Adaptive Management of Catchments for the Protection of Water Quality: Drawing on International Experience

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Abstract

The problem of diffuse water pollution originating from agriculture and other rural land uses poses particular challenges for public policy and may require innovative adaptive management approaches for its solution. Unlike point source pollution diffuse pollution cannot easily be controlled through monitoring and regulation. The polluters are typically uneducated in the environmental consequences of their land use actions, numerous, dispersed and often remote. Pollution pathways into the environment are diverse and difficult to trace, and pollution events are not evenly distributed, either spatially or

temporally. Thus monitoring and enforcement costs for regulation are high, even if the originators of pollution can be definitively identified.

Catchments are heterogeneous and the available physical and socio-economic data needed to determine optimal technical solutions, and regulatory or other policy regimes, are rarely adequate. Solutions also ultimately require behavioural change on the part of land users, and must be flexible and adaptive to stochastic catchment conditions and to long-term trends such as climate change. To be sustainable an adaptive management approach is needed, in which the development of institutions and policies proceeds in parallel with improved scientific understanding and management of the catchment.

Assessment of the social and economic implications of measures to reduce diffuse pollution is also challenging. In agriculture diffuse pollution is an externality of processes that produce goods, livelihoods and landscape attributes that sustain rural communities, are generally desired by society, and in some incidences can be recognised as 'public goods'. This raises questions of whether reducing water pollution will compromise the viability of the rural economy, and of how the costs of water protection should be distributed. Pollution mitigation measures can also have both positive and negative externalities. Analysis must extend beyond the farm to consider all aspects of land use, landscape heritage and the rural economy, including the viability of settlements, tourism, habitat management for biodiversity and recreation management.

For policy the key point is that the incentives provided by markets will not signal all such values to land users, thus justifying both intervention by government and/or community, and an evolutionary approach. Identifying and ranking the goals for such interventions and how best to implement them merits wide stakeholder involvement and an appropriate degree of democratic accountability. In broad terms, means to address the problem include: economic policy instruments; regulation; voluntary agreements with land users; self-regulation; advisory and education campaigns; and direct

land management strategies. The central challenges are how to determine and implement the best combination of measures for a specific catchment, given local conditions and wider policy constraints. Determination of the optimal governance regime for a catchment must take account of both national (or EU-wide) policy constraints and catchment specific characteristics. The latter including all relevant physical, socio-economic and cultural characteristics. This can only be achieved through an adaptive process.

Internationally new models of governance for land and water resource management are developing. Subject to increasing scarcity of the resource and to growing pollution pressures, water governance can involve problems that are characterised by high levels of uncertainty and a diversity of competing values and claims. The problems may be intractable for a single agency working alone, but the establishment of effective partnerships and collective action must overcome the tendency of stakeholders to pursue narrow self-interests. Catchment-scale projects must involve multiple agencies from different levels of government and from civil society, and thus partnerships and structures that result in effective cooperation and coordination at local level are essential. Complexity and conflicts of interest are inevitable, but these are conditions under which effective participatory and adaptive processes can deliver incremental benefits in terms of improved outcomes at affordable cost.

This paper reports the results of a comparative analysis of international catchment management programmes and provides a synthesis of key programme elements and lessons of success. Whilst the empirical evidence shows there are no dogmatic solutions, some universal attributes can be identified and incorporated in the beginnings of a 'template' for land and water management at catchment scale. It is concluded that land management and diffuse sources of pollution have a local basis and protection of water at source necessitates the fostering of local instruments and participation of stakeholders in an adaptive process, supported by an enabling policy and regulatory environment. There is a need for local and wider legitimacy of organisational structures and institutions, and assimilation of duties and responsibilities in partnerships that offer a unified and

integrated catchment programme. Key elements include the legislative and policy provisions needed to support such programmes, and determination of the most effective balance between regulation, voluntary initiatives and economic incentives in changing the behaviour of land users.

1. Background

Demands on water resources are increasing throughout the UK and internationally, and trends indicate that current water resource use is unsustainable. Catchments (watersheds or river basins) are natural units for managing the volume of water abstracted and for protection of water quality because they comprise a convenient naturally defined topographic area from which water drains to an identifiable point. They are therefore an obvious base for integrated analysis and management of the quantity and quality, of water, its economic use, and ecosystem functions. However, this principle should not be applied without appreciation of the typically poor match between physically defined catchment boundaries and existing political and administrative boundaries. Also the relevance of analyses of particular physical processes or water management systems at a smaller sub-catchment scale.

That use and protection of water resources must assume a catchment or watershed framework is increasingly recognised. For example, the European Union Water Framework Directive (WFD) requires water resources to be managed by river basin rather than existing political administrative boundaries.

A parallel, and similarly international, development is the emergence of new models of governance in water management. Subject to increasing scarcity of the resource, water governance can involve contradictory, complex and interrelated problems that are characterised by high levels of uncertainty and a diversity of competing values and claims. These problems defy definitive formulation of the problematic itself, or of rules for determination of a final

optimal solution. They require a 'process' or adaptive management approach that seeks iterative improvements over time rather than a final resolution. The problems are typically intractable for a single agency working alone, but the establishment of effective partnerships and collective action must overcome the tendency of stakeholders to pursue narrow self-interests (whether land users or 'single issue' interest groups). The role for central government is to set the essential legislative and regulatory framework and to foster more democratic, participatory and adaptive approaches to problem solving and implementation; achieving this through local instruments and participation of stakeholders supported by sound scientific understanding and an enabling policy environment

The extent to such developments are being codified in legislation is illustrated by the statutory incorporation of public participation into the production of river basin management plans by the WFD. Internationally 'stakeholder participation' has become central to debates about resource use conflicts, policy choice and implementation, the accountability of public and private agencies, and the internalization of external social and environmental costs by all actors. However, relatively little is known about how best to initiate and sustain such processes for catchment management for the control of diffuse rural pollution.

To address this issue a scoping study was carried out which involved an initial assessment of the potential of catchment management measures for water quality improvement. Specific research methods included literature review, individual and group interviews during study tours and site visits, policy review, and comparison of catchment characteristics and management programmes. Regular meetings of the research team were held, and two workshops that facilitated engagement with a wider network of stakeholders. The work focused on catchment agricultural programmes implemented through change in land and water management practices on farms, and on the participatory and other governance arrangements necessary to implement these successfully. An initial characterisation and assessment of such approaches from selected cases was made and is summarised below.

2. Brief profiles of catchments studied

2.1 New York City's Watershed Protection Plan and the Cannonsville Catchment, USA

This programme protects the water supply for New York City (NYC) that mainly originates from three catchments in upstate NY: the Catskill, Delaware and Croton systems (approx. 5,100 km^2). The surface waters from the Catskill and Delaware systems in particular carry little sediment and are not filtered before delivery to about nine million consumers. Recognising the growing pollution pressures arising in the catchments, and that it owned, managed and could control only a small proportion (<10%) of the land supplying its reservoirs, NYC through its Department of Environmental Protection (DEP) entered into a Watershed Agreement with Federal, State and local stakeholders. Its purpose is to maintain 'filtration avoidance' and to resolve the conflict between economic growth in the watersheds and deterioration in water quality. Changes required for water quality protection are partly voluntary, partly regulatory and fully funded by NYC. They include land acquisition (willing-seller only) or purchase of easements on land use, regulations addressing waste-water treatment, septic systems and stormwater pollution, and partnerships to improve infrastructure, management systems and fund environmentally sustainable economic development.

The Cannonsville reservoir in Delaware County, NYS, suffers from excessive phosphorus concentrations and the need to reduce phosphorus loads in the streams that feed it imposes particular constraints on farming and other activities in the catchment. This and other improvements in water quality are coordinated by the Delaware County Action Plan (DCAP). The premise that the local capacities of Delaware County are the best means to meet water quality goals reflects the autonomy granted to local government under the Home Rule provisions of the Constitution of New York State, and a historically established ethos of vigorous local democracy and community involvement. DCAP operates under the authority of elected local government and engages with all agencies in-

volved in the watershed protection programme. Its operation encompasses: planning & economic development; community services (local water supply and septic systems); stormwater and highway runoff management; agriculture; forestry; stream corridor management; and monitoring, modelling and research.

Improvement in on-farm practices and water quality protection measures is achieved through DCAP and the Watershed Agricultural Council (WAC), a committee composed of farmers, agribusiness and NYC DEP representatives, which engages local research and extension services to work with farmers. The resulting Watershed Agricultural Programme operates through implementation of whole-farm plans prepared by planning teams with individual farmers, with the twin objectives of improving water quality while maintaining farm economic viability. NY State Water Resources Institute at Cornell University, the NYS Department of Environmental Conservation (DEC), USDA-NRCS, and NYC DEP provide research and monitoring activities. Effective coordination of the efforts of all these agencies has been a feature of the programme.

2.2 Catatonk Creek Watershed, USA

The Catatonk Creek watershed (390 km^2) is part of the headwaters of Chesapeake Bay watershed. 'Citizens for a Controlled Creek' is a local initiative to promote sound river restoration. Flood attenuation and control of stream bank erosion were the initial concerns, but recognising that an integrated approach to watershed management could generate benefits beyond flood protection, the group now addresses wetland and stream bank restoration, natural stream design and improved management of diffuse pollution. The group works with technical support from the Upper Susquehanna Coalition, a network of county level professionals employed by local government, which formed to develop strategies, partnerships, programmes and projects to protect the headwaters of the Susquehanna. These watershed initiatives are significant for their potential contribution to the Chesapeake Bay Watershed Programme which requires a reduction of more than 40 percent in nutrient and sediment loading.

The success of both of these US examples depends in large part on raising local awareness of issues through education and promoting local ownership of the problems. A major inroad into communities is via school children and, for example, 'Project WET' (Water Education for Teachers) is a programme and resource pack aimed at schools and educators across the US. It was noted during project workshops, however, that the prescriptive format of the National Curriculum in UK schools may constrain the response of teachers to comparable ideas.

2.3 The Groundwater Protection Programme of the Water Board of Oldenburg and East Friesland (OOWV), North West Germany

From groundwater the OOWV produces the domestic water supply for one million people living in a rural area of 7800 km^2. Its southern water catchment areas are located in a region of intensive agriculture where farmers compensate for low fertility sandy soils with high animal density and intensive use of organic and in-organic manures. A 'water-surplus' of 300mm per year also results in high leaching rates. This combination of factors led to high nitrate concentrations in the production wells in the 1980s. In response the OOWV, together with local government (the District Administration of Weser-Ems), developed a comprehensive programme of groundwater protection based on cooperation between local partners.

The main elements of this programme are regulation, cooperation with farmers, promotion of organic farming and purchase of land and its afforestation, supported by scientific research, and public outreach activities. As part of the necessary regulatory framework the district administration designated the catchments as water protection areas within which legal restrictions could be placed on land use. Farmers receive compensation payments where these restrictions impose constraints on farm productivity and incomes. OOWV works with the local Chamber of Agriculture to provide extension advice to farmers and to encourage them to enter into voluntary agreements under which they receive payments for further spe-

cific on-farm measures such as reduced row spacing for maize and using less fertiliser. Particular efforts are made to promote adoption of organic farming with financial support for conversion to organic methods and technical support for both production and marketing. Commercial consultants are engaged as farm advisors in this aspect of the programme. "Groundwater protection forests" are an established practice in Germany and OOWV has purchased land in the water protection areas and handed it over to the State Forest of Lower Saxony for afforestation, mainly with deciduous trees. However, the scale of this is limited by adverse local reaction to large scale land use change.

Groundwater protection is financed by higher water rates paid by the water consumer. Currently the private water user pays 5 cents per cubic meter (industrial and agricultural use is charged at a lower rate), and 40 percent of this amount is used for groundwater protection and sustainable land use. Financial contributions to the programme are also gained from other sources such as environmental foundations.

2.4 The Drastrup Project, Aalborg, Denmark

Sixty percent of the residents of this city in northern Denmark are supplied with water by the Aalborg Municipality, through a public utility company run on a commercial basis in competition with private water suppliers. The water source is groundwater, abstracted from three areas to the south of the city and supplied untreated. In the 1980s it was identified that the quality of this resource was threatened by nitrate pollution (plus pesticides and other chemicals) and the Drastrup groundwater protection project was launched in 1992.

Land use change and the removal of polluting activities from designated groundwater protection areas are achieved through a unified approach to spatial planning. Land is converted from intensive agriculture to extensive farming and recreational areas through voluntary and compensated agreements for change in farming practices,

voluntary land sales, or 'land swaps' for areas outside the protected zones. Gravel pits and waste disposal sites are also closed and restored through voluntary purchase agreements. Legislation also allows for compulsory land purchase but this is regarded as a last resort. Public information campaigns encourage residents within the protection areas to make their homes and gardens pesticide and chemical free. To date at least 210 hectares have been converted to permanent grass or forest, and monitoring of wells has shown improvements in nitrate and pesticide concentrations. Finance for the project is provided by the Aalborg city council.

2.5 The Tamar Catchment in S.W. England and the Westcountry Rivers Trust

The Tamar catchment has an area of 930 km^2 and provides the water supply for the city of Plymouth. In the South West of England, as in other areas of the UK, diffuse pollution of water from agricultural sources has become a major concern. The Tamar has suffered from eutrophication and toxic algal blooms in dry years, while soil erosion, sedimentation and localised flooding are also significant.

A programme to manage diffuse pollution from agriculture through voluntary action by farmers is being implemented by the Westcountry Rivers Trust (WRT), an independent charitable trust based in the region. The aims are to protect fisheries, the riverine environment and public health, whilst sustaining or improving profitability for farmers and the economic viability of rural communities. WRT's methodology involves systematic and integrated identification of environmental impacts at a catchment scale through the 'ecosystem approach', followed by practical and iterative engagement with local stakeholders to address these impacts at source. Once priority sub-catchments or target areas are identified, remediation involves awareness raising for river managers and farmers, and development of practical solutions at an individual site or farm scale. Advice to farmers is based on whole farm planning and is delivered pro-actively. Site specific management plans are developed, integrating advice on best farm management practices with an appraisal of options to improve land use, reduce costs, improve returns and meet conservation priorities. WRT has worked with over 2000 farm-

ers in the South West and over 100 guidance sheets on best management practices have been developed and widely distributed. Wider education campaigns are also undertaken to raise public awareness. Funding is generated from charitable donations and from success in winning grant finance from the UK government, EU and foundations.

2.6 The Broads in East Anglia and the Upper Thurne Working Group

In the drier east of England and subject to continual development pressures from farming and recreation, the Broads and its rivers face complex threats to water quality and the aquatic environment. As a result the area provides a model of multi-agency involvement and multiple stakeholder interests and competing priorities. The Norfolk and Suffolk Broads Act of 1988 established the Broads Authority and requires it to manage the Broads (an area of shallow lakes and waterways originating from medieval peat diggings). Guiding principles are: sustainability (social progress that recognises the needs of everyone); effective protection of the environment; wise use of natural and cultural resources; maintenance of economically and socially thriving communities; and working in partnership. The aim is for 'living landscapes': a long-term vision for the Broads as a more naturally functioning and biologically diverse wetland in harmony with its economic and social uses, and taking into account the impacts of climate change over the next 100 years.

The Upper Thurne Working Group is a forum of stakeholders presently addressing the issues arising from tourism, recreation, urban discharge and agriculture for its catchment. It is multi-agency, incorporates public, private and voluntary sector stakeholder interests, and is tasked with producing a water management plan for the Upper Thurne. The group is independently chaired and includes English Nature, Environment Agency, Defra, Parish Councils, Hickling Broad Sailing Club, Internal Drainage Broads, National Trust, Norfolk Wildlife Trust, and RSPB.

3. A synthesis of issues and lessons

3.1 Understanding the problem

A clean environment and good water supplies are vital to human health, quality of life and economic well-being. Farming is the main source of diffuse water pollution but also produces goods, livelihoods and landscape attributes that sustain rural communities. These are generally desired by society, raising the question of how the costs of water resource protection should be distributed. Diffuse pollution of water cannot easily be controlled as the sources are numerous and dispersed, and pathways into the environment are diverse and difficult to trace. Thus the monitoring and enforcement costs of regulation are potentially high. In the broadest terms, means to address this problem include: economic policy instruments (taxes and subsidy); regulation (including planning instruments such as zoning and legislation); voluntary agreements with land users (with or without compensation); advisory and education campaigns; and direct land management strategies (i.e. land purchase/substitution and change in use). The central challenge is how to determine and implement the best combination of measures for a specific catchment, given local conditions and wider policy constraints.

3.2 Key lessons of experience

This study has observed catchment protection programmes that address diffuse pollution at source, and has drawn on the knowledge and experience of a diverse group of stakeholders. From this the following lessons appear to have wide relevance and applicability.

1). Each catchment and all sources of pollution must be analysed in an integrated and holistic way. Environmental criteria must also be integrated with the economic, social and cultural goals of those affected by change.

Given the interconnections between land, and surface and groundwater, to protect or enhance one area of a catchment whilst ignoring

adjacent and particularly upstream areas is not a viable solution. Similarly a diversity of interests and priorities among all stakeholders must be acknowledged. The groundwater protection programmes observed in Germany and Denmark have some limitations in these regards. They tend to protect the recharge zone and boreholes but not the wider catchment, achieving public health goals with regard to water supply but not necessarily wider environmental and social objectives. A similar lesson from the New York State experience in the USA is that targeting only farming whilst ignoring other sectors and interest groups in the local community, may reduce credibility with farmers and may achieve only partial success. Thus it is important to develop an integrated and cross-sectoral approach to the management of diffuse pollution.

2). A range of technologies and management options to reduce diffuse water pollution exist. Despite some gaps in the understanding of how land use practices, soil types and pollution pathways interact, existing knowledge is sufficient to support the design and implementation of diffuse pollution mitigation measures and best management practices for agriculture under a wide range of conditions. Guidance is available for many farming systems and environments in the USA, and is accumulating for the UK and for countries in continental Europe.

Two core principles have wide applicability. First, that selection of measures is best made through preparation of site specific 'whole-farm' plans, developed by extension agents who provided educational and technical assistance to individual farmers. Second that a multiple barrier approach should be adopted that operates at three levels:

1. minimising the on-farm sources of pollutants,
2. modifying farm infrastructure and the 'landscape' between the source and stream to block pollution pathways or at least minimise risk, and
3. use of the stream margin as a final barrier.

Thus measures can range from precision nutrient management for crops and livestock, through barnyard and farm track improvements,

to buffer strips along watercourses and stream bank stabilisation measures.

3) A target based approach and adequate research base are required.

The approach to pollution control in the USA is comprehensive and target driven in a way that is not yet seen in most of the UK or continental Europe. For example, the New York City and Chesapeake Bay watersheds must meet pollutant loading targets from point and diffuse sources that do not exceed specified threshold levels set as Total Maximum Daily Loads (TMDLs). The thresholds are determined, with extensive public participation, to ensure that specified uses of the water bodies (drinking water, fishing, recreation, etc.) are sustained. To meet the threshold loading limits it is necessary to:

1. estimate the loadings of pollutants from farms, highways and other impervious surfaces, solid wastes, wastewater, wetlands and stream-corridors and any other significant source of the pollutants; and
2. quantitatively determine management options for these planning components so the cumulative reductions achieved by the options will in total meet the thresholds, whilst taking account of the economic, social and environmental consequences of such options.

This quantification depends upon interdisciplinary knowledge and the US has invested heavily in investigation of the sources, movement and fate of pollutants in the laboratory, the field and in the catchment. This knowledge base provides the opportunity to compile and integrate understanding for application at geographic scales according to specific decision making requirements. Such interdisciplinary "meta-scientific" research currently supports the ongoing decision making in the New York City and Chesapeake Bay Watersheds.

4). Land management and diffuse sources of pollution have a local basis and protection of water at source necessitates the application of sound scientific understanding plus the fostering of local instruments and participation of stakeholders, supported by an enabling policy and regulatory environment.

Catchment-scale projects must involve multiple agencies from different levels of government and from civil society, and thus partnerships and governance structures that result in effective cooperation and coordination at local level are essential. The problems to be addressed are complex and conflicts of interest are inevitable, conditions under which effective participatory processes can deliver incremental benefits in terms of improved outcomes at affordable cost. Participation works when it builds shared knowledge and the capacity for trust and collective action, but it must be supported by a sound scientific base, an appropriate regulatory and policy environment, adequate financing, and the necessary degree of autonomy and accountability. The means to address diffuse pollution are well matched to programmes based on voluntary action, whilst an adaptive process of collective problem identification and decision making can best bring about the long-term changes in land and water management desired.

This is exemplified by the approach taken in the NYC watershed, but also 'mirrored' by aspects of the surface and groundwater protection projects observed in Germany, Denmark and the SW of England. The following are key features.

- Agreed strategic goals (that establish interdependence of stakeholders in recognition of a shared problem), and specific objectives that are realistic and measurable (e.g. the use of TMDLs).
- Engagement of all stakeholders - including farmers, land and water professionals, taxpayers, interest groups, and government – from the earliest stages of problem identification and goal setting.
- Local leadership with legitimacy and recognition provided through local accountability and endorsement from higher levels of government, but supported by a technical and advisory steering committee.
- The flexibility and capacity to evolve in form, scope and responsibilities as knowledge and experience are gained.
- A strong scientific base informed by research into catchment characteristics, interpretation of monitoring data, use of computer-based models and GIS, and applicability of farm best management practices.
- Monitoring systems to assess performance of measures implemented and provide further data to enhance catchment models.
- Widely targeted public awareness raising, information and education campaigns.

- Use of farm level intermediaries that are knowledgeable, trusted and have full local acceptance.
- Incentives for farmers in the form of practices to reduce pollution that also improve profitability, assistance to finance capital improvements, or compensation for income foregone.
- Adequate financial resources.

4. Conclusions

Differences emerge in how catchments are managed between the USA and Europe. Water management in the USA has tended to be 'bottom-up' and in Europe 'top-down'; a situation that has to be remedied if the spirit of the EU Water Framework Directive is to be fully implemented. The will to involve local people and to bridge the gap between regulator and locality is present in many European agencies but such initiatives tend to be *ad hoc*, embryonic and fragmented. This may match the diversity of European catchments and ground water resources, but more coordination and a greater critical mass of activity will be necessary to meet the goals of the Water Framework Directive. A 'template' for catchment management is needed, which should not be overly prescriptive, but should provide detailed guidance on process, on policy and on governance arrangements, and to aid selection of technical alternatives.

In the UK, without such a template there may be a risk that implementation of catchment governance measures will rush ahead of research and consensus, and that more than one authority will bid for, or impose, governance structures. Candidate organisations to implement catchment management are Defra, the EA and local government, whilst from the experience of the Tamar Catchment and elsewhere, arguably the voluntary sector also has an important role to play. During this study it was observed by some stakeholders that there is a 'democratic deficit' in water management in the UK, arising from a top-down approach over many decades and from neglect of the role of local government. There follow risks of poor governance: ranging from the competing objectives of different agencies, to double subordination on the part of farm and other enterprises, through to confusion and possible alienation of stakeholders. In fa-

vour of local government involvement is that, unlike statutory bodies, local government officers represent an elected body that is locally accountable. In Germany and Denmark local government is taking the lead in land and water management, whilst on a larger scale in the US catchments substantial progress is being made in the assimilation of legal responsibilities at different levels of government to achieve integrated governmental partnerships for effective catchment management.

This preliminary study has identified a number of clear research priorities. There is a need for diagnostic analysis of 'drivers' and processes of change in economy and water and land use, and critical examination of appropriate models for catchment governance, legal measures, planning and implementation procedures based on stakeholder participation, and transfer of scientific and management understanding to foster local management capacities. In particular, examination is needed of the balance between national and local government, and the parallel emergence of local and non-governmental environmental improvement initiatives. This should investigate how to foster an assimilation of duties and responsibilities in a partnership between these three that can offer a unified and integrated catchment programme. Guidance is needed on the legislative and policy provisions needed to support such programmes, determining the most effective balance between regulation, voluntary initiatives and economic incentives.

As noted above, goal setting is core in improved catchment management. An area of innovation in the UK would be determination of water quality targets in the form of TMDLs and/or maximum admissible concentrations for the most important diffuse pollutants, defined for sample UK catchments with respect to raw water chemical and ecological status. Determination of the separable and aggregate contribution of all pollutant sources to the receiving waters of the selected catchments would follow through use of appropriate modelling techniques, and results would inform parallel work with stakeholders and economic analysis. Overall the research would seek to determine whether the water quality requirements for 'good ecological status' and public health are achievable whilst sustaining a

'living landscape' that provides jobs, livelihoods and other amenities, and what management options for this are available.

Given that resources for detailed investigations will tend to be limited to the most problematic areas, there are issues of scale to be resolved with regard to the application of physical models and the linking of outcomes at micro and macro levels. Models can screen large areas, guide attention and target specific locations for study, but considerable investigative work at micro level may still be required before solutions can be tailored to the locality. Related to this, incremental improvements and 'gap filling' are needed for the scientific knowledge base that supports selection and design of diffuse pollution mitigation measures and farm best management practices.

Allocation of loading reductions between sources, and planning of how best to work with farmers and rural communities to achieve land use change, will require analysis of the cost effectiveness of proposed measures. There is relatively little data available on the economic outcomes of alternative measures at farm and catchment level, and of the implications for farm income support and environmental stewardship schemes. In the UK this gap is being addressed within programmes such as that of the Westcountry Rivers Trust and Defra's Catchment Sensitive Farming initiative, but outputs to date are uneven and incomplete. The related issue of cost recovery must also be addressed, concerning who should pay for the clean up of waters, and to what extent the 'polluter pays principle' should be applied in agriculture. Dependent on this, and although some management options can improve both farm profitability and water quality, it will usually be necessary to design farmer incentive and/or regulatory schemes.

There is similarly a lack of economic evaluation of participatory approaches to water quality improvement and of processes of adaptive management and social learning. Unresolved questions surround how best to initiate and sustain such processes in this context, which individuals and organisations must be involved, and what are the incremental costs and benefits compared to alternative approaches.

Successful implementation of management options will require adequate and appropriate monitoring. How to achieve this in the most cost effective way requires further investigation and guidance. Issues also arise with regard to the extent to which monitoring can be integrated into processes of stakeholder engagement. This can be a means to mobilise participation and inclusive processes of social learning, but may raise issues of training, accountability and accuracy of observation.

Overall, to guide selection and implementation of protection measures and the supporting policies and governance arrangements necessary a 'catchment management template' is needed. This would compile and comprehensively integrate the scientific understanding and governance procedures available and tested through actual decision-making and management practice in leading improved catchments. It would also provide a basis for extending and sharing scientific, planning and management procedures with catchment management programmes developing across Europe and elsewhere.