 3m from the shore, on each of the three visits to each lake. After filtering out larger zooplankton (120µm), samples were maintained under natural-light simulating fluorescent light at 20°C for 14 days. Algal development was assessed using fluorescence during the assay, and chlorophyll$_{-a}$ analysis at the end. Growth was calculated from fluorescence measurements made between days 4 and 7, and yield from the chlorophyll$_{-a}$ measurement on day 14.

For each lake and each series of assays, **six treatments were established each in triplicate**:

- control (no nutrient addition)
- phosphorus addition (final concentration of P addition, 6 mmol-P/m^3)
- nitrate addition (90 mmol-N/m^3 as NO_3)
- ammonium addition (90 mmol-N/m^3 as NH_4)
- phosphorus and nitrate (concentrations as above)
- phosphorus and ammonium (concentrations as above)

Periphyton growth response (algae growing on lake bottom surfaces) was assessed using in-situ experiments (two per site, running between the visits, that is experiment length 7-8 weeks) using flowerpots attached to the lake floor at a depth of around 50 cm. The flower pots were filled with agar solution containing different nutrients to test algal growth response: no nutrients (control), phosphorus (0.015 mmol/m^3), nitrate and ammonium as 0.15 mmol/m^3 solutions. Previous work had shown that this long exposure time was suitable for such upland, nutrient-low lakes, with sloughing off of surface growing periphyton scarcely occurring over such a time scale.

Variation

Phytoplankton and periphyton response to nutrient addition varied between lakes and between different times of the year (viz. the three visits, early spring to summer). In 62% of cases, indications as to nutrient limitation of phytoplankton derived from the growth data corresponded to those derived from the 14-day yield. **Phosphorus alone was limiting for around half the sites in early spring, and nitrogen alone for 20%, but by the summer 80% of samples were co-limited by both nutrients** (that is, algal development increased only if both nutrients were added). Ammonium appeared to be a marginally more effective source of nitrogen than nitrate (just significant at the 5% probability level).

For periphyton (surface growing), co-limitation was prevalent in both spring (48%) and summer (60%), with phosphorus limitation 32% in spring 20% in summer, and nitrogen limitation 20% in both periods.

The authors conclude that this study provides evidence of nitrogen limitation in lakes, with small upland UK lakes showing approximately the same degree of limitation by phosphorus as by nitrogen, and most likely to be co-limited (limited by both nutrients). Nitrogen limitation was more likely than phosphorus limitation where the DIN (dissolved inorganic nitrogen) concentration was <6.5 mmol/m^3 and the molar ratio of DIN/total dissolved phosphorus was <53.

The authors suggest that the relatively high frequency of nitrogen limitation in these lakes may result from the fact that cyanobacteria (blue-greens), capable of fixing atmospheric nitrogen, do not develop in such upland lakes.

In the second study cited, the authors further investigated the relationships between the lake catchment characteristics and whether the lakes

showed phosphorus or nitrogen limitation. Multiple regression based on catchment land cover, were able to explain 42% - 78% of variation in parameters including alkalinity, pH, phosphorus, nitrogen, and chlorophyll. The authors conclude from this analysis that phosphorus limitation was more likely in catchments rich in shrub-heath and bracken, and less likely in catchments with pastures and meadows. Nitrogen limitation occurred more often in catchments with marshland, rough grass and deciduous woodland and less often in catchments with rough pasture and shrub-heath.

"Nutrient limitation of phytoplankton and periphyton growth in upland lakes", Freshwater Biology 47, pages 2136-2152, 2002 www.blackwell-synergy.com

S. Maberly[1], L. King[2], M. Dent[1], R. Jones[5], C. Gibson[3].

"Linking nutrient limitation and water chemistry in upland lakes to catchment characteristics", Hydrobiologia 506-509, pages 83-91, 2003 www.springerlink.com

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Italy

Persistent anthropogenic nutrient sources

The Mediterranean Ortebello Lagoon is located in Southern Tuscany, on the Italian West Coast, at around 42°30N. Its total area is just over 25 km2, divided into two connected basins, with an average depth of 1m.

Eutrophication of the lagoon, resulting principally from urban, fish farm and agricultural wastewater emissions, led by the 1980's to environmental problems. Macroalgae (seaweed) blooms began to occur in the 1960's, leading through decomposition and consequent sulphate reduction, to dissolved oxygen depletion, dissolved toxic gases, and so aquatic fauna mortalities, a reduction in lagoon fish catch qualities, and outflows of discoloured water towards nearby tourist beaches.

In the early 1990's, the local basin authority OLERA instigated a programme of actions:

- **nutrient removal at the two urban waste water treatment works**. With this installation, 85% of soluble nitrogen and 79% of soluble phosphorus were removed from the works' discharge.

- **partial nutrient removal (phytotreatment pond) for 2 out of 4 land-based fish farms**. This installation achieves only 40% soluble nitrogen removal and 20% soluble phosphorus removal. Treatment efficiency was also further reduced when a lead from the phytotreatment pond into the lagoon occurred. No nutrient removal was installed for the 2 other fish farms, which continue to discharge directly into the lagoon.

- **macroalgae harvesting**, to remove biomass and stored nutrients from the lagoon. This also caused disturbance of the sediments, contributing to mixing, thus accelerating breakdown of organic matter and "sinking" phosphorus to carbonates and clay particles in the sediment (thus reducing bioavailable nutrients in the lagoon)

- **pumping of sea water into the lagoon** to accelerate exchange with the sea. The natural exchange is very limited (tidal range of less than 50cm). From 1993 to 2000, 39 complete lagoon water volumes were pumped in.

Persistent eutrophication symptoms

This programme of action enabled significant improvements, including recovery of sea grass and a return to phosphorus limitation of macroalgae / reduced macroalgae growth. However, from 1999, macroalgal growth was again recorded. This study aims to establish whether this is related to the remaining anthropogenic nutrient inputs, or to sediment phosphorus releases.

To establish this, monitoring of nutrient inputs, nutrient concentrations, and macroalgae and seagrass were carried out in 1999 and 2000. The monitoring aimed to establish nutrient budgets for the lagoon, and to compare ecosystem response in parts of the lagoon close to the remaining nutrient discharge sites (persistent anthopogenic sources) to response in the central lagoon area.

This confirmed that the sediment disturbance by macroalgae harvesting makes sediment phosphorus effectively unavailable for algal development, and that ecosystem dysfunction occurs mainly close to the persistent point nutrient discharges.

Sewage and fish farms

The persistent point source nutrient inputs to the lagoon (that is, remaining after implementation of the OLERA action programme in the 1990's) are as follows:

	KgN	KgP
Raw nutrient load from the two sewage works	33,000	4,400
Discharge from these sewage works after nutrient removal	**5,300**	**900**
Raw nutrient load from the four fish farms	132,000	6,700
Discharge from the fish farms after treatment (phytopond for 2 farms, no treatment for 2 farms)	**103,000**	**5,700**

Thus 5% only for nitrogen and 16% only for phosphorus of persistent point source nutrient input come from sewage works, and 95% N, 84% P from fish farms, because of the poor or inexistent nutrient removal operating at the farms.

The authors conclude that the nutrients available for macroalgae growth in the lagoon today come mainly from these persistent point sources.

Given the high level of nutrient removal already being achieved for the urban sewage, and the relatively very small contribution of the persistent nutrient input from this source, **it seems likely that further action in sewage works will not have any significant effect, and that action should focus on the fish farms**, both improving the nutrient removal for the two farms already connected to the phytotreatment pond, and installing treatment for the two farms which are still discharging directly into the lagoon.

"Restoration of the eutrophic Orbetello Lagoon (Tyrrhenian Sea, Italy): water quality management", marine Pollution Bulletin (Elsevier) www.elsevier.com/locate/marpolbul, *Vol. 46, Issue 12, December 2003, pages 1540-1548* http://dx.doi.org/10.1016/S0025-326X(03)00315-1

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See also:

Lenzi et al., 1998 "Risultati di quattro anni di gestione dell'ecosistema lagunare di Ortebello attraverso la raccolta delle biomasse algali", Bioligi Italiani XXVIII (2), 7-12

Lenzi and Mattei, 1998, "Variazioni di dominanza nei popolamenti algali della laguna di Ortebello. Un'ipotesti che ne individua le cause", Atti della Società Toscana de Scienze Naturali, Memorie, Serie B 105, 35-45. http://www.dst.unipi.it/dst/pal/stsn.html

Northern Adriatic mesocosms

Influence of phosphorus/nitrogen ratios on algal growth

Algal development (chlorophyll$_a$ concentration) and alkaline phosphatase activity (APA = indicative of phosphorus limitation) were measured over 28 days in 25 litre mesocosms filled with 250 µm filtered seawater and with addition of [a] no nutrients = control, [b] 100 µmol/l nitrate plus 6.3 µmol/l orthophosphate, [c] 100 µmol/nitrate plus 1 µmol/l orthosphoshate. In both cases [b] and [c], orthosilicate and vitamins were also added. The [b] mesocosms corresponded to approximately the "Redfield Ratio" N/P, that is proportional to estimated algal physiological requirements (nutrient "balanced"), whereas the [c] mesocoms corresponded to a situation with excess nitrogen levels (in effect, in this experiment, reduced phosphorus levels).

The seawater was collected from an area at the limit between eutrophied and oligotrophic zones. The non-control mesocosms were triplicated, thus giving a total of 7 mesocosms. The non-enriched seawater contained approximately 0.15 µmol/l total phosphorus, near zero soluble phosphorus, and 6 µmol/l soluble nitrogen.

Algal blooms

Uptake of around 0.6 µmol/l orthophosphate occurred in all nutrient enriched mesocosms within 2 days, this representing over 50% of total phosphorus in the [b] mesocosms, but <20% of total phosphorus in the [c] – reduced phosphorus – mesocosms.

Algal blooms occurred in both [b] and [c] mesocosms, in both cases at around 10 days, reaching levels of 55 and 40 $\mu gChl_{-a}/l$ respectively. Algal densities then dropped to around 12-15 and 5-8 $\mu gChl_{-a}/l$ respectively. In the control, algal biomass remained low throughout the experiment.

APA, on the other hand, remained relatively low in the nutrient "balanced" [b] mesocosms: 10x lower than in the reduced phosphorus [c] mesocosms.

Phosphorus response

The authors note that although the algal bloom was more significant in the mesocosms with higher phosphorus [b], the difference compared to the "nutrient balanced" [b] mesocosms was much less than would be expected (6x difference in phosphorus addition). They suggest that this is because of high recycling rates of soluble phosphorus in systems with high levels of nitrate enrichment.

Thus, when phosphorus is the limiting nutrient, the algal communities appear to be able to recycle phosphorus internally and/or to develop with lower P/N cellular ratios than in systems where phosphorus and nitrogen are both available according to the "Redfield Ratio".

N/P ratio in the Northern Adriatic

The authors emphasise that the Northern Adriatic is highly eutrophied, in particular because of nutrients carried into the sea by the Po River (up to 70% of the regional marine nutrient load). The N/P ratio in the Po river waters was already elevated in the 1970's (40:1) but rose to around 100:1 by 2000 (i.e. the ratio used in these experiments in the [c] mesocosms) because of reductions in phosphate from municipal wastewaters over the period 1982-1988 (P-free detergents and improved sewage treatment).

The change in the nutrient ratios in the northern Adriatic surface waters, influenced by the Po River, coincided with a dramatic increase in the occurrence of mucilage events (related to algal blooms). Such events had been recorded around once every 10-15 years since the late 19th century, but then occurred in 1988, 1989, 1991, 1997, 2000, 2001, 2002, and 2003. The authors suggest that N/P ratio changes can be an important trigger of these mucilage problems.

"Northern Adriatic mesocsm experiment Rovinj 2003: nutrient dynamics". Periodicum Biologorum (Ilica 16/III,10000 Zagreb, Croatia), vol. 106, n°1, pages 17-22, 2004.

I. Ivancic, D. Degobbis, O. Pecar, D. Fuks, R. Kraus, T. Dakovac, Ruder Boskovic Institute Centre for Marine Research, G. Paliaga 5, 52210 Rovinj, Croatia. M. Manganelli, Ispels-Dipia, via Fontana Candida 1, 00040 Monteporzio Catone (RM), Italy. R. Scenate, National Institute of Health, V. le Regina Elena 299, 00161 Roma, Italy. Ingrid@cim.irb.hr *or* cmrr@more.cim.irb.hr

Scotland

Nitrogen and eutrophication

There is growing evidence suggesting that in certain types of lake and river worldwide, both upland and lowland, nitrogen may be the primary-limiting or co-limiting nutrient (alongside phosphorus). A scientific report to the Scottish Executive (September 2004) assesses the evidence for and significance of nitrogen's contribution to freshwater eutrophication, and the information and tools available to derive practical guidance on the importance of this.

Several European Directives require regulatory authorities to control the availability of nutrients in water, including the Urban Wastewater Treatment Directive 91/271, the Nitrates Directive 91/676 and the Water Framework Directive 2000/60. To comply with these Directives, it is useful to be able to define where and to what extent eutrophication symptoms are primarily or partly controlled by nitrogen, and where control is primarily and partly be phosphorus.

The report examines the different sources of nitrogen to surface waters: atmospheric deposition, leaching of rocks and soil salts, and above all agricultural diffuse loadings (fertiliser and manure spreading) and point sources (sewage works, animal manure discharges, industrial sources).

Agricultural nitrogen

In 1986, fertiliser was being applied to 89% of UK crops and grasslands, at an average rate of 128 kgN/ha/year, with an estimated 14-17% of total fertiliser and animal waste nitrogen applied to land being susceptible to reach surface waters.

The report concludes that:

> *"Although phosphorus is the main resource that limits phytoplankton growth in many lakes, there is growing evidence that suggests that in certain types of lake, UK and worldwide, both upland and lowland, nitrogen may be the primary–limiting or co–limiting nutrient."*

and that in upland lakes:

> *"nitrogen limitation may be frequent and the lakes accordingly sensitive to changes in nitrogen availability".*

Nitrogen limitation is also probable in upland streams and rivers. Further work should address the lack of available information in this area.

N:P ratios in UK rives are often "low", suggesting a potential for nitrogen limitation, but on the other hand nitrogen concentrations in river water are often in excess of plant and algal requirements, so that nitrogen is not in effect limiting (particularly in lowland rivers). Nitrogen limitation of summer phytoplankton has been reported from a river system in Germany (Kohler and Gelbrecht 1998). In fact, plant and algal biomass is more often related to flow conditions and light availability than to nutrient concentrations.

The phytobenthos (river floor plants and algae) is particularly liable to be nitrogen limited, because of high rates of denitrification in benthic films, with numerous examples from New Zealand, Canada and the USA.

The report summarises a number of **models available for modelling nutrient export to surface water on the basis of catchment characteristics** (NIRAMS, SPARROW, MAGPIE). Nutrient ratios, on the other hand, often give misleading or inaccurate information regarding which nutrient is limiting, and need to be used in combination with information on absolute concentrations of nutrients compared to plant and algal nutrient needs: more work is needed to clarify this for different types of UK ecosystem.

"Deriving practical guidance on the importance of nitrogen in freshwater eutrophication", report to the Scottish Executive, S. Maberly, L. Carvalho, J. Fisher, L. May, B. Reynolds, M. Theobal, M. Stutton, L. Defew. CEH (Centre for Ecology and Hydrology) www.ceh.ac.uk *: CEH Lancaster, Lancaster Environment Centre, Lancaster LA 1 4 AP with CEH Edinburgh, CEH Wallingford, CEH Bangor. September 2004. CEH reference LA/C02449/1. Full report at:* http://www.scotland.gov.uk/library5/environment/cehnreport.pdf

Phosphate recycling

Sweden
Feasibility of phosphorus recovery

In 2001, the Swedish Government instructed the Swedish Environment Protection Agency to investigate the feasibility of large-scale phosphorus recycling from wastewater, as well as sludge use on agricultural land. The EPA commissioned a group of researchers, whose findings are discussed in this paper.

The research group compared several different possible routes for recycling of phosphorus from wastewaters:

* separate collection of urine, recycled to agriculture without treatment (other than storage)
* separate collection of all toilet wastes, recycled to agriculture after pasteurisation
* agricultural spreading of sewage sludge after pasteurisation
* recovery of phosphorus in sewage works operating biological nutrient removal (P-recovery)
* extraction of phosphorus from sewage sludge incineration ashes

These routes were compared to a reference scenario assuming sewage sludge incineration with landfill of the resulting ash.

Need for P-recycling

The author notes that although phosphorus is a non-renewable and non-replaceable natural resource, there is no pressing need to recycle phosphorus. Known world phosphorus reserves correspond to around 100 years of consumption at today's use levels, but if prices for phosphorus were to increase to levels comparable to estimated costs of recovering phosphorus from sewage, then new resource reserves could be expected to be developed. On the other hand, soils in many developing countries would benefit (increased agricultural productivity) from increased phosphorus inputs.

The dominant end-use of mined phosphorus resources is the agricultural fertiliser industry. But only around 20% of the phosphorus supplied to agriculture is transferred into agricultural products, and only 8% is then found in municipal wastewaters (Brunner, 2001, for Austria). Therefore, any consideration of phosphorus recycling should certainly address agriculture, food processing and other uses of phosphorus as well as domestic wastewaters.

Phosphorus loads in domestic wastewater are estimated at 0.3 – 0.4 kg/person/year in urine plus 0.18 - 0.2 kg/p/y in faeces, plus an estimated 0.18 kg/p/y from detergents and other household products.

Potential of different routes

Spreading of sewage sludge on agricultural land offers the potential to recover the highest proportion of phosphorus in sewage (over 95%, where nutrient removal is operated in sewage works), but offers only low recovery proportions of other nutrients (nitrogen <20%, K, S). Separate recycling of urine or toilet wastes offer respectively 40 or 80% recovery of total sewage phosphorus, but better proportions of nitrogen recycling (50-70%).

The environmental impact of each route was assessed by calculating total energy consumption for operation (energy consumption related to infrastructure investment was assumed to be small compared to that related to operation, and was not calculated). Energy savings from reduced use of mineral fertilizers was included in the calculations. Energy consumption was considerably higher for separate collection of all toilet waste than for any other option (around 3x higher, because of the large volumes requiring pasteurisation and transport). Lowest energy consumption was for separate urine collection (but this did not take into account the energy content of the required infrastructure, and assumed no heat treatment of the collected urine). Energy consummation related to agricultural spreading of pasteurised sewage sludge, recovery of phosphorus from biological nutrient removal sewage works or from sewage sludge incineration ash were each similar, and close to those of the reference scenario (no phosphorus recovery).

Total economic costs per tonne of phosphorus recovered were also calculated, including in this case both investment and operating costs. Costs of separate urine collection and separate toilet waste collection were very considerably higher than all other scenarios.

Agricultural spreading of sewage sludge, recovery of phosphorus from biological nutrient removal sewage works or from sewage sludge incineration ash each showed costs similar to the reference scenario. The least expensive routes were agricultural spreading of sewage sludge (cheaper than the reference scenario) and phosphorus recovery in biological nutrient removal sewage works (3,600€/tonne-P additional cost compared to the reference scenario).

The author concludes that phosphorus recovery is not economically worthwhile, but that other issues may justify its development (depletion of non-renewable phosphate rock resources, environmental impacts related to phosphate mining …)

"Phosphorus recovery – an overview of potentials and possibilities", Water Science and Technology, vol. 49, n°10, pages 185-190.

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Water Science and Technology: IWA Publishing www.iwapublishing.com *Journal index:* http://www.iwaponline.com/wst/toc.htm *Journal vol. 49 n°10:* http://www.iwaponline.com/wst/04910/10/default.htm

Sludge management

Perspectives for phosphorus recovery

Two papers, published together in Water Science Technology (alongside the paper reviewed above) offer overviews of sustainable sewage sludge treatment strategies and of the potential for utilising the resources present in sewage sludges. Both papers emphasise the need for an integrated approach to sewage treatment taking into account sewage sludge production and management, which is directly linked to the water line processes in the sewage works, as well as source-control of pollutants to minimise contamination of sewage and so of sludge. Phosphorus is highlighted as offering an important potential for resource recovery.

W.H. Rulkens (Wageningen, The Netherlands) reviews **different treatment routes for sewage sludge and possible approaches for more sustainable sludge management**: improvement of sludge quality, beneficial use of organic carbon compounds and inorganics, reduction of sludge volumes, recovery of phosphates for reuse, new waste water treatment routes. He emphasises that sludge management must be addressed with a broad approach, considering simultaneously sludge treatment and sewage treatment operation. He states that that the effort to recover phosphorus can be expected to strongly increase in the near future.

Sludge as a resource

H. Kroiss (Vienna TU) discusses **sludge as a resource**, including economic and ecological aspects, as well as sociological issues. He notes that the proportion of regional phosphorus material flows present in sewage treatment sludges is 8-15% (higher figure where sewage works operate nutrient removal), which is a considerably proportion than for other elements or materials (eg. carbon: 0.2%, nitrogen 3%).

Regarding costs, he refers to the Austrian benchmarking study (2001, "Benchmarking in der Siedlungswasserwirtschaftat") which shows that sludge management, including stabilisation, represents 49-53% of sewage works operating costs. Sludge disposal represents around one half of these costs at 200-250€/tonne dry solids (tDS) or 3-4€/person equivalent (p.e.)/year. This is compared to the market value of nutrients in sewage sludge of 1.6€/p.e./year (nitrogen: 1.1 €/kgN, phosphorus: 2€/kgP).

He concludes that the most valuable element in sewage sludge is phosphorus. The most economic route for phosphorus recycling is agricultural spreading of sewage sludge, but this is subject to social obstacles and difficulties.

"Sustainable sludge management – what are the challenges", Water Science and Technology, vol. 49, n°10, pages 11-19.

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"What is the potential for utilizing the resources in sludge", Water Science and Technology, vol. 49, n°10, pages 1-10.

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The Scope Newsletter

The SCOPE Newsletter is produced by the Centre Européen d'Etudes des Polyphosphates, the phosphate industry's research association and a sector group of CEFIC (the European Chemical Industry Council).

The SCOPE Newsletter seeks to promote the sustainable use of phosphates through recovery and recycling and a better understanding of the role of phosphates in the environment.

The SCOPE Newsletter is open to input from its readers and we welcome all comments or information. Contributions from readers are invited on all subjects concerning phosphates, detergents, sewage treatment and the environment. You are invited to submit scientific papers for review.

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