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# An introduction to INCA : Integrating Nitrogen in Catchments

As any gardener knows, fertiliser makes plants grow faster. Fertilisers come in many forms — commercial mixes, manure, even treated sewage — but they all contain the same vital plant nutrient, nitrogen. Unfortunately, when excess fertiliser drains off agricultural fields, animal waste leaches from farmyards or sewage is discharged into rivers, they continue to make plants grow. Fast-growing weeds and algae can multiply ferociously, choking out light, depleting oxygen and killing fish. Bacteria move in, turning recreational lakes into smelly health hazards, and the rapid growth of weeds and algae is often at the expense of plants of conservation importance. High levels of nitrogen in drinking water may harm infants under six months old, and require expensive treatment.

Nitrogen comes not only from fertilisers and human and animal wastes but also from car and industrial emissions to the atmosphere that fall as rain or are deposited and captured as particles or gases by vegetation. This deposition can be high in areas close to the source and it is particularly important even in relatively clean areas where it provides the only N fertiliser and may lead to acid rain and river and lake acidification.

Reducing nitrogen is the solution, but how, and where? In a landscape that contains urban areas, farms, pastures and forests, where should efforts be targeted to reducing nitrogen sources, and how effective will those efforts be? How can we minimise financial costs and maximise environmental benefits? The issue is not simply local as it applies to regional, national and continental scales alike. And, for adequate understanding, data are needed from a wide variety of areas to see what the levels of N are and how they vary and in what way they vary from site to site. There are many studies of N pollution across the world and Europe has some of the best and most extensive measurements available. Given these needs and the opportunity to make use of the large amount of information available, the INCA (Integrated Nitrogen in Catchments) project brought European scientists together over the past three years to begin to answer some of these important questions.

INCA provides a simplified model of the way nitrogen inputs are processed and transported within the landscape. The landscape unit may be as large and complicated as a national-scale river or as small and apparently simple as a field of wheat. INCA takes all nitrogen sources, processes them through crops, semi-natural vegetation, microbes and soil to predict how much nitrogen will come out into the river or stream.

If that nitrogen level is too high (50 milligrams per litre of nitrate is the EU maximum), different options can be esplored to reduce it. These could include cutting back on fertiliser appliations, changing crops or crop rotations, planting forests, shutting down or upgrading sewage works, or combinations of these strategies. Of course, at this stage, all these strategies are virtual and on the computer screen only. The benefit of models such as INCA is that any number of different scenarios can be played out to identify those most likely to succeed.

Using INCA modelling is no substitute for taking measurements on how the real world is operating, but it does allow prediction of how N varies across landscapes where currently there are no measurements available. Further, it does provide some clues when asking the “what if” questions vital for making good guesses on how to manage the environment.

INCA was first developed for a typical UK landscape, so creating a broad (generic) easy to use version that could be used throughout Europe was a challenge. How to deal with pig farms in Brittany? Moors and heaths above the Arctic Circle? Cork oak forests in Catalonia? In some cases, simple adjustments were all that were necessary. Adding the possibility of a persistent snowpack allowed the model to function in Scandinavia. Other cases were less successful. Nitrogen in rivers in the extreme ‘drought-or-flood’ climate of the Mediterranean, for example, was never well modelled. But examining the differences between actual river concentrations and model results proved enlightening. The best way to explain the discrepancy was to assume that the river cannot transfer water back to the land during the dry season, and large amounts of groundwater (and the nitrogen dissolved in it) move from the river back *into* the land during floods. These insights may well form a basis for developing strategies to reduce water pollution in similar semi-arid environments.

INCA was also used to explore how nitrogen pollution in European rivers may change in the future. In 50 years, for example, the climate of many parts of Europe is expected to be warmer and wetter, but the rain should be cleaner as pollution controls reduce the incidence of acid rain (which contains nitrogen). INCA predicts that the nitrogen in rivers draining many agricultural areas will increase. Even though the rain will be cleaner, heavier rainfall means more water will leach through nitrogen-laden soils, and warming soils will decompose faster, releasing yet more nitrogen. Rivers in southern Scandinavia, on the other hand, should — on balance — benefit more from the reduction in acid rain and become less nitrogen-polluted.

INCA is a far from perfect depiction of the environment. Like many similar ecosystem models, it is better at predicting annual averages than daily events, and it frequently underestimates transient peaks in nitrogen that may come from unknown sources or poorly-understood internal processes. It works best for mixed agricultural catchments with large, constant inputs of nitrogen. INCA and models like it serve as useful guides to evaluate different strategies for nitrogen pollution abatement in a wide variety of environments across Europe. The model points out where understanding of these environments is flawed or lacking; measurements then show how good or how bad the estimates are!

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# Special Issue

# Assessing nitrogen dynamics in European ecosystems: integrating measurement and modelling

## Preface

This volume brings together recent work on the measurement, process understanding and modelling of nitrogen in European freshwater ecosystems. The work builds on the development of a generic nitrogen model for catchments across Europe (INCA: **I**ntegrated **N**itrogen in **CA**tchments model) and is a successor to a previous Special Issue of *Hydrology and Earth System Sciences*, Volume 6(3) (2000), 297–615. The present volume:

(1) brings together the final conclusions from the European EU-INCA study,
(2) provides the vanguard papers for a major new UK initiative on **Lo**wland **CA**tchment **R**esearch (LOCAR)
(3) reports contemporary and complementary research in the area of nutrient dynamics.

The key issues raised in this volume are:

- the factors contributing to nutrient transport and storage within a range of European ecosystems;
- the quantification of nutrient transport and storage within a range of European ecosystems through measurement and modelling approaches;
- the general applicability of measurement and modelling approaches to European systems;
- the relation between diffuse and point sources of nutrient pollution;
- the impacts of land management, climatic change and socio-economic factors on nutrient fluxes.

There are 22 papers in this volume. The first paper, which precedes this preface, provides a summary of the project in relation to public perspectives. Four papers describe regional water quality assessments. Two relate to the UK LOCAR programme (Neal *et al.*, 2004a, b); they report the first catchment-scale solute mass-balance and analysis of the spatial and temporal patterns for a broad suite of determinands in a Chalk groundwater system typical of much of lowland England. The third paper describes the spatial variations in the water quality and ecology of the River Lee in south-east England (Snook and Whitehead, 2004). The Lee represents a system of extreme contrasts: the northern part is dominated by arable agriculture while the southern part drains north-east London with a population of approximately two million people. The final paper in this group places the issues of nitrogen losses from catchments within a regional context for the Nordic and Baltic region (Vagstad *et al.*, 2004). A key feature of this case study is the large variability in losses across the catchments relating to physical, geomorphological, hydrological and land use factors.

Three papers then deal with wetland systems. The first describes a bio-indicator technique for assessing wetland ecosystem health (Kennedy and Murphy, 2004); the others focus on improving knowledge of the role of wetlands in nutrient storage and transport. Fisher and Acreman (2004) investigate the functioning of different wetland types to determine the key factors and processes controlling wetland behaviour in terms of nitrogen and phosphorus storage and transport; Machefert and Dise, (2004) review the hydrological controls on denitrification to determine an equation which may be included in nitrogen models to estimate denitrification flux

The next six papers deal with modelling nitrogen dynamics. The first two describe developments to the INCA soil temperature calculation and parameter temperature-dependency necessary when applying INCA to cold climates (Rankinen *et al.*, 2004a, b), followed by two describing applications of the INCA model to Maritime and Mediterranean climates (Granlund *et al.*, 2004; Bernal *et al.*, 2004). The remaining two papers describe an INCA application and an Artificial Neural Network to test the

INCA model structure (Lischeid and Langusch, 2004) and the parameter uncertainty in the INCA model resulting from uncertainty in the input data and the key data types required to calibrate the model successfully (Raat *et al.*, 2004).

Three papers then focus on the potential impacts of land-use, deposition and climate change on catchment hydrology and in-stream nitrate concentrations. In the first, the INCA model is used to investigate the impact of afforestation of former agricultural areas in Denmark (Bastrup-Birk and Gundersen, 2004). The next predicts the hydrological and in-stream nitrogen concentration response in Norway and Finland to the effects of climate and N deposition changes over time (Kaste *et al.*, 2004), while the third examines the effect of climate and crop rotations on flow and in-stream nitrogen concentrations in north-west France (Durand, 2004).

Four papers then describe contemporary model developments for assessing and managing nutrient leaching and in-stream concentrations. A WANDA model of N leaching from forest systems is described (Tietema, 2004) and estimates of N leaching from forested systems using this model are compared with regression model and SMART modelling estimates at the national scale in The Netherlands (Kros *et al.*, 2004). Davies and Neal, (2004) use existing regional water quality data within a Geographical Information System framework to make rapid assessments of nitrogen hot-spots in major river systems of contrasting land-use. Hewett *et al.*, (2004) then describe a practical scheme for determining how nutrient loss may be managed at the field or farm-scale, with reference to quantifying nutrient loss using the INCA-P model.

A concluding paper draws the volume to a close in relation to the science (Wade *et al.*, 2004).

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