School of Natural Sciences
Trinity College Dublin

Walsh PhD Fellowship: Nutrient source apportionment in Irish water bodies

Context: Nutrient transfers from land to water, caused by combinations of phosphorus and nitrogen loss from agricultural and urban sources, are considered to be one of the most pervasive water quality problems in developed countries. These sources have predominant periods of mass transfers and impacts in specific water body types according to influences of current hydrology and landuse and past activities and conditions. In Ireland, all water body types can be impacted by nutrient transfers; preventing these impacts from occurring requires a detailed understanding of dose-response issues at both low and high river flows and in standing water bodies. Building on ongoing catchment scale research into the delivery of nutrients to inland water bodies, this project aims to investigate the seasonal impacts of specific nutrient sources on a selection of rivers and lakes in Ireland. Utilising state-of-the-art high resolution monitoring facilities established through the Agricultural Catchments Programme (ACP), the objectives of the project are to:

1. use existing datasets of river discharge and nutrient concentration from meso- to macro-scale river catchments to develop nutrient load apportionment models;
2. use the nutrient load apportionment models to compared with patterns and residence times from a series of high resolution discharge and water quality river stations in Ireland; and
3. determine the water quality impacts of external and internal nutrient loading patterns in standing waters.

Requirements: Applicants should have a good primary degree (II1 or I) and a M.Sc. in an appropriate discipline (Geography, Earth Sciences, Environmental Sciences, Environmental Engineering, etc.). The successful candidate will be highly self-motivated and prepared for extended periods of hydrological and limnological field work working with modern field-based analytical equipment. (S)he will also be keen to publish the results of their research in high impact journals in the field. A full EU driving licence is required.

Award: The successful applicant will be enrolled as a student and based primarily in the School of Natural Sciences, Trinity College, University of Dublin, Ireland. Some time will also be spent at the Teagasc Johnstown Castle Research Laboratories, Wexford. The 4 year award (comprising EU-level fees, laboratory and fieldwork costs and a stipend of c. 15,000 Euro per year) will start as soon as possible after 1st October 2010. However the post will be kept open until the most suitable candidate is appointed.

Supervisors: Prof David Taylor (Trinity College, Dublin), Prof Phil Jordan, Dr Karl Richards and Dr Alice Melland (Teagasc, Johnstown Castle, Wexford).

Further Information/applications:
Prof David Taylor, School of Natural Sciences, Trinity College, University of Dublin
Phone: +353 (0)1 896 1581 Email: taylord@tcd.ie
http://www.naturalscience.tcd.ie/

Prof Phil Jordan, Teagasc Johnstown Castle
Phone: +353 (0)53 917 1260 Email: phil.jordan@teagasc.ie
http://www.teagasc.ie/agcatchments

Application Procedure: Submit **an electronic copy** of Curriculum Vitae, including the names and contact details of two academic referees, and a letter of interest to Prof David Taylor (taylord@tdc.ie).

Closing date for receipt of applications: 5pm (Ireland time) 31st July 2010.

1. PROJECT ABSTRACT

Nutrient transfers from land to water may cause eutrophication and lead to impaired ecological status. Legislation to mitigate phosphorus (P) and nitrogen (N) transfers from catchments is via the Nitrates and Urban Waste Water Treatment Directives for the major agricultural and sewage derived sources, respectively. Changes in the ecological status of Irish rivers, as defined by EPA Q-values that are based on metrics of macro-invertebrate communities, indicate that the proportion of channels considered unpolluted has fallen in recent years. The risk to surface waters has also been defined for River Basin Districts in Ireland and indicates higher risks from diffuse P sources. The apparent link between high diffuse risk and falling ecological status for rivers is based on the assumption of 'dose-response': diffuse nutrient risks from agriculture are assumed to be high owing to high proportions of agricultural land in catchments that are a source of nutrients. However, diffuse nutrient transfers are linked to high magnitude, episodic events that have relatively short-lived effects (i.e. low residence time) in rivers. A more appropriate conceptual model of dose-response in rivers is therefore required, one that is characterised not by episodic events but by low magnitude, high occurrence transfers of high residence time that maintain a high ambient nutrient status in rivers. Although they form a small part of an overall nutrient load, these transfers are more potent than episodic events in terms of eutrophic impacts in rivers. This project will use new and existing datasets to determine loads from the principle nutrient sources in catchments and also develop a more appropriate metric that determines the ambient nutrient concentration. With regards to standing water bodies, the project will determine the relative eutrophic effects on a case study lake of both external and internal nutrient loads. In terms of catchment management, the metrics will form a national tool for establishing the importance of point and diffuse nutrient transfers and their relative impacts in terms of flowing or standing water bodies.

2. PROJECT DESCRIPTION

2.1 Title: Nutrient Source Apportionment in Irish water bodies

2.2 Aim and objectives:

The aim of the research project is to develop a conceptual model of nutrient transfers, residence times and potential impacts for catchments in Ireland and will be delivered via three main objectives:

1. Use existing instantaneous, low resolution discharge and nutrient concentration data from meso- to macro-scale catchments and fit load apportionment models (LAMs)

2. Use this principle to establish patterns and residence times from a series of high resolution discharge and water quality stations in the Agricultural Catchments Programme (ACP)

3. Determine the eutrophic impacts of external and internal nutrient loading patterns at high resolution in standing waters.

2.3 Justification:

The nutrient transfer continuum (Haygarth et al. 2005) provides a framework for conceptualising the process of eutrophication from different source starting points. This model proposes that *sources* of nutrients are exposed to a *mobilisation* process, follow one or a number of *pathways* and are *delivered* to water bodies where an *impact* may manifest. It is an articulation of a dose-response model but considers the dose and transfer processes in the

catchment and the response in catchment water bodies. The model can be conceptualised for any nutrient source or any other catchment derived pollutant.

The transfer of phosphorus (P) to surface and groundwaters is the most pressing water quality problem in Ireland and is the primary cause of freshwater eutrophication. Levels of nitrogen (N) in groundwaters are generally limited but the nutrient could be responsible for eutrophication in some estuaries and coastal sites. With P, however, the link is clear, and P concentrations are a major factor underpinning the eutrophic status of lakes and rivers. Increases of P concentrations over the last c. 30-40 years, evident in both monitoring and sediment-based (palaeolimnological) datasets, are widely reported for lakes and rivers in agricultural catchments in Ireland and are associated with ecological changes.

Nevertheless, a tendency to attribute observed impacts (for example as Q status) from ambient riverine P concentration and the high loads that are assumed from agricultural landuse in upstream catchments (for example Donohue et al., 2006) require clarification and may, in a worst case scenario, apportion blame and mitigation resources to the wrong source (Withers and Jarvie, 2008). In the continuum concept, for example, diffuse transfers of P are not occurring when the pathway is not operating – that is to say, when it is not raining. When the connection is made, the loads tend to dominate annual budgets as they are allied with high magnitude discharges. Between storm events, ambient P concentrations are low and a reflection of no other sources (in pristine systems) or high and a reflection of point sources (Douglas et al., 2007). Periods between storms are generally associated with low load proportions that are experienced over a relatively long period. If this period coincides with a particularly ecologically sensitive time (e.g. spring) then any eutrophic impact potentially could be profound. In summary, it is residence time and not load that is important in terms of river P impact. Similarly in lakes, the residence time of nutrient concentration influenced by external and internal loads and especially during ecologically sensitive times will be a key factor in understanding recovery times from eutrophication. The importance of residence time to P impacts has now to be recognised in a new generation of source apportionment methods.

2.4 Methodology and other details:

The major aim of this proposal is to develop a conceptual model of nutrient transfers, residence times and potential impacts to investigate, for example, the extent to which river Q-values are influenced by low magnitude, high frequency, non-agricultural P sources in surface water dominated rivers and not by high magnitude, low frequency diffuse sources from soils. Two caveats need to be highlighted, however. First, where groundwater is the dominant proportion of river flow and where measured groundwater P concentrations are high, then the long residence times afforded by eutrophic groundwater flowing into rivers negates the premise that point sources provide the only significant between-storm source. Second, where a standing water body, such as a lake or reservoir, represents the end point of a river, then the trophic status of that water body is influenced by the river P load and/or the internal load and not the ambient P concentration of the inflowing river.

The boundaries of this proposal are therefore limited to rivers and lakes with significant surface and near-surface pathways and to where P is assumed or observed to be the major nutrient transfer requiring mitigation. Cognisance of the caveats will, therefore, be built into the final conceptual model of load apportionment. Nevertheless, surface pathway dominated rivers with influences from diffuse and point source P transfers represent the major river typology in Ireland and lake impacts from surface water sources. This is due to large areas of soils with impeded drainage and or impermeable geology that influence surface runoff and diffuse pollution, and also due to dispersed housing in the Irish landscape with small rural towns that influence point source pollution.

The research proposed will test the hypothesis that ambient P (or time-weighted) concentrations in rivers are not primarily linked to predominant landuse but to dispersed point sources. The logical alternative hypothesis will be to test whether the river P load (or flow-weighted concentration) is of more concern to the eutrophication of standing water-bodies that rivers drain into and to determine the seasonal role of internal loading. For sustainable

agriculture this will be an extremely important premise as it is often accepted by catchment managers that the largest nutrient source in catchments (for example Smith et al., 2005) has a ubiquitously high risk of impairing water bodies - *of all kinds*. As further constraining measures are considered for agriculture for the protection of specific water bodies and/or habitats beyond those already prescribed under the Nitrates Directive, finding a metric or series of metrics that appropriately follow the nutrient transfer continuum concept for the management of particular water bodies at risk is important. It is clear that the mitigation of all point and diffuse sources require attention under programmes of measures in the main EU directives aimed at water protection. However, with limited resources for inspecting the success of mitigation measures, establishing the nutrient sources and timing responsible for individual water body impacts assumes an even greater importance than might otherwise have been the case.

With these considerations, five Tasks (workpackages) will deliver the three objectives, above:

i. **Literature review and data compilation.** This task will select river catchments with established Q-value, discharge and P chemistry datasets from EPA and OPW sources. Other suitable datasets in Northern Ireland will also be collated from Environment Agency Northern Ireland (EANI) where inter-calibration with ecological metrics has been established. As data on river chemistry are generally only collected on a monthly basis, and there is some variation in quality – and in the type of data collected - between collecting stations and over time, the careful examination and quality assurance of several years of records of river data will be an important and time-consuming component of this stage of the proposed research.

ii. **Development of LAMs.** Data compiled and quality assured in Task 1, above, will be used in Load Apportionment Models (LAMs; Bowes et al., 2008; Neal et al., 2008; Jarvie et al., 2010) to establish the relative influence of *flow-independent*, continuous P point sources, and also from *flow-dependent*, episodic diffuse P sources. In these models, at baseflows, point source P is diluted as baseflow increases and, during runoff events, diffuse sources increase the concentration of P as flow increases. A *Qe* parameter determines the flow where the predominant influence of point sources end and where diffuse source predominance starts. The percentage time in a year that river flows are below *Qe* determines both the load of point sources and also the crucial period of time that this source and load influence ambient river P concentrations. This Task will form a single chapter in the PhD thesis and a paper submitted to an internationally regarded journal.

iii. **Detailed River Study**. The River Glyde at Tallanstown drains a 270km^2 catchment in a region of drumlins in Counties Cavan, Meath, Monaghan and Louth. The local hydrometric station was established in 1975. The catchment epitomises an extreme example of surface pathway-dominated river landscapes, characterised by poorly-drained soils and a range of grassland based agricultural landuses with different intensities of utilisation. Levels of human population are also relatively high, as the catchment contains two towns, Carrickmacross, Co. Monaghan and Kingscourt, Co. Cavan. There is a range of Q-value sampling points and a further two established hydrometric stations upstream. This workpackage will augment the EPA data with a targeted year of weekly and sub-weekly water chemistry sampling to include different P fractions (TP, TSP, SRP, MRP) and ancillary chemistry to include boron (B). Boron is a highly reliable indicator of point source inputs from Waste Water Treatment Works as it is a major ingredient of modern detergents (Jarvie et al., 2006). These data will help to validate the assumptions described above and should show an increase in concentration at ambient low flows in conjunction with increases of soluble P – if point sources are present and predominant below the *Qe* threshold. This Task will form a single chapter in the PhD thesis and a paper submitted to an internationally regarded journal.

iv. **LAMs and High-Resolution Data.** The fourth workpackage will be used to evaluate critically the assumptions in tasks 2 and 3 and the LAMs. Data will be used from

several high resolution monitoring stations maintained by the ACP that are generating sub-hourly TP and MRP (with similar NO_3-N, turbidity, conductivity and temperature) data with synchronous discharge measurements. These data series represent the most complete determination of nutrient transfer dynamics in rivers (Jordan et al., 2007), and data will be used ultimately to evaluate the Good Agricultural Practise regulations in 6 mini-scale catchments. The assumption of the *Qe* parameter is critical to LAM and only with a high resolution dataset can these assumptions be validated. For example, the process of small storm events impacting channel beds but below the annual *Qe* flow parameter may describe P transfer patterns ordinarily associated with flow-independence, i.e. rain-induced but below *Qe*. This Task will form a single chapter in the PhD thesis and a paper submitted to an internationally regarded journal.

v. **External and Internal Lake Nutrient Loading.** The fifth workpackage will use in-situ lake water quality probes monitoring Chl-a, DO, turbidity, temperature and pH to investigate the role of internal loading events compared with external loading events (Task 4) and the resulting eutrophic impacts. The role of lake stratification and sediment P release, wind-induced sediment resuspension and pH controls of ligand exchanges on resolubilised P during ecologically sensitive times will be established. Data from high resolution water quality stations and meteorological stations will provide ancillary data. This Task will form a single chapter in the PhD thesis and a paper submitted to an internationally regarded journal.

The five tasks will result in at least four manuscripts submitted to peer-reviewed internationally-regarded journals (e.g. *Water Research, Journal of Hydrology, Science of the Total Environment*) and the student candidate will be expected to present to at least one Irish and one international conference audience of scientific peers.

The two PIs (professors Taylor and Jordan) have a range of hydrology and limnology experience to manage and guide the proposed project, including early development of LAMs on Lough Sheelin catchment data, establishing long term datasets using high resolution monitoring, and leading the science team of the Agricultural Catchments Programme (ACP). The student candidate appointed to this project will be able to make use of state-of-the art facilities both in terms of access to field facilities in up to six highly instrumented catchments operated by the Teagasc ACP and also in terms of supervisory support and access to high specification laboratory facilities in TCD. In summary, the research will make good and effective use of high quality infrastructure that has recently been established, both in Teasgasc and TCD.

The student will be trained in a range of catchment science techniques including the use of spatial datasets in Geographical Information Systems, collection and analysis of hydrometric and hydrochemical data, boat handling, statistical analysis, analytical chemistry and the use of modern, bankside analysis equipment.

2.5 Expected outcomes:

There will be a series of outcomes from this project:

i. A fully validated conceptual model of P transfers from point and diffuse sources in surface pathway dominated catchments with reference to potential impacts in both flowing and standing water bodies

ii. A method for defining the load apportionment and predominance of P transfers in river catchments

iii. Catchment management tool determining where P mitigation should be targeted according to point or diffuse predominance on target water bodies

iv. A thesis submitted as published papers or submitted manuscripts (at least four) in internationally regarded peer-reviewed journals (target journals include *Water Research, Journal of Hydrology, Science of the Total Environment*).

v. A fully trained agri-environmental scientist with transferable skills in nutrient hydrochemistry and catchment hydrology – and expertise in an area of agri-environmental science that is traditionally contentious (definition of point verses diffuse nutrient transfers).

2.6 Briefly describe the college commitment to the development of the post graduate student:

Both PIs (Taylor and Jordan) have extensive experience of the successful supervision of graduate research students to PhD level. Training in the required specific skills for the PhD researcher will be delivered, through a combination of lectures, workshops, practicals, group discussion and individual mentoring. The student will have the opportunity to be an active participant in the new, joint TCD-UCD Innovation Academy, and to take the 10 ECTS module *Origins of Innovation* within the first 18 months of their registration in TCD. Through this structured programme they will be able to accumulate credits over the duration of their four years of registration as a research student. The student will also be encouraged to take modules from the current MSc programmes in the Schools of Natural Sciences and Engineering, such as *Water Resources Planning* up to a total of 30 ECTS (including the 10 ECTS module *Origins of Innovation*). The credits acquired will allow the student not only to develop their field and laboratory skills in areas highly relevant to their research, but also to graduate with a qualification in Innovation and Entrepreneurship, in addition to their PhD degree.

2.7 Briefly describe the collaboration between the college and Teagasc that will arise from this application?

The application will provide a synergy between catchment scientists and geographers/environmental/agricultural scientists and build on an established partnership between the two institutions (Profs David Taylor and Philip Jordan have worked on collaborative projects since 2003) working on the study of the fate and history of P transfer dynamics. Inclusion of Dr Karl Richards on the Teagasc supervisory panel will further this link and also between the ACP and other agri-environmental themes in Teagasc. Inclusion of Dr Joerg Arnscheidt, University of Ulster, UK, on the supervisory panel will also facilitate access to EANI data and to previously collected high resolution data. The collaboration will also engage cutting edge catchment science methods with the ACP; one of Europe's most ambitious catchment management programmes concerned with the evaluation of the Irish Nitrates Directive Action Programme. This will provide significant added value to the Programme and to scientists from each institution.

References

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