Euro-limpacs

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Preface

Monitoring and modelling the impacts of global change on European freshwater ecosystems.

Freshwater ecosystems are important resources, providing sources of water for drinking, industrial and agricultural usage, recreation and conservation. Diffuse and point source pollution continues to threaten the quality of these resources, and has already changed the chemistry and biology of many European river-systems. In addition to pollution derived from agriculture, industry and sewage disposal, freshwater ecosystems now face new problems likely from climate change, both directly and through the interaction with other drivers of change. In relation to water chemistry and ecology, the agencies responsible for the management of water resources face the problems of:

- recognising and quantifying the pollutant effect against some perception of good ecological status;
- resolving the potential conflict of different uses and interests within a catchment which are likely to have socio-economic consequences;
- predicting the change in the hydrology, water quality and ecology likely to result from future changes in pollutant inputs and climate change.

These problems are urgent. The adoption of the Water Framework Directive by the European Union has bound its participants to improve the chemical and ecological status of their freshwaters by 2015, and the improvement of the freshwater water resource and biodiversity is desirable throughout the World. The science to underpin the environmental management in river-systems is much needed. The Euro-limpacs project (GOCE-CT-2003-505540), funded by the European Union under Framework6, has been designed to help provide the science. It focuses on the key drivers of aquatic ecosystem change (land-use, nutrients, acid deposition and toxic substances) and examines their interactions with climate change using time-series analysis, space-for-time substitution, palaeolimnology, experiments and process modelling. It considers these interactions at three critical time-scales: (i) hours/days, concerned with changes in the magnitude and frequency of extreme events; (ii) seasons, concerned with changes in ecosystem function and life-cycle strategies of freshwater biota; and (iii) years/decades concerned with the ecological response to environmental pressure. A central activity is the creation of a tool-kit for integrated catchment modelling to simulate hydrological, hydrochemical and ecological processes at the catchment scale for use in assessing the potential impact of climate and socio-economic scenarios.

This special issue provides the vanguard results from the Euro-limpacs project. It also takes European understanding of rivers, lakes and estuarine studies further. It provides information on the likely impacts of climate change on freshwater ecosystems and gives new insight into the factors and processes operating in freshwater ecosystems that must be considered when making model-based assessments of the impacts of climate-change and management decisions. The volume covers five areas:

- Catchment hydrology and hydrochemistry;
- The links between hydrochemistry and ecology;
- Quantifying the effects of climate change, land management and effluent inputs on freshwater chemistry;
- Model uncertainty
- Freshwater ecosystem and socio-economic linkages

In this volume, new work is presented on understanding nutrient transport and retention at the field, catchment and national scale. A major component of the volume is the application of models to assess the likely impacts of climate change on freshwater chemistry and the likely ecological consequence in a range of European climates and landscapes. The fifteen papers in the issue compliment the activities to disseminate the results of the project at meetings around the world including meetings of the American Society of Limnology and Oceanography(ASLO), Acid Rain 2005 – the 7th International Conference on Acid Deposition and the 5th International Symposium on Ecosystem Behaviour – Biogeomon 2006. The volume also highlights the commitment of the European Union and its scientists to improve the freshwater water resource.

The Guest Editor

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Introduction

Monitoring and modelling the impacts of global change on European freshwater ecosystems.

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In 2000, the European Union adopted the Water Framework Directive (2000/60/EC) which aims to protect and improve the water resources and freshwater ecology of Europe. It is hoped that the aim will be achieved by setting standards on water quality and ecological status that will be met by reducing pollutant inputs to freshwaters from the surrounding catchments. The aims of the Directive are laudable and worth pursuing, but the practical application of the Directive and the assessment of its success are difficult for four reasons. Firstly, whilst the study of the relationships between the physical and chemical processes and the ecology within lakes is established, the equivalent science in rivers and wetlands is still relatively new. The understanding of how fluvial hydrochemistry controls the ecology and the feed-back mechanisms are not sufficiently understood to predict the ecological response in rivers and wetlands with certainty. Secondly, changes in the climate, which are currently predicted to exceed natural variability, may confound our current understanding of chemical cycles in the soils, groundwater, lakes, rivers and wetlands. Thirdly, the pollutants which affect the ecology, either directly within a catchment or indirectly by contributing to air pollution or climate change, are typically by-products of industry, farming, transport and power generation; all are essential to the economy of Europe and therefore pollution controls in these economic sectors will have social and economic consequences, which are not fully understood. Finally, questions remain over what “good” ecological status means.

Given the current state of scientific knowledge (European Environment Agency, 2003), research projects have been commissioned at the national and international scales to investigate how changes in pollutant inputs to river-systems, coupled with future predictions of climate change, will affect the chemical and ecological status of freshwaters (e.g. Euroharp; EuroLakes; CLIME; Lowland Catchment Research, LOCAR). One such project funded by the European Union is Euro-limpacs (www.eurolimpacs.ucl.ac.uk) which aims to determine how the chemistry and ecology of freshwater systems throughout Europe will change in response to changes in land-management, atmospheric deposition and effluent inputs set against the background of expected climate change.

This volume brings together the first monitoring and modelling results of the Euro-limpacs project and other contemporary work to define the current state of the modelling effort; and to provide new data and considerations requiring attention by environmental modellers. The volume provides the foundation papers on which further modelling efforts will be built and describes the study sites used. Most importantly the papers provide new model-based assessments of the factors and processes controlling the behaviour of the water quality and ecology in river-systems and quantitative estimates of the likely response of freshwater ecosystems to climate change. Gaps in the data and model-based assessments are identified in the individual papers.

Euro-limpacs: an overview

Euro-limpacs began in February 2004 and will finish in January 2009. The project is ambitious. It brings together scientists from universities, research institutes and environmental consultancies in 19 different countries. The project includes both experimental and modelling studies and is split into ten work-packages (Figure 1).

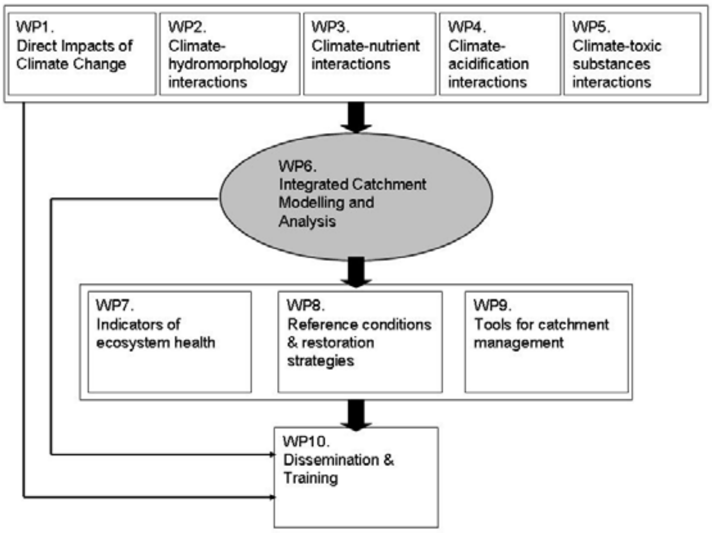
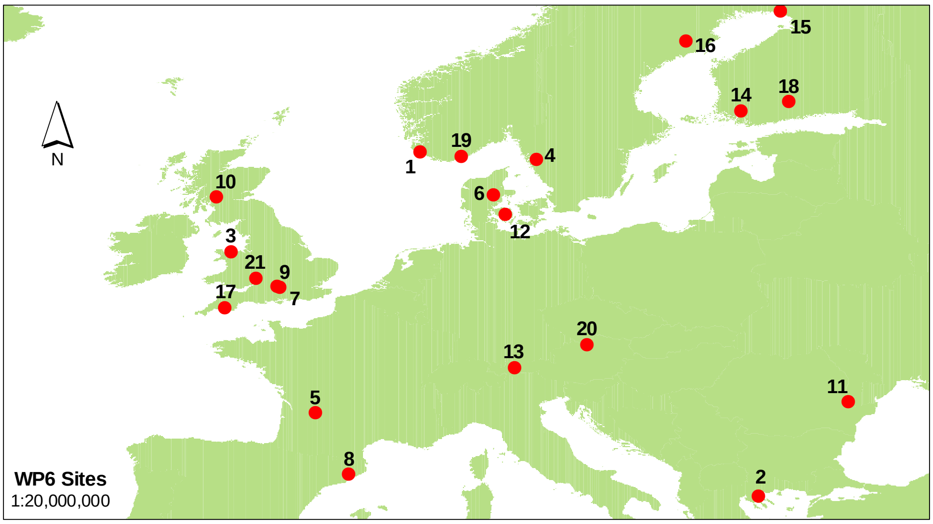


Figure 1. The work-package structure of the Euro-limpacs project.

The first five concentrate primarily on experimental work to determine the likely impacts on freshwaters from direct changes in hydrology; changes in channel geomorphology and sediment accumulation rates; eutrophication; acidification; and toxic substances, such as mercury and persistent organic compounds. Additional research is focusing on establishing indicators of ecosystem health, strategies for remediation of freshwaters where the biodiversity has been reduced, and methods of disseminating the knowledge accumulated in the project to all those interested in it. The tenth work-package deals with the administration of the project, training provision for the tools and methods developed in the project and the maintenance of the web-site. Catchment-scale modelling is central to the integration of knowledge derived from the experimental studies and the delivery of forecasts of change to the indictor, restoration and information dissemination work-packages.

Mathematical models that simulate the storage and transport of pollutant inputs through the soils and groundwater of a river-system are required to understand and quantify the likely response-time between a pollutant entering the system and its subsequent emergence in the surface-waters, and thereby determine what management options are viable to improve river ecology within the time-scale of the Directive. The aims of the catchment-scale modelling work-package are (i) to improve process understanding within freshwater ecosystems through modelling approaches and (ii) to provide quantitative estimates (with uncertainty) of the likely impacts of global change on freshwater ecosystems. At the catchment-scale, steady-state models integrate knowledge of flow-pathways and source areas to determine the output from the land or river based on the input mass and an empirical method of estimating the retention in the soils and the groundwater; dynamic models incorporate also ideas of transient storage and representations of biochemical cycling. As such, catchment-scale models are useful as they can be used to investigate the possible controls on the water quality and ecology, though there are problems due to an inability to identify the optimum model structure and parameter-set (Beven, 2002). Despite this, models are still useful as they are a means of considering all the factors and processes that affect the water quality and the modelled forecasts of the response to climate change compliment other techniques, such as space-for-time substitution and analogue matching which rely on finding surrogate components of a river-system, such as a lake or wetland, for the predicted temperature and precipitation conditions. A wide variety of models are being developed in the Euro-limpacs project ranging in complexity from perceptions of how a system works, illustrated in a report or paper, to dynamic, mass-balance chemical and ecological models, formalised as a set of equations coded as computer software. The catchment-scale models are described in this volume.

Catchment monitoring



1, Bjerkreim, Norway
2, Cheimaditida, Greece
3, Conwy, UK
4, Gårdsjön, Sweden
5, Garonne, France
6, Gjern, Denmark
7, Kennet, UK
8, La Tordera, Spain
9, Lambourn, UK
10, Loch Lomond, UK
11, Lower Danube, Romania
12, Odense, Denmark
13, Piburger See, Austria
14, Savojoki, Finland
15, Simojoki, Finland
16, Svartberget, Sweden,
17, Tamar, UK
18, Teuronjoki, Finland
19, Tovdalselva, Norway
20, Waldaist, Austria
21, Wye, UK

Figure 2. The location of the key sites for catchment-scale modelling in the Euro-limpacs project.

Given the history of hydrological, biogeochemical and ecological research in European lakes, rivers and wetlands, the project is able to draw upon substantial existing data sets. Twenty-one sites have been chosen which cover Europe (Figure 2) and are representative of different pollution issues, spatial scales, climates and river-system components (Table 1). The study-areas are in Austria, Denmark, Greece, Finland, France, Norway, Romania, Spain, Sweden and the UK (Table 1). The areas of the study sites range over 8 orders of magnitude, from small research sites such as Svartberget and Gårdjsön, to large river-systems which have a number of water pollution issues and competing water uses (Table 1).

Country	Study Area	Area km^2	System Components Present			Key Issues	Climate	Eco-region
			River	Lake	Wetland			
Austria	Piburger See	2	✓	✓		Eutro.	Cool Continental	Mountainous
	Waldaist	275	✓			Sediment	Cool Continental	Mountainous
Denmark	Gjern	110	✓	✓		Eutro.	Warm-humid	Atlantic
	Odense	486	✓			Eutro.	Warm-humid	Atlantic
Greece	Cheimadidita	35		✓	✓	Eutro.	Mediterranean/Cool Continental	Mediterranean
Finland	Savijoki	15.4	✓		✓	Eutro.	Sub-artic	Boreal
	Simojoki	3160	✓	✓	✓	Acid., N sat.	Sub-artic	Boreal
	Tueronjoki	439	✓	✓	✓	N sat, Eutro.	Sub-artic	Boreal
France	Garonne	56500	✓	✓	✓	Eutro.	Warm-humid	Atlantic
Norway	Bjerkreim	685	✓	✓	✓	Acid., N sat., C	Warm-humid	Boreal
	Tovdalselva	1855	✓	✓	✓	N sat, Eutro.	Warm-humid	Boreal
Romania	Lower Danube Wetland	210			✓	Eutro.	Cool Continental	Continental
Spain	La Tordera	124	✓		✓	✓	Mediterranean	Mediterranean
Sweden	Gårdsjön	0.005		✓		Acid., N sat., C	Warm-humid	Boreal
	Svartberget	0.5	✓	✓		Acid., Hg	Sub-artic	Boreal
UK	Conwy	590	✓		✓	Acid., Eutro., C	Warm-humid	Atlantic
	Kennet	1030	✓		✓	Eutro.	Warm-humid	Atlantic
	Lambourn	263	✓		✓	Eutro.	Warm-humid	Atlantic
	Loch Lomond	781	✓	✓		Eutro.	Warm-humid	Atlantic
	Tamar	917	✓		✓	Eutro.	Warm-humid	Atlantic
	Wye	4140	✓	✓		Acid., Eutro., C	Warm-humid	Atlantic

Table 1. A summary of the key study areas used in the Euro-limpacs project for catchment-scale modelling. Acid. = Acidification, Eutr. = Eutrophication, N sat. = N saturation, C = Carbon.

Study Area	Number of Monitoring Sites	Period of Collection
Piburger See		
Waldaist	1	1997 - ongoing
Gjern	2	1987 - 2000
Odense	1	1950 - ongoing
Cheimaditida		
Savojoki	1	1971 - ongoing
Simojoki	2	1970 - ongoing
Teuronjoki	2	1981 - ongoing
Garonne		
Bjerkreim	4	1980 - ongoing
Todalselva	3	1973 - ongoing
Lower Danube	2	1950 - ongoing
La Torderra	2	1994 - ongoing
Gårdjsön	3	1980 - ongoing
Svartberget	2	1981 - ongoing
Conwy		2000 - ongoing
Kennet	10	1960 - ongoing
Lambourn	2	1962 - ongoing
Loch Lomond	4	1963 - ongoing
Tamar	7	1956 - ongoing
Wye	13	1950 - ongoing

Table 2. A summary of the site and river-system discharge monitoring.

Study Area	Number of Monitoring Sites	Frequency of Collection	Period of Collection	Determinands
Piburger See	1	Monthly	1975 - ongoing	NO_3, NH_4, TP, TDP, pH, base cations, acid anions, Alk
Waldaist	1	Monthly	1997 - ongoing	NO_3, NO_2, NH_4, PO_4, TOC, DOC, pH, Alk, BOD/COD, O_2 saturation
Gjern	2	Fortnightly	1987 - 2000	TN, NO_3, NH_4, TP, DRP, PO4, SRP, pH, SS
Odense	1	Fortnightly	1987 - 2002	TN, NO_3, TP, DRP, pH, SS
Cheimaditida				
Savojoki	1	Fortnightly	1984 - ongoing	TN, NO_3, NH_4, TP, DRP, TOC, pH, base cations, acid anions, Alk, SS,
Simojoki	1	Monthly	1984 - ongoing	TN, NO_3, NH_4, TP, PO4, TOC, pH, base cations, acid anions, Alk, Hg, SS
Teuronjoki	1	Monthly	1969 - 1988	TN, NO_3, NH_4, TP, PO_4, pH, Alk
Garonne				
Bjerkreim	20	Fortnightly	1980- ongoing	TN, NO_3, TP, PO_4, TOC, DOC, pH, base cations, acid anions, Alk
Todalselva	2	Fortnightly	1980- ongoing	TN, NO_3, TP, TOC, pH, base cations, acid anions, Alk,
Lower Danube				
La Torderra	3	Monthly	1994 – ongoing	TON, NO_3, NH_4, TP, PO_4, DIC, pH, base cations, acid anions, Alk, Hg, other trace metals, BOD/COD, O_2 saturation, CO_2
Gårdjsön	3	Monthly	1980 - ongoing	NO_3, NH_4, DON, TP, DOC, pH, base cations, acid anions, Hg
Svartberget	3	Weekly	1981 - ongoing	TN, TON, NO_3, TP, PO_4, TOC, pH, base cations, acid anions, Alk, Hg, other trace metals, CO_2
Conwy	31	Quarterly	2004 – ongoing	TN, NO_3, NH_4, DON, TOC, DOC, pH, base cations, acid anions, Alk,
Kennet	20	Quarterly	1973 - ongoing	TON, NO_3, NO_2, NH_4, TP, PO_4, DHP, SUP, PP, TDP, DOC, SRP, pH, base cations, acid anions, Alk, SS, CO_2
Lambourn	2	Weekly	2002 - 2004	TN, NO_3, NO_2, NH_4, DON, TP, DHP, DOC, pH, base cations, acid anions, Alk, other trace metals, SS
Loch Lomond	45	Monthly	1965 - ongoing	NO_3, NO_2, BOD/COD, O_2 saturation
Tamar				
Wye	742	Monthly	1992 – ongoing	TON, NO_3, NO_2, PO_4, pH, base cations, acid anions, Alk, SS

Table 3. A summary of the site and river-system water chemistry monitoring

Study Area	Number of monitoring sites	Frequency of collection	Period of Collection	Determinands
Piburger See	1	Monthly	1972 - 1988	ChlA
Waldaist	2		1994 – ongoing	macro-invertebrates, diatoms
Gjern				
Odense			1980 - ongoing	fish, macro-invertebrates
Cheimaditida	1			ChlA, diatoms
Savojoki				
Simojoki	2	Quarterly	2002 - ongoing	ChlA
Teuronjoki	1		1975 - ongoing	ChlA, macrophytes
Garonne				
Bjerkreim	5	Annual	1996 - ongoing	macrophytes, fish, macro-invertebrates, zooplankton
Todalselva	5	Annual	1996 - ongoing	macrophytes, fish, macro-invertebrates, diatoms
Lower Danube				
La Torderra	2	Monthly	1994 – ongoing	ChlA, macro-invertebrates, diatoms
Gårdjsön				
Svartberget				
Conwy	20	Single study	2002	macro-invertebrates
Kennet	3	Monthly	1974 – 1975 and 1997 - 2000	macrophytes, epiphytes, macro-invertebrates
Lambourn	1	Weekly	2002 2004	ChlA, macrophytes, macro-invertebrates, diatoms
Loch Lomond	6		1987 - ongoing	ChlA
Tamar				
Wye			1992 - ongoing	ChlA

Table 4. A summary of the site and river-system biological and ecological monitoring

Many of the study-areas have a long history of hydrological monitoring, beginning in the 1950s at four of the sites (Table 2). A wide-range of determinands are sampled at the 21 study-areas, covering the key water pollutants central to the Euro-limpacs project: sediment, nitrogen, phosphorus, carbon and mercury (Table 3), and many sites have biological data available (Table 4). In addition, a broad range of other measurements are available describing the hydrology (i.e. precipitation, air temperature), effluent-inputs and deposition. Water chemistry has been monitored routinely at 12 of the study-areas since the 1980's or before. Table 3 describes the long-term monitoring only and does not include additional measurements made during short-term projects. Compared to the monitoring of water chemistry, the measurements of the biology and ecology in the 21 study areas are made at fewer sites, with shorter periods of sampling and less frequent measurements. Despite this, these data-sets are amongst the best in Europe with surveys of fish, macrophytes, macro-invertebrates, diatoms, zooplankton and Chlorophyll ‘a’ concentrations (Table 4).

Based on differences in temperature and precipitation, climate zones can be defined for Europe: southern Spain, Italy and Greece can be classified as ‘Mediterranean’, the Alps as ‘cool continental’, northern Norway, Sweden and Finland (i.e. above 60^{o} N) as ‘sub-artic’ and the remaining area as ‘warm humid’. Thus, the 21 study-areas selected for the model-based assessment of pollutant impacts on European freshwater ecosystems cover a range of climate zones, ranging from the sub-Arctic north to the Mediterranean, and from maritime ‘warm humid’ sites in the western UK, an Alpine ‘cool continental’ catchment in Austria to a continental site in the Lower Danube. The study-areas can be also classified according to eco-region (Table 1). The salient features of the sites are as follows:

Austria. There are two catchment sites in Austria. The Piburger See is a mountain lake in the eastern Alps, which suffered from eutrophication during the 1960s. Comprehensive restoration measures were undertaken in the 1970s: sewage diversion, deep water with-drawl and change in agricultural practice. These efforts were successful and the trophic-status was restored to oligo-mesotrophic. The Waldaist is located to the north of the Danube and drains coniferous forest on an acid-bedrock. This catchment is one of the sites used in the experimental work package to study the effects of changing hydrology on sediment transport, channel morphology, inundation frequency and extent, and the impact on the aquatic environment. Data describing the land-use, hydromorphology and the biological community are available.

Denmark, France, UK. The Gjern, Odense, Garonne, Kennet, Lambourn, Wye, Conwy and Tamar river-systems are all dominated by agriculture and have some sewage effluent inputs. The River Gjern drains an area of 110 km^2 in Denmark and includes one lake with an area of 0.39 km^2. Due to the input of nutrients from agriculture and sewage the Gjern is eutrophic. The River Odense, also in Denmark, is larger (486 km^2) but is also eutrophic. Both systems are monitored long-term by the National Environmental Research Institute and time-series describing the flow, water chemistry and ecology are available from 1950.

The study site in south-west France is the Garonne river-system (56 536km^2). In an Atlantic Pyrennean climate, the Garonne is one of the largest west European alluvial rivers in a non-industrialized region. Thus, the Garonne provides an example of a fluvial landscape essentially modified by agriculture and, more recently, by urbanisation. The fish assemblages of the Garonne have been mapped in detail and provide a key ecological data-set with which to investigate the relationship between fish assemblages and the controlling environmental factors.

The Kennet (1164 km^2) and one of its tributaries, the Lambourn (263 km^2) are typical of Cretaceous Chalk catchments in southern England. Much of the precipitation percolates into the Chalk aquifer and consequently the flow response in the catchments is highly damped. The catchments are mainly rural, with arable agriculture being the predominant land-use. There are several large towns along the main channel, from which treated sewage is discharged directly into the Kennet. The catchment provides water for public and industrial supply by means of direct surface and groundwater abstractions, and there is concern that the nutrient concentrations in the rivers and wetlands have caused ecological problems, in particular the growth of unsightly algae which may suppress the growth of macrophytes. The Lambourn has been the focus of a major national research programme to study the hydrology, water quality and ecology of a lowland UK river-system. Detailed measurements of macrophyte and epiphyte and biomass in the Kennet and Lambourn are available (Flynn et al., 2002; Wright et al., 2002).

The River Wye is a large (4136 km^2) and diverse catchment which spans the border of Wales and England. The upland north-west of the catchment is composed of outcrops of Ordovician and Silurian sandstones, shales, grits and mudstones. The lowland catchment, south east of Hay-on-Wye is underlain by Old Red Sandstone, comprising readily-weathered marls of the Herefordshire lowlands and the more resistant sandstones of the Black Mountains. There is a marked contrast in precipitation across the catchment, with mean annual rainfall of 2450 mm (1951 – 1995) at Cefyn Brwyn in the upland north-west catchment, compared with 717mm (1971 – 1995) at Yarkhill in the lowland east of the catchment (Marsh and Lees, 2003). The high precipitation inputs to the upland catchment and low groundwater inputs mean that the river regimes in the west tend to be flashier whereas, in the eastern lowlands, there is a more substantial groundwater supply, resulting in the lowland tributaries exhibiting less variable flow regimes. Land use in the Wye catchment is dominated by agriculture and the type of agriculture varies considerably across the catchment, largely according to topography. Sheep farming is the main agricultural activity on the grassland and moorland of the upland west of the catchment, whereas in the lowland eastern part of the catchment, arable and dairy farming predominate, with fruit, potato and hop production. In 1994, the lower River Wye (from Hereford to the tidal limit) and the River Lugg were designated ‘Eutrophic Sensitive’ areas under the Urban Wastewater Treatment Directive (1991). As a result of this, tertiary treatment to reduce phosphorus discharges was introduced at some of the larger STWs in the lower Wye catchment during the latter part of the study period. The headwaters are recovering from acidification.

The 590 km^2 Conwy catchment drains a predominantly rural, upland area of North Wales, with a low population and minimal industry. The catchment contains a range of soils and land-use that may be considered characteristic of many upland regions in the UK: blanket peat bog (part of the largest peatland area in Wales); high montane areas with thin organic and organo-mineral soils; conifer forests; and improved grassland. Land-use is largely restricted to low-density sheep grazing in the uplands, and higher density sheep and some cattle grazing on improved grasslands. The catchment is the subject of detailed spatial surveys of riverine DOC, particulate organic carbon (POC), nutrient and major ion chemistry, and samples have also recently been collected for ^{14}C analysis of DOC, to enable source attribution and determination of organic matter age. Due to the extensive area of blanket peat, high catchment exports of DOC to estuarine and coastal waters have also been the subject of detailed study (EU DOMAINE project). Like the Wye, the headwaters are also recovering from acidification.

The River Tamar is a large (917 km^2), predominately rural catchment of moderate relief in the south-west of England. There are significant alluvial flats (wetlands) in the middle reaches, and the land-use is a mixture of arable agriculture, grazing and forestry. Climatic conditions over the middle and upper Tamar catchment are typical of Atlantic Britain, with mild wet winters and cool, moist summers.

Loch Lomond is a large lake in western Scotland (71 km^2). The main rivers draining into the loch are Endrick Water and the River Falloch both of which have mountainous catchments. In total the loch drains an area of 781 km^2. Endrick Water, which drains the Campsie Fells, is developed on Old Red Sandstone overlain by drift, and the flow in the river is diminished by export of water from the Carron Reservoir into the River Forth. The River Falloch is a very wet (approximately 2900 mm a^{-1}), mountainous catchment developed on ancient metamorphic formations. There is a slight eutrophication threat to the loch from diffuse agricultural pollution in the southern catchments.

Norway, Sweden, Finland. There are two catchment sites in Norway. The Bjerkreim river-system in southern Norway is a large (685 km^2) mountain to fjord catchment, dominated by mountains and heathlands; it is a salmon river, which has been acidified by long-range transported sulphur and nitrogen compounds. The Tovdalselva catchment, in southern-most Norway, is larger (1855 km^2) but also has been acidified. Both river-systems have a 25-year history of hydrological and water quality monitoring.

The 0.50 km^2 Svartberget Catchment lies 70 km inland from Sweden's east coast. Half of the runoff occurs during the snow-free half of the year (June to November), and a third of runoff occurs during 3-4 weeks of spring flood in April or May. The catchment is forested with Norway Spruce (*Picea abies*) in low, wetter areas and Scots Pine (*Pinus sylvestris*) on higher, better-drained areas. The source of the stream is 0.08 km^2 of mire. Monthly stream chemistry data are available since 1981. Weekly samples have been collected since 1996 and analyzed for major anions, cations, nutrients and DOC. Several transects have been studied in detail for hydrology and soil solution chemistry. Detailed studies of trace elements (e.g. Hg, Al speciation), DOC character, stable and radioactive isotopes have been conducted at various times.

The experimental site at Gårdjsön is located about 10 km from the Swedish west coast, 50 km north of Gothenburg. The region has a humid climate, and the research area is characterised by an acid lake whose terrestrial catchment is dominated by forest and podsolic soils, with inclusions of barren rock and peaty soils. The Gårdjsön study-area receives moderately high deposition of sulphate, nitrate and ammonium, and has been used for nitrogen addition experiments to simulate the impacts of increased deposition (Wright and VanBreemen, 1995).

The River Simojoki, Finland discharges to the Gulf of Bothnia in the Baltic Sea. The river drains an area of 3160 km^2, and is a salmon river in near-natural state. The dominant human impact is forestry, and there are concerns that drainage and tree-felling may adversely impact the nitrogen cycle. In contrast, the Savijoki catchment is located in south-western Finland in the southern boreal zone; it is a small (16 km^2), agriculture-dominated sub-catchment of the River Aurajoki that discharges into the Baltic Sea. Savojoki contains no lakes and belongs to the Finnish network of small representative catchments, originally established for hydrological research in 1957. Agriculture, mainly spring cereals, is assumed to be the main source of diffuse nutrient losses. The River Teuronjoki catchment (439 km^2), in southern Finland, includes the intensively studied Lake Pääjärvi which is part of the EuroWaterNet monitoring network.

Greece, Spain. Lake Cheimaditida is located 20 km south-east of Florina in north-west Greece. The land surrounding the lake is mainly agricultural, deciduous and shrub-woodland or wetlands. Historically, the lake has been used as a freshwater supply for drinking and irrigation. The catchment is close to the main mountain range of Greece and therefore has a climate that resembles a more mid-European type, with a mean annual temperature of approximately 12.3 ^{o}C and a mean annual rainfall of 520 mm. The lake and the surrounding area have an important ecological function supporting approximately 140 different bird species and 21 rare plants; however, the biodiversity of the lake is currently falling.

La Tordera is a predominantly forested catchment in north-east Spain (868 km^2). The climate is typically Mediterranean: precipitation falls mainly in autumn and spring with only occasional storms in summer. A sub-catchment of La Tordera will be used initially (124 km^2) for the modelling work, which includes areas of agriculture and a waste-water treatment plant.

Romania. The Small Island of Braila, declared a natural reserve in 1994, is a complex of wetlands in the Lower Danube area. This is one of the rare areas bordering the river which has preserved its natural hydrological conditions and which contains a representative sample of habitats, which are characteristic of floodplains as well as an ancient inland delta. Comprising seven small islands with a total surface area of 210 km^2 (including Danube arms), the area is a site of major interest for birds, both for the quality of the habitats present and for its location on the migration routes midway between the nesting areas in the north of Europe and the wintering areas in Africa.

Catchment-scale data analysis

The volume starts with the latest results from data analysis of nitrogen dynamics in clay and chalk catchments (Neal et al., 2006a), P dynamics in agricultural soils (Heathwaite et al., 2006), and the long-term changes in carbon export from upland and forested systems (Vourenmaa et al., 2006). All three nutrients are central to the Euro-limpacs project and the implications of each study provide considerations that must be factored into the modelling effort: the differences in the nitrogen dynamics in chalk and clay catchments; the effect of tile drains on phosphorus and nitrogen residence times in agricultural systems and the long-term trends in carbon concentrations and the possible causal factors and processes which should be investigated in a model-based assessment. Hilton et al. (2006) and Neal et al. (2006b) make a significant progress in understanding how algae concentrations are determined in river-systems. Hilton et al. (2006) propose a new conceptual model for predicting the predominance of algae or macrophytes based on residence time. Neal et al. (2006b) support the conceptual model of Hilton et al. (2006) with an analysis of the chlorophyll ‘a’ concentrations measured in two of the major river-systems of England: the Thames and Humber.

Economic integration

Birol et al. (2006) provide a paper on using economic methods to inform water resources management. The paper reviews the methods available and provides a case-study of how interviews with the public can be used to determine a perceived value of the Cheimaditida wetland and lake in Greece. This is an important topic as public participation is central to the philosophy of the WFD. Based on this study, it is possible to visualise how economic valuation of environmental restoration can be integrated with the catchment modelling: the models can be used to predict the likely changes hydrology and water quality (and ultimately the ecology) as a result of global change and management options, and then the Choice Method or Contingent Valuation Method can be used to calculate how much the public is willing to pay for the engineering required to reduce water pollution or regulate flows. This would be useful as it would provide civil-engineers with a budget for the restoration of a specific site.

Catchment modelling

Component model development

Over the duration of the project, individual models are being applied at the study sites depending upon the key pollution issues. Specifically, MIKE11-TRANS and the NAMS models are being applied to assess nitrogen, sediment and phosphorus dynamics in the Gjern and Odense (Andersen et al., 2006); the PEARLS model has been applied to the Conwy , and is currently being applied to Bjerkreim (Evans et al., 2006; Cooper et al., 2000); INCA-Sed is being applied to the Kennet, Lambourn, Gjern and Odense (Jarritt and Lawrence, 2006); INCA-P is being applied to the Lambourn, Wye, Savijoki and Tueronjoki sites (Wade et al., 2002a); INCA-N is being applied to the Piburger See, Gjern, Odense, Garonne, Kennet, Lambourn, Tamar, Endrich, Falloch, Tovdalselva, Gårdjsön, Savijoki, Teuronjoki, and La Tordera (Whitehead et al., 1998; Wade et al., 2002b). Further applications are planned for Cheimaditida, and Neajlov. In addition, a new carbon model has been created and a mercury model is under development; both are based on the INCA framework.

Replication

A central theme to the catchment-scale modelling work-package is that of replication. This had two facets. In the first, a single model is applied to river-systems across Europe to assess the likely changes in stream water nitrate concentrations, key source areas and the relative export of nitrate from point and diffuse sources. In the first instance, this will be the INCA-N model which will be applied to the 16 sites listed in the previous section. This work builds on the earlier EU-INCA project (Neal, 2002; Wade and Neal, 2004). The second facet is that different models will be applied at the same site so that structural uncertainty can be factored into predictions of the water quality response to climate change. For instance, INCA-N, INCA-P, INCA-Sed and MIKE11-TRANS are being applied to the River Gjern, Denmark to assess the impacts of climate and land-use change on nitrogen, phosphorus and suspended sediment concentrations; specifically, to determine the differences in prediction of the general trends in flow and in-stream nutrient and sediment concentrations.

Model Chains

Model chains are also being developed where models that simulate either a river or a lake are used in combination. The purpose is to simulate the hydrology, chemistry and ecology, and the dynamic behaviour of rivers, lakes and wetlands as a single continuum, rather than considering these as individual components of the river-system. The linkage of MAGIC, HBV, INCA-N and the Fjord model is reported in this volume (Kaste et al., 2006). Other models will be chained to describe the continuum of nutrient flow in the rivers and lakes. For example, INCA-N and INCA-P will be linked with a deep lake model, HYDRO-1D to simulate the impacts of climate change on algal growth in Loch Lomond, UK whilst INCA-P will be linked with MyLake to simulate algal growth in Lake Pääjärvi, Finland. MAGIC was combined with the PEARLS model to simulate the recovery from acidification across the distributed network of a river-system (Evans et al., 2006).

Model integration

Models are also being integrated rather than chained: instead of the data being transferred between models using text files, the individual models become one. For example, INCA-P and INCA-Sed are being integrated to provide a better representation of particulate phosphorus transport. INCA-P simulates macrophyte dynamics and therefore links the flow and water quality with macrophyte growth (Wade et al., 2001). With model integration, care is required so that the model complexity does not become such that it is difficult to calibrate and test the resultant model. Ideally catchment-scale models should be able to reproduce the observed data whilst minimising complexity.

Equifinality

Water quality modelling is difficult because of an inability to scale point-flux measurements typical of routine monitoring to a value representative of an area which is generally required in models. This inability prevents the identification of the model which best represents a system since the optimum model structure and parameter set can not be found. A key component of the modelling work in Euro-limpacs is to use appropriate methods for examining parameter sensitivity and uncertainty. This has begun with the use of Markov-Chain Monte-Carlo methods for assessing scenario-data and parameter uncertainty in the MAGIC model, and a general sensitivity analysis of both INCA-Sed (Jarritt and Lawrence, in press) and INCA-C. The use of measurements of nitrogen processes as a possible way to reject parameter-sets during model calibration of INCA-N was investigated by Rankinen et al. (2006).

Model based assessments of the factors and processes controlling water chemistry and ecology at the catchment-scale.

Within the project, Artificial Neural Networks were used by Park et al. (2006) to classify and predict fish assemblages from physical catchment characteristics at the local and regional scale. The sensitivity of the MAGIC model to climate change factors was considered by Wright et al. (2006) to provide a basis for future acidification modelling studies. Evans et al., (2006) estimated the recovery from acidification in a distributed river-network, and linked the predicted water quality to the presence of the invertebrate species, *Baetis rhodani*, a biological indicator of acidification. The storage and release of sulphur during and after periods of drought was modelled by Aherne et al., (2006), who also considered the implications of this mechanism in delaying the recovery of soils and a lake from acidification.

Three papers in this volume report the use of models to determine the likely change in nutrient retention in large river systems. The first was a national scale estimation of N leaching and retention in Finnish river-systems using the N_EXRET model (Lepistö et al., 2006). The second quantified the response of the nitrogen concentrations throughout the river continuum from the acidified headwaters to the estuary of the Bjerkreim river, and used these predictions to estimate the changes in the primary productivity of the Fjord in response to climate change (Kaste et al., 2006). The affects of predicted changes in precipitation on the in-stream nitrogen dynamics in a large river-system which contains a lake in the Gjern catchment were estimated by Andersen et al. (2006).

Whitehead et al., (2006) provide a modelling assessment of nitrogen concentrations in the River Kennet in response to climate change, and extend the study by considering a series of management options which may help to mitigate the effects of climate change. The results highlight the variation in the predictions from the General Circulation Models (GCMs). In the Kennet system, the three different models all predict a general warming but at different rates, whilst for precipitation the HadCM3 model predicts less and the CSIRO and CGCM model predicts more.

Wider comment

Given the discrepancy in the climate scenarios from the three different GCMs, any modelling assessment of climate impacts must consider a range of climate models and

Intergovernmental Panel on Climate Change (IPCC) scenarios. A new methodology, based on Monte Carlo, for incorporating uncertainty estimates resultant from down-scaling Global Circulation Models within hydrological and hydro-chemical models has been proposed by Wilby and Harris (in press). This technique appears promising to provide a common framework for creating the ensemble of nitrogen predictions throughout Europe; it is capable of estimating the cumulative uncertainty from the GCMs, the down-scaling method, the choice of hydrochemical model and the chosen parameters in the hydrochemical model.

Many of the catchment-scale models used in Euro-limpacs are spatially distributed and therefore simulation results are available for points throughout the catchment and within the river-network. The model-based assessments of climate change presented in this volume suggest that the models are sensitive enough to predict the changes in the freshwater chemistry. A major challenge is to link the ecology to the chemistry; this has been done at a conceptual level for algae and as formal equations for macrophyte growth and the presence of an invertebrate, sensitive to acidification (Hilton et al., 2006; Wade et al. 2001; Evans et al., 2006). However, there is a need to keep complexity and data requirements to a minimum whilst still producing useful model results.

Hilton et al. (2006) and Neal et al. (2006b) suggest that residence time is key to determining the growth of algae in river-systems. Lepistö et al. (2006) found that the highest retention of nitrogen is in river-systems with the highest percentage of lakes: biological uptake of nitrogen is greater as residence time increases. Thus catchment-scale models of algal growth must account for the residence time in reservoirs, lakes and canals; the total length of the river, the distribution of the river-network and its fractal character, if present, must be represented. This would require the extension of the model of algal growth proposed by Whitehead and Hornberger (1984) to the entire river network from its basis of simulating the main channel only. The implication of the work by Hilton et al. (2006) and Neal et al. (2006b) is that residence time is more important than nutrient concentration in determining the algal biomass; rivers in the UK are typically saturated with nutrients and these are unlikely to be a limiting factor. This has implications for catchment management: removing nutrients from sewage works or imposing controls on farming may not reduce algal growth. Further work on light limitation is required.

Questions still remain over the key sources of, and the factors and processes controlling, nutrients in river-systems. The relative impact of phosphorus from agriculture and sewage remains unclear given phosphorus from agriculture may be bound to sediment whilst that from sewage is in a soluble form (Neal and Jarvie, 2005). Over the next 3 years the catchment modelling in Euro-limpacs will aim to determine the effects of these forms of phosphorus on the in-stream macrophyte population. The dynamic models will also be used to determine the stores of nitrogen, sediment and phosphorus in catchments in order to estimate if nutrient concentrations in rivers can be reduced within the timescales of the WFD.

Carbon concentrations in river-systems in North America and Europe are increasing though the cause is unknown; climate controls have been proposed (Evans et al., 2005). The movement of mercury in the environment is closely related to the carbon cycle in soils and rivers. It is intended that Euro-limpacs modelling work-package will deliver the latest methods to simulate the transport and fate of nutrients, sediment and mercury in catchments.

In all these model developments and applications there is a need to incorporate all the latest process understanding and data. Current emphasis within the UK and the US seems to be upon large integrated-projects that measure many catchment variables in an attempt to explain the hydrology and hydro-chemistry observed in-stream, as in the case of the UK Lowland Catchment Research programme (LOCAR). It is unclear if such data will help to define model structures and parameter sets given the infinite-set of possible combinations, or overcome the inability to scale point measurements to area-based flux estimates. The monitoring of stream-water chemistry at high-frequencies (hourly) over long time-periods (decades) for selected determinands may help to characterise the range of residence times for different pollutants and determine any fractal character that is not simulated by current ‘bucket’ models such as INCA-N (Kirchner et al., 2001). The latter approach is appealing because it does not rely on constructing a conceptual model of the system but allows the residence-time distribution to be determined from measurement. The fractal approach should, however, be used in conjunction with process-based studies to help discriminate between “true age” and “apparent age” , the latter which is caused by the mixing of waters of different age, and deterministic models are still required to quantify the mass of pollutant, such as nitrogen, transferred from the soil-system to the unsaturated zone and/or groundwater. The modelling work within the Euro-limpacs project will begin to explore these ideas.

References

Andersen HE, Kronvang B, Larsen SE, Hoffmann CC, Jensen TS, Rasmussen EK. Climate-change impacts on hydrology and nutrients in a Danish lowland river basin. Sci Tot Environ. This volume.

Aherne J, Larssen T, Cosby BJ, Dillon PJ. Climate variability and forecasting surface water recovery from acidification: modelling drought-induced sulphate release from wetlands. Sci Tot Environ. This volume.

Beven K. Towards an alternative blueprint for a physically based digitally simulated hydrologic response modelling system. Hydrol Process 2002;16:189-206.

Birol E, Karousakis K, Koundouri P. Using economic valuation techniques to inform water resources management: a survey and critical appraisal of available techniques and an application. Sci Tot Environ. This volume.

Cooper DM, Jenkins A, Skeffington R, Gannon B. Catchment-scale simulation of streamwater chemistry by spatial mixing: theory and application. J. Hydrol. 2000;233:483-498.

EEA (European Environment Agency). Europe’s environment: The third assessment. Environmental assessment report No 10. 2003. Office for Official Publications of the European Communities, Luxembourg. 343pp.

Evans CD, Cooper DM, Juggins S, Jenkins A, Norris D. A linked spatial and temporal model of the chemical and biological status of a large, acid-sensitive river network. Sci Tot Environ. This volume.

Evans CD, Monteith DT, Cooper DM. Long-term increases in surface water dissolved organic carbon: Observations, possible causes and environmental impacts. Environ. Pollut. 2005;137:55-71.

Flynn NJ, Snook DL, Wade AJ, Jarvie HP. Macrophyte and periphyton dynamics in a UK Cretaceous chalk stream: the River Kennet, a tributary of the Thames. Sci Tot Environ 2002;282/283:143-157.

Heathwaite AL, Burke SP, Bolton L. Field drains as a route of rapid nutrient export from agricultural land receiving biosolids. Sci Tot Environ. This volume.

Hilton J, O'Hare M, Bowes MJ, Jones JI. How green is my river? A new paradigm of eutrophication in rivers. Sci Tot Environ. This volume.

Jarritt NP, Lawrence DSL. Fine sediment delivery and transfer in lowland catchments: Modelling suspended sediment concentrations in response to hydrologic forcing, Hydrol Process. In press.

Kaste Ø, Wright RF, Barkved LJ, Bjerkeng B, Engen-Skaugen T, Magnusson J, Sælthun NR. Linked models to assess the impacts of climate change on nitrogen in a Norwegian river basin and fjord system. Sci Tot Environ. This volume.

Kirchner JW, Feng X, Neal C. Catchment-scale advection and dispersion as a mechanism for fractal scaling in stream tracer concentrations. J Hydrol 2001;254:82-101.

Lepistö A, Granlund K, Kortelainen P, Räike A. Nitrogen in river basins: sources, retention in the surface waters and peatlands, and fluxes to estuaries in Finland. Sci Tot Environ. This volume.

Marsh TJ, Lees ML (Eds.) Hydrological Data United Kingdom, Hydrometric Register and Statistics 1996-2000. 2003. Centre for Ecology and Hydrology, Wallingford, 208 pp.

Neal C. Assessing nitrogen dynamics in catchments across Europe within an INCA modelling framework. Hydrol. Earth Sys. Sciences 2002;6:297-615.

Neal C, Jarvie HP. Agriculture, community, river eutrophication and the Water Framework Directive. Hydrol Processes 2005;19:1895-1901.

Neal C, Jarvie HP, Neal M, Hill L, Wickham H. Nitrate concentrations in river waters of the upper Thames and its tributaries. Sci Tot Environ. This volume (a).

Neal C, Hilton J, Wade AJ, Neal M, Wickham H. Chlorophyll-a in the rivers of eastern England. Sci Tot Environ. This volume (b).

Park Y-S, Grenouillet G, Esperance B, Lek S. Stream fish assemblages and basin land cover in a river network. Sci Tot Environ. This volume.

Rankinen K, Karvonen T, Butterfield D. An application of the GLUE methodology for estimating the parameters of the INCA-N model. Sci Tot Environ. This volume.

Urban Waste Water Treatment Directive (91/271/EEC): OJ 1991;L135:40-52. Amended to clarify standards for total nitrogen and phosphorus by Directive 98/83/EC: OJ 1998;L67:29-30.

Vuorenmaa J, Forsius M, Mannio J. Increasing trends of total organic carbon concentrations in small forest lakes in Finland from 1987 to 2003. Sci Tot Environ. This volume.

Wade AJ, Neal C, (Eds.) Assessing nitrogen dynamics in European ecosystems: integrated measurement and modelling. Hydrol. Earth Sys. Sciences 2004;8:597-860.

Wade AJ, Hornberger GM, Whitehead PG, Jarvie HP, Flynn N. On modelling the mechanisms that control in-stream phosphorus, macrophyte and epiphyte dynamics: An assessment of a new model using general sensitivity analysis. Wat Resourc Res 2001;37:2777–2792.

Wade AJ, Whitehead PG, Butterfield D. The Integrated Catchments model of Phosphorus dynamics (INCA- P), a new approach for multiple source assessment in heterogeneous river systems: model structure and equations. Hydrol. Earth Syst. Sci., 2002a;6:583–606.

Wade AJ, Durand P, Beaujouan V, Wessel WW, Raat KJ, Whitehead PG, Butterfield D, Rankinen K, Lepisto A. A nitrogen model for European catchments: INCA, new model structure and equations. Hydrol. Earth Syst. Sci. 2002b;6:559–582.

Water Framework Directive (2000/60/EC): OJ 2000;L327:1-72.

Wilby RL, Harris IA. A framework for assessing uncertainties in climate change impacts: low flow scenarios for the River Thames, UK. Wat Resourc Res. In press.

Wright JF, Gunn RJM, Winder JM, Wiggers R, Vowles K, Clarke RT, Harris I. A comparison of the macrophyte cover and invertebrate fauna at three sites on the River Kennet in the mid 1970s and the late 1990s. Sci Tot Environ 2002;282/283:121-142.

Wright RF, VanBreemen N. The Nitrex Project – An Introduction. Forest Ecology and Management 1995;71:1-2.

Wright RF, Aherne J, Bishop K, Camarero L, Cosby BJ, Erlandsson M, Evans CD, Forsius M, Hardekopf DW, Helliwell R, Hruška J, Jenkins A, Kopáček J, Moldan F, Posch M, Rogora M. Modelling the effect of climate change on recovery of acidified freshwaters: relative sensitivity of individual processes in the MAGIC model. Sci Tot Environ. This volume.

Whitehead PG, Hornberger GM. Modelling algal behaviour in the River Thames. Water Res 1984;18:945-953.

Whitehead PG, Wilson EJ, Butterfield D. A semi-distributed Integrated Nitrogen model for multiple source assessment in Catchments (INCA): Part 1 – model structure and process equations. Sci. Tot. Environ. 1998;210/211:547-588.

Whitehead PG, Wilby RL, Butterfield D, Wade AJ. Impacts of climate change on in-stream nitrogen in a lowland chalk stream: an appraisal of adaptation strategies. Sci Tot Environ. This volume.

Nitrate concentrations in river waters of the upper Thames and its tributaries

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Abstract

The spatial and temporal patterns of in-stream nitrate concentrations for the upper Thames and selected tributaries are described in relation to point and diffuse sources for these rural catchments. The rivers associated with catchments dominated by permeable (Cretaceous Chalk) bedrock show a smaller range in nitrate concentrations than those associated with clay and mixed sedimentary bedrock of lower permeability. The differences reflect the contrasting nature of water storage within the catchments and the influence of point and diffuse sources of nitrate. Nitrate concentrations often increase in a gradual way as a function of flow for the rivers draining the permeable catchments, although there is usually a minor dip in nitrate concentrations at low to intermediate flow due to (1) within-river uptake of nitrate during the spring and the summer when biological activity is particularly high and (2) a seasonal fall in the water table and a change in preferential flow-pathway in the Chalk. There is also a decrease in the average nitrate concentration downstream for the Kennet where average concentrations decrease from around 35 to 25 mg NO_3 l^{-1}. For the lower permeability catchments, when point source inputs are not of major significance, nitrate concentrations in the rivers increase strongly with increasing flow and level off and in some cases then decline at higher flows. When point source inputs are important, the initial increase in nitrate concentrations do not always occur and there can even be an initial dilution, since the dilution of point sources of nitrate will be lowest under low-flow conditions. For the only two tributaries of the Thames which we have monitored for over 5 years (the Pang and the Kennet), nitrate concentrations have increased over time. For the main stem of the Thames, which was also monitored for over five years, there is no clear increase over time. As the Pang and the Kennet river water is mainly supplied from the Chalk, the increasing nitrate concentrations over time clearly reflect increasing nitrate concentrations within the

groundwater. It primarily reflects long-term trends for agricultural fertilizer inputs and significant aquifer storage and long water residence times.

The results are discussed in terms of hydrogeochemical processes and the Water Framework Directive and are compared with data from other eastern UK rivers. The importance of diffuse sources of nitrate contamination is highlighted. On a flow weighted basis, the average diffuse component of nitrate is around 95% for the Thames Basin rivers draining Chalk and for the corresponding rivers draining less permeable strata, there is a more significant but not major point source component (at least in terms of flux); the average diffuse component is 79% in this case. These data fit well with earlier assessments of agricultural sources to UK surface waters. Under baseflow conditions the diffuse sources remain dominant for the Chalk fed Thames Basin rivers, but point sources can be dominant for the low permeability cases. On a proportionate basis, the Thames Basin rivers are similar to the rural rivers of the Tweed and Humber Basins in terms of percentage diffuse components although the lower intensity agriculture occurring for the rivers monitored means that the average nitrate concentrations are lower for the rural rivers of central and northern England and the borders with Scotland: the Humber and Tweed.

Key words

Nitrate, RELU, river, Chalk, aquifer, Cherwell, Dun, Kennet, Lambourn, LOCAR, LOIS, Pang, Ray, Thame, Thames, Water Framework Directive.

FIELD DRAINS AS A ROUTE OF RAPID NUTRIENT EXPORT FROM AGRICULTURAL LAND RECEIVING BIOSOLIDS

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ABSTRACT

We report research on the environmental risk of incidental nutrient transfers from land to water for biosolids amended soils. We show that subsurface (drainflow) pathways of P transport may result in significant concentrations, up to 10 mg total P l^{-1}, in the drainage network of an arable catchment when a P source (recent biosolids application) coincides with a significant and active transport pathway (rainfall event). However, the high P concentrations were short-lived, with drainage ditch total P concentrations returning to pre-storm concentrations within a few days of the storm event. In the case of the drainflow concentrations reported here, the results are unusual in that they describe an 'incidental event' for a groundwater catchment where such events might normally be expected to be rare owing to the capacity of the hydrological system to attenuate nutrient fluxes for highly adsorbed elements such as P. Consequently, there is a potential risk of P transfers to shallow groundwater systems. We suggest that the findings are not specific to biosolids-alone, which is a highly regulated industry, but that similar results may be anticipated had livestock waste or mineral fertilizer been applied, although the magnitude of losses may differ. The risk appears to be more one of timing and the availability of a rapid transport pathway than of P source.

KEY WORDS: biosolids, sewage sludge, phosphorus, diffuse pollution, drainage, agriculture

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Increasing trends of total organic carbon concentrations in small forest lakes in Finland from 1987 to 2003

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Abstract

Trends in total organic carbon (TOC) concentrations over the period 1987-2003 were studied in 13 small forest lakes. Recovery from acidification (reduced SO_4 deposition) and long-term changes in runoff as potential drivers for the trends were examined. The results showed that TOC concentrations have increased throughout Finland. Ten of the 13 lakes showed a significant increasing TOC trend ($p < 0.05$), and included both clear water and humic lakes. The largest annual increase in TOC occurred in lakes with the largest average concentrations. The magnitude of the TOC trends were not significantly related to the proportion of peat soils in the catchment but the catchment size was an important predictor. Decreasing SO_4 deposition and improved acid-base status in soil due to the recovery from acidification implied an increased mobilisation of organic acids and TOC. There was little evidence that the long-term increasing trend in TOC concentrations was related to long-term changes in runoff. However, large seasonal and inter annual fluctuations in runoff did appear to affect TOC concentrations for a number of years.

Keywords: organic carbon; DOC; TOC; lakes; acidification; runoff; climate

Using Economic Valuation Techniques to Inform Water Resources Management: A survey and critical appraisal of available techniques and an application.

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Abstract:

The need for economic analysis for the design and implementation of efficient water resources management policies is well documented in the economics literature. This need is also emphasised in the European Union's recent Water Framework Directive (2000/60/EC), and is relevant to the objectives of Euro-limpacs, an EU funded project which *inter alia*, aims to provide a decision-support system for valuing the effects of future global change on Europe's freshwater ecosystems. The purpose of this paper is to define the role of economic valuation techniques in assisting in the design of efficient, equitable and sustainable policies for water resources management in the face of environmental problems such as pollution, intensive land use in agriculture and climate change. The paper begins with a discussion of the conceptual economic framework that can be used to inform water policy-making. An inventory of the available economic valuation methods is presented and a critical discussion is presented on the scope and suitability of each for studying various aspects of water resources. Recent studies that apply these methods to water resources are reviewed. Finally, an application of one of the economic valuation methods, namely the contingent valuation method, is presented using a case study of the Cheimaditida wetland in Greece.

Keywords: water resources, economic value, cost benefit, hedonic pricing, travel cost, contingent valuation, choice experiment.

How green is my river? A new paradigm of eutrophication in rivers

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Abstract

Although the process of eutrophication is reasonably well understood in lakes, there is currently no conceptual understanding of how eutrophication develops in rivers. This issue is addressed here. A review of the main processes controlling the development of eutrophication in lakes has been carried out as a precursor to considering the effect in rivers. The importance of hydraulic flushing in controlling algal growth suggests that short-retention-time rivers will show different effects compared to long retention-time, impounded rivers. The latter are likely to operate like lakes, moving from macrophyte domination to phytoplankton domination whereas the former move to benthic and filamentous algal domination. Subsequently, a conceptual model of the development of eutrophic conditions in short-retention-time rivers is developed. Although there is general agreement in the literature that an increase in nutrients, particularly phosphorus, is a pre-requisite for the eutrophic conditions to develop, there is little evidence in short-retention-time rivers that the plant (macro and micro) biomass is limited by nutrients and a good case can be made that the interaction of hydraulic drag with light limitation is the main controlling factor. The light limitation is brought about by the development of epiphytic algal films on the macrophyte leaves.

The implications of this conceptual model are discussed and a series of observable effects are predicted, which should result if the model is correct.

Keywords: eutrophication, river, macrophyte, epiphytic algae, nutrient, model, review

Chlorophyll-a in the rivers of eastern England.

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Abstract

Chlorophyll-a concentration variations are described for two major river basins in England, the Humber and the Thames and related to catchment characteristics and nutrient concentrations across a range of rural, agricultural and urban/industrial settings. For all the rivers there are strong seasonal variations, with concentrations peaking in the spring and summer time when biological activity is at its highest. However, there are large variations in the magnitude of the seasonal effects across the rivers. For the spring-summer low-flow periods, average concentrations of chlorophyll-a correlate with soluble reactive phosphorus (SRP). Chlorophyll-a is also correlated with particulate nitrogen (PN), organic carbon (POC) and suspended sediments. However, the strongest relationships are with catchment area and flow, where two straight line relationships are observed. The results indicate the importance of residence times for determining planktonic growth within the rivers. This is also indicated by the lack of chlorophyll-a response to lowering of SRP concentrations in several of the rivers in the area due to phosphorus stripping of effluents at major sewage treatment works. A key control on chlorophyll-a concentration may be the input of canal and reservoir waters during the growing period: this too relates to issues of residence times. However, there may well be a complex series of factors influencing residence time across the catchments due to features such as inhomogeneous flow within the catchments, a fractal distribution of stream channels that leads to a distribution of residence times and differences in planktonic inoculation sources. Industrial pollution on the Aire and Calder seems to have affected the relationship of chlorophyll-a with PN and POC. The results are discussed in relation to the Water Framework Directive.

Key words

Chlorophyll, rivers, nutrients, nitrate, particulate nitrogen, organic carbon, phosphate, silica, sediments, Aire, Calder, Don, Humber, Kennet, Lambourn, Pang, Thames, Trent, LOCAR, LOIS, RELU, Water Framework Directive.

An application of the GLUE methodology for estimating the parameters of the INCA-N model

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ABSTRACT

The conceptual and parameter uncertainty of the semi-distributed INCA-N (Integrated Nutrients in Catchments - Nitrogen) model was studied using the GLUE (Generalized Likelihood Uncertainty Estimation) methodology combined with quantitative experimental knowledge, the concept known as 'soft data'. Cumulative inorganic N leaching, annual plant N uptake and annual mineralization proved to be useful soft data to constrain the parameter space. The INCA-N model was able to simulate the seasonal and inter-annual variations in the stream-water nitrate concentrations, although the lowest concentrations during the growing season were not reproduced. This suggested that there were some retention processes or losses either in peatland/wetland areas or in the river which were not included in the INCA-N model. The results of the study suggested that soft data was a way to reduce parameter equifinality, and that the calibration and testing of distributed hydrological and nutrient leaching models should be based both on runoff and/or nutrient concentration data and the qualitative knowledge of experimentalist.

Keywords: GLUE, INCA, soft data, uncertainty analysis, nitrogen, fuzzy rule.

Stream fish assemblages and basin land cover in a river network

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Abstract

This study focused on characterizing fish assemblages in the Adour-Garonne basin and identifying the relative influences of landscape-scale features on observed patterns in stream fish assemblages. Two different artificial neural network algorithms were used: a self-organizing map (SOM) and a multilayer perceptron (MLP). A SOM was applied to determine fish assemblage types, and a MLP was used to predict the fish assemblage types defined by the SOM. Thirty four species were collected at 191 sampling sites in a major river-system, the Adour-Garonne basin, and topographical factors, namely altitude, distance from source and surface area of drainage basin were measured. Using GIS, land cover types (agricultural land, forests and urbanized artificial surface) were calculated for each site and expressed as percentage of the surface area of basin. These variables were introduced to the MLP and factorial discriminant analysis for the prediction of assemblage types. As a result, the SOM distinguished three fish assemblage types according to the differences of species composition, and the assemblage types were better predicted with landscape-scale features by MLP than discriminant analysis. The percentages of agricultural land and the surface area of a basin showed the greatest influence on assemblage types 1 and 2, and distance from source was the most important factor to determine assemblage type 3.

Keywords: fish, assemblages, river, basin, land cover, ANN, GIS

Modelling the effect of climate change on recovery of acidified freshwaters: relative sensitivity of individual processes in the MAGIC model

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Keywords: freshwaters, model, acid deposition, acidification, climate change

Abstract

The MAGIC model was used to evaluate the relative sensitivity of several possible climate-induced effects on the recovery of soil and surface water from acidification. A common protocol was used at 14 intensively-studied sites in Europe and Eastern North America. The results show that several of the factors are of only minor importance (increase in pCO_2 in soil air and runoff, for example), several are important at only a few sites (seasalts at near-coastal sites, for example) and several are important at nearly all sites (increased concentrations of organic acids in soil solution and runoff, for example). In addition changes in forest growth and decomposition of soil organic matter are important at forested sites and sites at risk of nitrogen saturation. The trials suggest that in future modelling of recovery from acidification should take into account possible concurrent climate changes and focus specially on the climate-induced changes in organic acids and nitrogen retention.

A linked spatial and temporal model of the chemical and biological status of a large, acid-sensitive river network

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Keywords: Acidification, surface waters, dynamic, modelling, PEARLS, MAGIC

Abstract

Freshwater sensitivity to acidification varies according to geology, soils and land-use, and consequently it remains difficult to quantify the current extent of acidification, or its biological impacts, based on limited spot samples. The problem is particularly acute for river systems, where the transition from acid to circum-neutral conditions can occur within short distances. This paper links an established point-based long-term acidification model (MAGIC) with a landscape-based mixing model (PEARLS) to simulate spatial and temporal variations in acidification for a 256 km^2 catchment in North Wales. Empirical relationships are used to predict changes in the probability of occurrence of an indicator invertebrate species, *Baetis rhodani*, across the catchment as a function of changing chemical status. Results suggest that, at present, 27% of the river network has a mean acid neutralising capacity (ANC) below a biologically-relevant threshold of 20 μeq l^{-1}. At high flows, this proportion increases to 45%. The model suggests that only around 16% of the stream network had a mean ANC < 20 μeq l^{-1} in 1850, but that this increased to 42% at the sulphur deposition peak around 1970. By 2050 recovery is predicted, but with some persistence of acid conditions in the most sensitive, peaty headwaters. Stream chemical suitability for *Baetis rhodani* is also expected to increase in formerly acidified areas, but for overall abundance to remain below that simulated in 1850. The approach of linking plot-scale process-based models to catchment mixing models provides a potential means of predicting the past and future spatial extent of acidification within large, heterogeneous river networks and regions. Further development of ecological response models to include other chemical predictor variables and the effects of acid episodes would allow more realistic simulation of the temporal and spatial dynamics of ecosystem recovery from acidification.

Climate variability and forecasting surface water recovery from acidification: modelling drought-induced sulphate release from wetlands

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Abstract.

Climate-induced drought events have been shown to have a significant influence on sulphate (SO_4^{2-}) export from forested catchments in central Ontario, subsequently delaying recovery of surface waters from acidification. Field and modelling studies have demonstrated that water table drawdown during drought periods promotes oxidation of previously stored (reduced) sulphur (S) compounds in wetlands, with subsequent efflux of SO_4^{2-} upon re-wetting. Although, climate-induced changes in processes are generally not integrated into soil-acidification models, MAGIC (Model of Acidification of Groundwater in Catchments) includes a wetland compartment that incorporates redox processes driven by drought events. The potential confounding influence of climate-induced drought events on acidification recovery at Plastic Lake, south-central Ontario (under proposed future S emission reductions) was investigated using MAGIC and two climate scenarios: monthly precipitation and runoff based on long-term means (average-climate scenario), and variable precipitation and runoff based on the past 20-years of observed monthly data (variable-climate scenario). The variable-climate scenario included several periods of summer drought owing to lower than average rainfall and higher then average temperature. Nonetheless, long-term regional trends in precipitation and temperature suggest that the variable-climate scenario may be a conservative estimate of future climate. The average-climate scenario indicated good recovery potential with acid neutralising capacity (ANC) reaching approximately 40 $\mu\text{mol}_c\ L^{-1}$ by 2020 and 50 $\mu\text{mol}_c\ L^{-1}$ by 2080. In contrast, the forecasted recovery potential under the variable-climate scenario was very much reduced. By 2080, ANC was forecasted to increase to 2.6 $\mu\text{mol}_c\ L^{-1}$ from –10.0 $\mu\text{mol}_c\ L^{-1}$ in 2000. Elevated SO_4^{2-} efflux following drought events (introduced under the variable-climate scenario) has a dramatic impact on simulated future surface water chemistry. The results clearly demonstrate that prediction of future water quality, using models such as MAGIC, should take into account changes or variability in climate as well as acid deposition.

Key words: wetlands, climate variability, drought, MAGIC, redox-oxidation processes, sulphate, Plastic Lake, Canada

Nitrogen in river basins: sources, retention in the surface waters and peatlands, and fluxes to estuaries in Finland

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Key words: catchment, lake, nitrogen, export, retention, peatland, river basin

Abstract. Nitrogen export from diffuse and point sources and its retention in the major river basins of Finland is quantified and discussed. The estimated total export from river-basins in Finland was 119 000 tonnes N a^{-1} for the period 1993 to 1998 based on N export from different land use types defined in a GIS-based assessment model, incorporated with estimates of N inputs from atmospheric deposition and point sources. Agriculture contributes 38% of the total export, varying in the range 35-85% in the south-western basins and 0-25% in the northern basins. This estimate of N export from agriculture was based on regional N balances together with data from small agricultural research catchments. Forestry contributes on average 9%, with increasing dominance towards eastern and northern parts of the country: from 2-15% in the southern-mid-western Finland basins to 10-30% in the large northern basins. 'Background' N export from forests on both mineral and organic soils contributes 27% on average; in the northern basins it may contribute from 40% up to 90% of the total load. The estimate was calculated based on practically all data available from 42 small, experimental catchments in Finland. Of the total N input to Finnish river-systems,

0 to 68% was retained in surface waters and/or peatlands, with a mean-retention of 22%. The highest retention of N (36-61%) was observed in the basins with the highest lake percentages. The lowest retention (0-10%) of N was in the coastal basins with practically no lakes. In the national N mass balance, 38 000 tonnes N a^{-1} (32%) was estimated as lake retention and 4 000 tonnes N a^{-1} (3%) as retention in peatlands. On the basis of mass balances and sensitivity analysis, retention was in most cases estimated to be in the range of 7.5-12.5 kg $ha^{-1}a^{-1}$ in lakes and 0-1.5 kg $ha^{-1}a^{-1}$ in peatlands. The model results were tested using the split-sample technique and uncertainty estimates for different data sources are provided and discussed.

Linked models to assess the impacts of climate change on nitrogen in a Norwegian river basin and fjord system

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Abstract

Dynamically-downscaled data from two Atmosphere-Ocean General Circulation Models (AOGCMs), ECHAM4 from the Max-Planck Institute (MPI), Germany and HadAm3H from the Hadley Centre (HAD), UK, driven with two scenarios of greenhouse gas emissions (IS92a and A2, respectively) were used to make climate change projections. These projections were then used to drive four effect models linked to assess the effects on hydrology, and nitrogen (N) concentrations and fluxes, in the Bjerkreim river basin (685-km^2) and its coastal fjord, southwestern Norway. The four effect models were the hydrological model HBV, the water quality models MAGIC, INCA-N, and the NIVA FJORD model. The downscaled climate scenarios project a general temperature increase in the study region of approximately 1^{o}C by 2030-2049 (MPI IS92a) and approximately 3^{o}C by 2071-2100 (HAD A2). Both scenarios imply increased winter precipitation, whereas the projections of summer and autumn precipitation are quite different, with the MPI scenario projecting a slight increase and the HAD scenario a significant decrease. As a response to increased winter temperature the HBV model simulates a dramatic reduction of snow accumulation in the upper parts of the catchment, which in turn lead to higher runoff during winter and lower runoff during snowmelt in the spring. With the HAD scenario, runoff in summer and early autumn is substantially reduced as a result of reduced precipitation, increased temperatures and thereby increased

evapotranspiration. The water quality models, MAGIC and INCA-N project no major changes in nitrate (NO_3^-) concentrations and fluxes within the MPI scenario, but a significant increase in concentrations and a 40-50% increase in fluxes in the HAD scenario. As a consequence the acidification of the river could increase, thus offsetting ongoing recovery from acidification due to reductions in acid deposition. Additionally, the increased N loading may stimulate growth of N-limited benthic algae and macrophytes along the river channels and lead to undesirable eutrophication effects in the estuarine area. Simulations made by the FJORD model and the HAD scenario indicate that primary production in the estuary might increase up to 15-20%, based on the climate-induced changes in river flow and nitrate concentrations alone.

Keywords: climate change, nitrogen, acidification, runoff, freshwater, marine eutrophication.

Climate-change impacts on hydrology and nutrients in a Danish lowland river basin

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Abstract

The Mike 11-TRANS modelling system was applied to the lowland Gjern river basin in Denmark to assess climate-change impacts on hydrology and nitrogen retention processes in watercourses, lakes and riparian wetlands. Nutrient losses from land to surface waters were assessed using statistical models incorporating the effect of changed hydrology. Climate-change was predicted by the ECHAM4/OPYC General Circulation Model (IPCC A2 scenario) dynamically downscaled by the Danish HIRHAM regional climate model (25 km grid) for two time slices: 1961-1990 (control) and 2071-2100 (scenario). HIRHAM predicts an increase in mean annual precipitation of 47 mm (5%) and an increase in mean annual air temperature of 3.2 ^{o}C (43%).

The HIRHAM predictions were used as external forcings to the rainfall-runoff model NAM, which was set up and run for 6 sub-catchments within and for the entire, Gjern river-basin. Mean annual runoff from the river basin increases 27 mm (7.5%, $p<0.05$) when comparing the scenario to the control. Larger changes, however, were found regarding the extremes; runoff during the wettest year in the 30 year period increased by 58 mm (12.3%). The seasonal pattern is expected to change with significantly higher runoff during winter. Summer runoff is expected to increase in predominantly groundwater fed streams and decrease in streams with a low base-flow index. The modelled change in the seasonal hydrological pattern is most pronounced in 1st or 2nd order streams draining loamy catchments, which currently have a low base-flow during the summer period. Reductions of 40-70% in summer runoff are predicted for this stream type.

A statistical nutrient loss model was developed for simulating the impact of changed hydrology on diffuse nutrient losses (i.e. losses from land to surface waters) and applied to the river basin. The simulated mean annual changes in TN loads in a loamy and a sandy sub-catchment were, respectively, +2.3 kg N ha^{-1} (8.5%) and +1.6 kg N ha^{-1} (6.9%).

The rainfall-runoff model and the nutrient loss model were chained with Mike 11-TRANS to simulate the combined effects of climate-change on hydrology, nutrient losses and nitrogen retention processes at the scale of the river basin. The mean annual TN export from the river basin increased from the control to the scenario period by 7.7%. Even though an increase in nitrogen retention in the river system of 4.2% was simulated in the scenario period, an increased in-stream TN export resulted because of the simulated increase in the diffuse TN transfer from the land to the surface-waters.

Keywords: Climate-change; modelling; runoff; nutrient loss; nutrient retention; total nitrogen; total phosphorus; NAM; Mike 11; TRANS

Impacts of Climate Change on In-stream Nitrogen in a Lowland Chalk Stream: An Appraisal of Adaptation Strategies

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ABSTRACT

The impacts of climate change on nitrogen (N) in a lowland chalk stream are investigated using a dynamic modelling approach. The INCA-N model is used to simulate transient daily hydrology and water quality in the River Kennet using temperature and precipitation scenarios downscaled from General Circulation Model (GCM) output for the period 1961-2100. The three GCMs (CGCM2, CSIRO and HadCM3) yield very different river flow regimes with the latter projecting significant periods of drought in the second half of the 21st century. Stream-water N concentrations increase over time as higher temperatures enhance N release from the soil, and lower river flows reduce the dilution capacity of the river. Particular problems are shown to occur following severe droughts when N mineralization is high and the subsequent breaking of the drought releases high nitrate loads into the river system. Possible strategies for reducing climate-driven N loads are explored using INCA-N. The measures include land use change or fertiliser reduction, reduction in atmospheric nitrate and ammonium deposition, and the introduction of water meadows or connected wetlands adjacent to the river. The most effective strategy is to change land use or reduce fertiliser use, followed by water meadow creation, and atmospheric pollution controls. Finally, a combined approach involving all three strategies is investigated and shown to reduce in-stream nitrate concentrations to those pre-1950s even under climate change.

KEY WORDS

Kennet, climate change, water quality, nitrate, ammonia, Thames, land use, adaptation.