ACIAR WORKING PAPER No. 52 September 2001

Watershed Management for Water Quality Improvement:

the role of agricultural research

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AUSTRALIAN CENTRE FOR INTERNATIONAL AGRICULTURAL RESEARCH

Watershed Management for Water Quality Improvement: the role of agricultural research

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September 2001

Willett, I.R. and Porter, K.S. 2001. Watershed management for water quality improvement: the role of agricultural research. ACIAR Working Paper No. 52, 54p.

ISBN

1 86320 316 8 (printed)
1 86320 317 6 (electronic)

Design: Clarus Design, Canberra

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Summary

Land and water management is increasingly being based on watersheds, and the watershed, or integrated catchment, approach has received wide acceptance for implementing projects for the improvement of water quality. The watershed approach is being promoted as a means of bringing about environmental improvements, particularly at scales that require changes by multiple landholders. This report provides an outline of the implementation of watershed programs in the United States, with particular reference to examples in New York State, a description of the regulatory framework that largely drives implementation, and indicates where research fits in with watershed implementation programs.

The implementation of the various watershed projects to improve water quality in the U.S. show features in common. They start with a planning period to identify significant pollutants, a description of the physical and social characteristics of the watershed and the water body, and the setting of priorities for implementation. This planning period may take two years and offers opportunities to establish educational and outreach activities, the identification of research needs, and community consultation on objective setting and modes of operation. Implementation activities start with on-farm assessments of pollutant sources and transport routes, usually by farm planners in consultation with farmers. Farm business objectives are a major consideration during the planning processes. Best management practices are selected for implementation, and projects normally assist with the application for cost sharing through government programs.

Watershed implementation projects have in-built evaluation activities to monitor progress in terms of farmer participation and effectiveness of their participation. Outcome evaluations in terms of impacts on water quality are much more difficult, generally long term, and expensive at all but the smallest scales.

The main impetus for implementing watershed activities to improve water quality derives from legislation, originating with the *Clean Water Act* (*Water Pollution Control Act of 1972*) and the *Safe Drinking Water Act of 1974*. A government regulatory approach is taken to reduce point-source pollution through the State Pollution Discharge Elimination System, and its technology design standards. Community-level support is required for the implementation of activities to reduce non-point sources of pollution. In this case government involvement is primarily based on providing technical support and incentives for changing land and water management practices that result in improved water quality. Ultimately it is envisaged that the private sector will take increased responsibility by the further development and introduction of marketable permits and pollutant trading programs.

The practical and regulatory implementation of water body protection programs, watershed protection, and ultimately, trading programs, are based on the loadings of a particular pollutant to a water body. This procedure takes the form of estimates of the point and non-point sources of a particular pollutant and the capacity of the receiving water body to receive it. This capacity is determined in terms of target average pollutant concentrations to meet the water quality criteria for the designated use of the water. The loading of a pollutant to a water body will increasingly in the future follow the total maximum daily load (TMDL) approach, which is endorsed and supported by the US Environmental Protection Agency. The TMDL is an estimate of the maximum amount of pollutant that can be safely added to a water body over a specified period. It follows the identification of water-quality-limited waters within each State, the identification of causes and sources of pollution in particular water bodies, and results in priority setting of water bodies, and

therefore their watersheds. This report provides examples, from simple initial estimates to those requiring the application of geographical information system (GIS) and modelling approaches.

Research to support watershed projects can be identified and established at the planning phase. The planning stage involves the application of scientific knowledge such as the interpretation of routine water quality monitoring data, GIS and other geographic tools, determination of target reductions of pollutant loads to water bodies, identification of priority problem areas, and the assessment of the technical feasibility of objectives. These subjects also provide research agendas for general application for watershed activities.

Once implementation gets underway scientific input may be arranged through a scientific support group within the management of the watershed project. This may lead to increased relevance of the scientific, social and economic research to the particular watershed improvement activity. It may also provide a link between the scientists and the watershed inhabitants who will be expected to implement recommendations from research.

The report concludes with an outline of particular features of watershed activities that may be expected in less-developed countries.

Acknowledgments

The first author records his gratitude to all the staff at the New York State Water Resources Institute for their kind hospitality and help during his study leave. He is grateful to Cornell University's Center for the Environment for its part in hosting the visit. He also acknowledges staff members from the university departments of Soil and Crop Sciences, and Agricultural and Biological Engineering, for many interesting discussions. Thanks are also due to the Inter-agency Scientific Support Group, and other groups engaged in the Delaware County Watershed Management Program, for allowing him to participate in their meetings and discussions.

Lastly, but by no means least, he is grateful for the leave granted by ACIAR that enabled this period of study to be undertaken. The release from daily duties for a sustained period to learn of others' approaches to land and water management issues was greatly appreciated.

Abbreviations

AEM	Agricultural environmental management
BMP	Best management practice
CAFO	Confined animal feeding operation
CWA	*Clean Water Act*
CWT	Coalition of Watershed Towns
DEC	Department of Environmental Conservation (NY State)
DEP	Department of Environmental Protection (NY City)
EPA	Environmental Protection Agency (United States)
GWLF	Generalised watershed loading function
NPDES	National pollution discharge elimination system
NRCS	Natural Resources Conservation Service (USDA)
NYC	New York City
NYS	New York State (also NY)
SPDES	State pollution discharge elimination system
TMDL	Total maximum daily load (actually applies to annual load)
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WAC	Watershed Agricultural Council
WAP	Watershed Agricultural Program
WRI	Water Resources Institute, New York State

1 Introduction

1.1 Background

In the last decade or so land and water management, and particularly the interaction of the two, has been increasingly based on watersheds[1], and the 'watershed approach' has received wide acceptance for implementing actions to abate, improve or restore land and water degradation. The watershed approach has been promoted as a means of bringing about environmental improvements, particularly at broad scales, in which changes are required in areas involving many landholders, multiple land and water uses, and, often, multiple government authorities. Agricultural and natural resource research can be framed to support implementation of watershed-based projects aimed at environmental improvement. Watershed based programs may offer the means of utilising the results of research on land, soil and water, or perhaps of reducing the time lag between the production of research results and their utilisation.

1.2 The watershed approach

The watershed approach has been adopted by US agencies concerned with resource management, including soil erosion and siltation of water bodies, flood abatement, water supply, salinisation, wildlife conservation, fishery protection, forestry management and preservation of native vegetation. A feature of the approach is that a comprehensive view of an identified natural unit is taken; it recognises human communities are part of it, and that changes in human activities will have multiple effects. It therefore has many similarities with an ecosystems approach. Although the watershed approach is comprehensive, involving all natural resources and human activities, this report will focus on agriculture and its impact on water quality as a particular example.

According to the US Environmental Protection Agency[2] (EPA) rapid progress has been made in reducing water pollution from point discharges such as those from industrial plants and sewage treatment plants. However, problems of pollution from non-point sources such as agricultural land persist and have gained increased prominence as point sources have diminished. The EPA is promoting the watershed approach with the expectation that it will lead to further improvements in water quality.

A watershed represents a logical natural unit for the management or study of water resources, and, as water is intricately linked to land use and management, to land. The outlet to which the watershed drains is a natural integrator responding to activities within the watershed. In focusing on a particular watershed it is more likely that all aspects of land and water management are considered, and that priorities for the basin will be better identified. The approach explicitly requires partnerships between people affected by land and water management decisions, with the aim of integrating the decisions with the economic, social and cultural goals of those affected. The partnerships also bring together those who are causing problems with those who are being impacted by them. It is expected that joint problem identification and decision making will bring about long-term improvements to land and water management.

1. The U.S. term 'watershed' is used in this report in the same sense as 'catchment', which is in more common use in Australia. 'Watershed' can be ambiguous in common usage in both countries, meaning either a water basin draining to a hydrologically defined point, or (often figuratively) as the dividing line between two basins. The term is used here in the catchment sense, and has been retained, as it is prevalent in the US source materials.
2. This section is largely based on US EPA (1998) materials under www.epa.gov/owow/watershed

Expected benefits of the watershed approach include integration of the environmental, financial, social and administrative aspects of bringing about improvements to natural resources, cost savings by building upon existing resources, improvement of coordination to reduce duplication, and long-term community development leading to reduced conflicts.

The watershed approach should be based on strong science and data, so that management techniques are soundly based. The approach is widely adopted by US agencies interested in land and water management, and the research providers. This has led to an integration of the regulatory, administrative and technical arms of governments. Importantly, it has also led to a fairly systematic approach to addressing environmental problems that are supported by scientific research, techniques and tools, often in the form of computer-based models. In many instances the watershed approach has provided a direct channel for the utilisation of research results by planners, regulators, policy-makers, and implementers involved in land and water management activities.

This report describes some watershed-based programs in the US, where the approach receives widespread support. The nature and operation of watershed agricultural management programs are described, along with government frameworks that largely drive them. The report concludes with an outline of how research can be aligned with watershed-based activities.

2 Implementation of watershed agricultural programs to improve water quality

2.1 Introduction

The United States has made progress in reducing the pollution of water bodies since the introduction of the *Water Pollution Control Act of 1972* (now the *Clean Water Act*), and the associated national and State pollution discharge elimination systems that were directed at reducing point-source discharges of pollutants. In the last decade or so it was recognised that further water quality improvement required reductions in non-point sources of pollutants in addition to those being brought about by reducing point sources. This has placed land management, and agriculture in particular, to the fore. In 1989 the US EPA attributed 76% of the pollution in US lakes to non-point sources (EPA 1989), with the majority of that linked to nitrogen and phosphorus derived from agriculture. Areas with intensive livestock agriculture are those most likely to cause non-point pollution of ground and surface waters by nitrogen and phosphorus (Breeuwsma et al. 1995; Sharpley and Rekolainen 1997).

It is recognised that reductions in non-point-source pollution are more difficult to accomplish than reductions in pollution from point sources. Point sources can be readily identified and attributed to particular polluters, they can be treated before discharge, and are amenable to government regulation. On the other hand, non-point sources are by definition diffuse, require actions by multiple watershed inhabitants and agencies, are highly variable in time and space, and are not readily amenable to government command and control.

There have been numerous projects and programs to implement reductions in non-point-source pollutants in the United States, particularly after amendments to the *Clean Water Act* in 1987. This section presents a brief overview of the approach taken and the lessons learned in the implementation of programs to improve water quality. This is followed by some examples from New York State.

2.2 Overview of the implementation of watershed agricultural programs to improve water quality

Implementation of programs to improve water quality typically follows planning steps. The USDA–Natural Resources Conservation Service (NRCS) follows a nine-step process (Stinivasen et al. 1993):

1 Identify the problems
2 Determine objectives
3 Prepare an inventory of resources
4 Analyse the resource data
5 Formulate alternative solutions
6 Evaluate alternative solutions
7 Determine a course of action
8 Implement the plan
9 Evaluate the results

Given the amount of data and the multi-faceted requirements of analyses, computer-based systems usually support the planning processes, particularly at steps 3 to 5. These consist of geographic information systems (GIS) integrated with watershed and field-scale modelling tools for hydrological, physical and chemical processes (Moffitt 1995). Problem definition (step 1) and evaluation of results (step 9) are also likely to be largely technology and science based. Several steps, particularly 5 to 8, will involve economic, educational and community considerations.

The list does not reveal the importance of education and community involvement during the planning and implementation phases, or institutional arrangements outlined below. Successful management of non-point sources in the watershed depends upon educating and fully engaging watershed communities, their representatives, and government agencies in planning and implementation. Such engagement should occur from the outset of even preliminary work in the watershed to ensure community acceptance and adoption of management decisions. Education and capacity building starts in advance of project implementation, and should be incorporated into the early planning phases of a project.

Common elements of agricultural projects to implement activities aimed at improving water quality, and associated planning and evaluation are summarised in Table 2.1. The identification of critical pollutants and the target concentrations will be strongly influenced by the intended use of the water. For example phosphorus concentrations less than 0.02 mg/L may be necessary to prevent eutrophication of surface water intended for drinking water supplies, whereas higher concentrations would be acceptable in other circumstances. Biological and ecological impacts related to ecosystem function, or human health factors, may determine target water quality parameters but these are often translated back to chemical properties more amenable to laboratory analyses. In water bodies subjected to industrial or urban pollution it is more likely that biological factors such as changes in the composition of aquatic organisms, or the analysis of key aquatic species for very slowly degradable pesticides or non-degradable heavy metals will be included in monitoring pollution.

Chemical data may be available for only small parts of a water body but in the early planning phases it is often possible to identify water degradation by observation, for example, of algal blooms or excessive sedimentation. Historical records may also be of use (NYS DEC 1996). In addition, indicators of water quality are available and these can assist recognition of degradation (Terrell and Perfetti 1996). Ultimately, chemical and biological monitoring will be necessary. At the end of this planning phase all pollutants should have been identified, as well as potential pollutants arising from activities in the watershed.

It has been emphasised (Raymond 1996) that common perceptions of water-related problems by all groups concerned with water protection are required for successful collective action during subsequent implementation phases.

An assessment and description of the watershed will be required. The first step is to prepare a base map and begin the development of a GIS for storage, manipulation and presentation of information. A preliminary assessment of point and non-point sources of pollutants can be made at this stage. Simple (overview) modelling based on pollutant discharges from particular land uses in the watershed can proceed as soon and these data are available. Land use information will come from many sources, including maps, taxation records, aerial photographs and satellite images.

An important determinant of the need for management action is whether or not the quality of receiving waters complies with the standards specified for the best uses of those waters. The capacity of the water body to receive pollutants is defined as the loading that is less than that which would produce non-compliance with the designated water quality standards for those pollutants. A loading of a pollutant that in a specified time would produce an average concentration equal to the standard, less some determined safety margin, is termed a total maximum daily load (TMDL). Should the current loading of any pollutant exceed the TMDL, then the difference indicates the amount of reduction needed to restore and adequately protect that water body. This procedure therefore estimates reductions in the pollution load that are required to reverse water quality degradation. In the US this TMDL procedure, along with supporting models, is promoted and supported by the US EPA (Section 4.2).

It will be obvious by this stage of the planning process that there will be need for a wide range of skills, and there will be potential involvement of many agencies and scientific institutions. In addition, watershed community involvement in the planning will be essential, and of increasing importance during implementation. Strong leadership from a management team will be essential to bring together all the participants and to address the issues listed in Table 2.1.

Implementation of land management and agricultural practices to improve water quality is brought about by the identification and application of best management practices (BMPs). These are wide ranging and include structural improvements on farms, land management near streams, and stream management, as well as management changes such as nutrient management planning and integrated pest management. Compilations of appropriate BMPs are available for many particular problems, cropping systems and environments of the USA. Watershed project staff in consultation with individual farmers usually identify and assist the farmer in determining priorities and in selecting management options. The costs of implementing BMPs are borne either by the farmers or by governments in cost sharing arrangements (which may range up to 100% of the costs).

Watershed implementation projects should have built-in evaluation programs. These customarily measure the inputs in terms of the adoption of BMPs and their effectiveness. Measures of overall impact in terms of improved water quality may be readily made around individual small scale BMPs, such as farmyard improvements, but are much more difficult and expensive to make at larger scales.

2.3 Features of successful watershed agriculture projects

Evaluation of the effectiveness of watershed agriculture projects has resulted in the recognition of the common features for successful outcomes. A report by the NCSU (1992) presents a summary of the lessons learned. This section is largely based on this report and EPA's (1997) 'Top ten lessons learned', with additional observations from individual watershed-based water quality improvement projects.

2.3.1 Definition of implementation project objectives

As in other types of projects, it is necessary to have general, overall objectives, along with specific objectives that provide criteria for subsequent evaluation. It is important to set realistic and measurable specific objectives. It is also essential to appreciate the time lag between improved practices in the watershed and their impact on water quality.

Table 2.1 Implementation of watershed agricultural management for improved water quality

Watershed management implementation	Non-technical Issues arising	Science and engineering
Watershed planning		
Identifying critical and significant pollutants (sediment and chemicals)	Education and outreach	Data on water quality, biological/ecological indicators, human health
Watershed properties	Demographic information	Application of geographic and topographic tools, data management, determination of land use, management practices
Water bodies	Laws and regulations	Determination of the reduction in maximum loading capacity to water bodies (for designated use)
Setting priorities and targeting problem areas	Interested parties, watershed inhabitants, governments	Technical feasibility
Project management		
	Government institutions and local groups involved Laws and regulations Administration Project manager Education and outreach Consultation Incentives for participation	Scientific support Specialist advisory committees
On-farm assessments		
Farmers and field teams, extension staff, engineers, planners	Farm business objectives	Tools, decision support materials, worksheets
Whole-farm planning		
Farmers and farm planners	Farm business objectives	Worksheets, tools, decision support materials and technical methods
Selection and implementation of best-management practices		
Selection by farmers and implementation teams	Funding, cost sharing	Evaluation and design of BMPs (technical and financial) Impact of BMPs on local water quality
Evaluation		
Program evaluation Outcome evaluation	Participation × effectiveness of participation Impact on water quality Financial impacts	Program evaluation based on inputs Monitoring of implementation impacts on water quality

In order to set achievable water quality improvements, a good understanding of the water quality problems and the land and water resources of the watershed are required. At one level, the Federal regulatory framework (in the US), requiring priority setting and formal listing by States, will lead to the selection of priority watersheds and problem definition, particularly of the pollutants of concern. However, the imposition of problem identification by small specialist groups, or groups advocating particular issues, will work against common actions by multiple agencies and community groups that will be required to implement a watershed project (Raymond 1996). The participation of all involved agencies and representatives of affected communities in a project area should occur at the time of problem identification and the establishment of objectives and goals.

Although the common recognition of problems may arise from a crisis, such as a disease outbreak related to polluted water, such events are rare. Raymond (1996) noted the following triggers that may lead to problem recognition and collective action:

- Fears of contaminated drinking water
- Fears of personal safety (such as floods)
- Threats to recreational uses, including closure of beaches, interference with boating, and diminished aesthetic appeal
- Threats to economic investments such as decreased property values and associated taxation revenues, loss of water-related business and development potential, loss of reservoir capacity due to sedimentation, property losses due to flooding, and increased costs of treating drinking water
- Avoidance of regulations – farmers, for example, may fear increased regulation and loss of local control. This may be coupled with perceived infringement of individual property rights, and the fear of changes in the watershed community as a result of regulation.

A watershed is likely to include community groups advocating some of these issues. In fact, lakeside landholders concerned about property values, along with businesses dependent on high quality water for tourism, and county governments dependent on both for taxation income, frequently provide the impetus for watershed activities (for example, Keuka Lake Foundation 1996). In relation to agriculture it is likely that pollution arising from farms will impact at some distance downstream from the farm, and farmers are more likely to be concerned about the threat of increased regulation (as in the New York City watersheds, Section 2.4.2). Conflicts between some of the groups is almost inevitable so that leaders in watershed planning require skills in conflict resolution with the aim of producing innovative solutions rather than cycles that generate more conflict (Raymond, undated).

2.3.2 *Project planning and management*

Watershed-scale projects involve multiple agencies, often from local, State and Federal levels of government, and also non-governmental community representatives. Cooperation and supportive participation by all groups has proven essential to successful project implementation. A supportive State-level committee can promote coordination of government and community representation. However, it has proven important to involve participation of farmers and the general public in decisions at the local level through local coordinating committees. In agricultural watersheds it is essential that farmers are involved, to provide credibility to the wider farming community.

Project management may not be readily achieved because of conflicts between groups. Examples include those between watershed farmers and downstream urban users of reservoir water, or between farmers and local businesses within watersheds. On some matters the rural community of farmers and local businesses may have common interests in conflict with those of an urban population. The acceptance of regulations to bring about improvements in water quality is likely to vary between the participants in watershed projects with perhaps the higher levels of government at one extreme, and some individual farmers at the other. In general it can expected that urban dwellers are more accepting of watershed regulations than agricultural or rural communities.

These sorts of conflicts have potential to hinder, or even prevent, the introduction of management practices designed to improve water quality. These problems have the potential to absorb much of the resources of implementation projects, and experienced project management staff are necessary.

Project management also involves the task of encouraging farmer participation in watershed implementation projects. A major consideration here is the provision of financial support for implementation of new practices. As financial support for implementation usually comes from multiple government agencies, the project management can facilitate the processes of funding for farmers by minimising paperwork with a single application. In practice, it appears that only well-planned and coordinated groups are likely to attract government grants for the implementation of projects.

Project advisory and technical support committees, which may be formed for particular periods for specified purposes, are required to provide advice on technical matters such as information and training, hydrology, land management, and water quality. These groups are a major outlet for research findings, and may involve a cooperating university or other research organisation.

2.3.3 *Information and education*

Information and educational activities are essential to gain farmer participation in watershed projects. This applies not only to the level of farmer participation but also to the standard of the implementation of BMPs, and particularly those that are management-intensive, such as changes to nutrient or pesticide management, and BMPs that require ongoing maintenance of structure and machinery. Experience has shown that one-to-one contact between project personnel and farmers is necessary for gaining farmer support for project objectives and successful implementation.

Information and educational activities need to start in advance of project implementation to encourage participation and to foster ownership of the program by farmers. Research plots and field demonstrations of new management practices and pilot BMP demonstration projects are effective means of disseminating information. It is preferable that local and trusted community members such as established and respected extension staff conduct the educational activities and provide the technical support needed. Non-government organisations may also be able to carry out informational and technical programs. In New York State, for example, farm planners must be certified as a condition of the plans they develop being adopted for funding purposes. Increasingly the State is encouraging the recruitment of planning staff for this purpose from the private sector.

It has also proven essential that information and education programs be consistent – that no conflicting messages are presented to farmers. A particularly important need is to establish incentives or other support to ensure that management measures adopted are sustained over time and do not lapse because the funding stops. In general, multiple means of program delivery and support, rather than reliance on a single medium, should be used.

2.3.4 *Incentives and barriers to farmer participation*

At least in New York State, most farmers are financially limited, and have not enjoyed a comfortable affluence for some time. Therefore, in voluntary watershed projects it has proven essential to provide incentives to farmers to promote participation and sustained implementation of BMPs. Both financial and non-financial incentives are available.

The provision of financial incentives through cost-sharing programs is the most important single factor in obtaining farmer participation. In particular, financial support for changes that improve productivity or decrease farmer inputs are likely to be accepted, as are those that result in improved farm infrastructure. One unplanned outcome can be that farmers have incentives to only select those parts of programs, or BMPs, that are attractive, and are then disinclined to implement other practices that merely improve water quality.

The threat of new environmental regulations promotes participation where farmers perceive that voluntary actions will possibly avert the regulations. On the other hand, a general dislike of government programs and officials does deter some farmers from participating. In part this reserve can be overcome by the employment of trusted local community members in the implementation of projects and the streamlining of government procedures and paperwork by project staff.

2.3.5 *Tracking and evaluation of project implementation*

Continuous tracking of progress, program evaluation and monitoring are necessary. It is essential to be able to track progress in implementation in order to interpret any changes observed in water quality, and is desirable to sustain funding. Tracking of the activities of non-participating farmers, as well as the implementation and maintenance of BMPs by participants, is also desirable.

Priority for implementation should be given to those areas of farms that are critical sources of pollutants — usually those areas enriched with pollutants and subject to hydrological conditions which facilitate their transport to water bodies. Areas in which the hydrology poses a higher risk of transporting contaminants to watercourses are referred to as 'hydrologically sensitive' areas. The identification of these areas is a subject of continuing research but a first approximation is usually achievable without intensive studies. Water quality improvement projects should aim for 100% participation of farmers in the critical source areas. One problem with voluntary programs is that it is by no means assured that farmers located in critical source areas of a watershed will participate. Or, if participating, that they will select and maintain the BMPs most likely to be effective for the primary pollutant. It has proven important to show flexibility in the design of BMPs and to receive regular feedback from implementing farmers to identify improvements, preferably by regular visits to the farms by project staff.

2.3.6 *Water quality monitoring*

Evaluation of program effectiveness in improving water quality requires long-term commitment to monitoring water quality at critical points in the watershed. There are two considerations. First the antecedent or background conditions need to be determined, against which improvements in water quality can be assessed. Second, it should be recognised that there are usually lags of perhaps many years before water quality improves as a result of the management changes adopted. Therefore, monitoring should begin at least 2 years in advance of project implementation and for up to 15 years afterward to account for variation within and between seasons and years. Therefore, the monitoring institution (usually a State agency) needs to be closely involved from the earliest stages of project planning and long-term commitment secured. In addition, water-management agencies need to be involved, as their activities can affect water quality at the monitoring points. For example, a rapid draw down of a reservoir can change water quality measurements in the reservoir to an extent that obscures improvements brought about by better land management.

Definition of water quality problems requires a detailed hydrological description of the watershed and this may need up to 24 months if new water quality monitoring is necessary, because of seasonal variations. The identification of sources of pollutants varies greatly between the types of pollutants. For example, sources of faecal coliform may be readily identified, but sources of sediment and nutrients may be difficult to identify because of multiple sources, storage within the landscape, and in-stream processes.

Monitoring programs need to have clear objectives in detecting impacts of improvements in land management on water quality. Commonly, monitoring is based on regularly spaced sampling over a long period. However, non-point sources tend to have greatest impact during periods of high run-off. Hence, to estimate loading of pollutants reliably it is highly desirable to perform flow weighted sampling, preferably by automatic sampling. As a less preferred alternative, regular sampling can be supplemented by more frequent measurements during storm events. In addition, special sampling surveys may be made for specific purposes such as determining the effectiveness of particular BMPs. For this purpose, spot sampling down the river may be made to track a specified body of water as it flows downstream. More generally, monitoring is based on fixed sampling points with measurements made before and after implementation. Pairing similar watersheds in which changes are adopted in only one watershed is especially effective in giving a benchmark against which changes in the other watershed can be better assessed. As a rule of thumb, long-term (6 to 10 years) monitoring at twice per month intervals is required to detect a 40% change in a contaminant concentration.

The detection of water quality changes in response to the introduction of BMPs can be made at the field, sub-watershed or watershed scale, with the difficulty, expense and time to detect changes likely increasing as the scale increases. During monitoring, land use in the watershed and explanatory variables such a precipitation needs to be quantified.

Data management from monitoring programs is critical and should be coordinated by a central agency. Particular problems arise because of the widely varying time scales of the data (for example comparing daily rainfall data, bimonthly water quality data, and annual land use data) and the multiple sources from which the watershed data must be sought.

2.4 Examples of recent agriculture watershed projects to improve water quality

In this section, examples of two projects are described. It will be noted that the examples reflect and illustrate the common themes outlined in Section 2.3.

2.4.1 Agricultural environmental management in New York State

The Agricultural Environmental Management (AEM) program in New York State has been implemented to manage non-point-source pollution caused by agriculture in response to the Federal *Clean Water*, *Coastal Zone Management*, and *Safe Drinking Water Act*s. It has been founded under the State Governor's name (Pataki et al. 1997) and in 2000 was formally enacted into State law. In addition to the Federal and State farm policies and purposes, the AEM program is also concerned with problems arising from disputes that have arisen between farmers and neighbours from non-agricultural backgrounds. Under AEM, manure and nutrient management are key factors in contributing nutrients and pathogens to surface waters, and also regarding odours. AEM's overall goal is to successfully deal with environmental issues facing the State's farms while maintaining a healthy agricultural economy.

AEM has features in common with other recent initiatives, in that it is:

- voluntary
- watershed based
- holistic, and accounts for business objectives
- based in the context of farms as business enterprises
- locally directed by county and watershed-based groups, and
- based on tested, scientifically sound management practices.

2.4.1.1 Management and operation

AEM is managed at its highest level for priority setting, planning, coordination, and policy setting by the NY State Soil and Water Conservation Committee. The committee consists of five voting members, appointed by the Governor, and 9 advisory members. The advisory members represent: the College of Agriculture and Life Sciences at Cornell University, the College of Environmental Science and Forestry at Syracuse University, Cornell Cooperative Extension, USDA–NRCS, NY State Conservation District Employees Association, NY State Department of Agriculture and Markets, and the NY State Departments of Environmental Conservation, Health and State. NY Agriculture and Markets is the host organisation. Operationally, AEM is further guided by a steering committee composed of some of the above State agencies, and farmer and watershed environmental organisations. In turn, the AEM steering committee provides guidance to the State's 58 soil and water conservation districts.

Local working groups based on county soil and water conservation districts form the core of the AEM program activities, with support from Cornell Cooperative Extension, USDA–Farm Services Agency, USDA–Natural Resources Conservation Service, and NY Department of Environmental Conservation.

The local county working groups identify and prioritise natural resource concerns through a watershed planning process specified and maintained in manuals and other materials provided by AEM. The local working groups arrange local outreach and educational programs and attempt to attract public participation. AEM has a key role in obtaining funding from existing State and Federal sources for implementation of on-farm improvements. It has a continuous program to evaluate its effectiveness. The participation of the private sector has been increasing with the implementation of BMPs, for example in soil testing for determining nitrogen side dressings in corn, and in preparing farm plans. AEM particularly encourages consultants to qualify as 'certified planners'. Such private individuals, or the companies they represent, also refer to Cornell University for scientific advice, and training related to BMP implementation.

Implementation of AEM's approach follows five tiers in which county project teams coordinated by local working groups work with farmers. The procedure is as follows:

- Tier 1. Farmers complete a questionnaire.
- Tier 2. Worksheets are prepared to assess farmers' impacts and potential impacts on the environment. The farmers do this themselves using their answers to the questionnaire.

- Tier 3A. Plans are developed by the farmer with the county project teams to address the concerns identified where they do not seriously affect farm viability.

or

- Tier 3B. Whole-farm plans are prepared for farms where serious environmental concerns are identified.
- Tier 4. Implementation is by introduction of best management practices (BMPs), and the county team advises on funding sources.
- Tier 5. There is frequent evaluation in terms of participation rate and participation effectiveness.

The procedure is designed to target those farms with greatest potential to impact on the environment, and to achieve cost efficiency through targeting funding and human resources.

AEM is a full statewide program. However, AEM is particularly active in several watersheds where it is building on existing activities. The watersheds illustrate priorities associated with drinking water protection (Lake Skaneateles and New York City reservoirs), protection of near pristine waters for recreation and tourism (Keuka Lake), and rehabilitation of an impaired reservoir (Wappinger's Creek). Watershed work associated with the Upper Susquehanna and Sandy Creek relate to protection of larger downstream water bodies (Chesapeake Bay and Lake Ontario). Forty-nine of the 57 counties of New York State are in some stage of implementing AEM (AEM 1999). The range of activities, and the Federal and State support for planning and implementation are summarised in Appendix 2-1 (AEM 1999).

Although still largely at the planning and BMP identification stages (Tiers 1 to 3), full implementation of AEM plans is proceeding expeditiously. An initial assessment of implementation has been made (Bellows and Wildeman 1998). In the farm planning phases it was found to be important to plan meetings with farmers at times and places convenient for them, their families and farm workers. Emphasis is given to incorporating the farmers' goals and plans for the farm into AEM farm plans. At Tiers 2 and 3 the following were found to favour farmer interest and participation:

- That AEM farm planners are prepared for each farm visit by doing some background work in advance.
- That farm advisory groups were necessary to enhance program credibility.
- Farms unlikely to receive external funding can still be assisted through educational and technology transfer elements of the program leading to their adoption of practices not requiring large capital outlays (nutrient management, pasture management, reduced tillage, and farmyard management).
- Participating friends and relatives and information from farmers' organisations influenced non-participants. Visits to participants' farms were also effective.
- Some groups had begun monitoring water quality changes by sampling, either by hired technicians or through local educational institutions.
- Amendments were made to planning worksheets for specific farming systems such as vineyards and dairies.
- Farmers' concerns were determined, including:
  - concern about possible involvement of regulators and increased regulation
  - an unwillingness to be involved with government programs

  - the perception that AEM worksheets were just another survey
  - the idea that the program does not apply to them
  - lack of long-term interest for rented land, and by farmers approaching retirement where there is no family succession, or where the land will be used for non-agricultural uses

- It is recognised that private sector consultants need to be involved. For example the application of integrated pest management (IPM) may be dependent on private pesticide applicators.

A weakness of voluntary programs can be a low participation rate by farmers. AEM offers both financial and non-financial incentives to encourage voluntary participation. Firstly, AEM teams are familiar with Federal and State cost-sharing programs for planning and implementation of projects aimed at reducing non-point-source pollution. County project teams assist the farmers in obtaining financial support. Although it is not necessary to be involved in AEM, participation improves farmers' chances of securing financial support from government sources. Most importantly, AEM activities include farm business evaluations as part of their whole planning process, resulting in improved farmer understanding of their business. Financial receipts for implementing BMPs are exempt from taxable income.

An ongoing program of evaluation in terms of the numbers of farmer participants and their effectiveness is an integral part of AEM. It is straightforward to determine if program administration, management and communications are working, and tracking the number of participants or numbers of BMPs implemented. However, it has not been easy to track whether BMPs are being operated and maintained correctly.

The biggest problem facing outcome evaluation is the overall impact of the program on water quality. Monitoring programs are very expensive and must be continued for up to 15 years (plus at least two years' pre-implementation data) to detect changes in large water bodies. Perhaps, as in the case of the pesticide use reduction in IPM programs, a BMP that appears to attract general support, we can assume that reducing the inputs of potential pollutants will result in an environmental improvement.

2.4.2 *New York City Watershed Agricultural Program*

This program is concerned with protecting the drinking water supply catchment for New York City (NYC). The City's water supply (5300 ML/day) originates from three watersheds in upstate NY — the Catskill, Delaware and Croton systems (approx. 5,100 km^2), supplemented by a small quantity of local ground water. Apart from some streams feeding the Ashokan reservoir, the surface waters carry little sediment and are not filtered before delivery to about 9 million inhabitants. US EPA regulations require filtration of drinking water for human consumption, but on the basis of its good quality supply, NYC has received temporary exemptions for use of unfiltered water. The costs of installing filtration has been estimated by the City at US$ 4 to 6 billion with annual recurring costs of US$350 million, and would double the costs of water rates in the City. However, filtration will be introduced for the water arising from the Croton system (the smallest surface source of drinking water which supplies about 10% of the total water to the City). Even for this watershed area, NYC has taken the approach of protecting the quality of its water supply source areas as a prior precaution to filtration. It is argued that watershed protection is required even if filtration is ultimately installed. The situation is remarkable in that the City owns and manages only a small proportion (about 9%) of the watershed areas supplying its reservoirs and does not have full legal and planning control over the areas.

NYC, through its Department of Environmental Protection, has entered into a Watershed Agreement with Federal, State and local stakeholders. Its purpose is to maintain its 'Filtration Avoidance Determination' issued by the EPA, and to resolve the apparent conflict between supporting agriculture and other economic activities in the watersheds with the need to manage and maintain the watershed to prevent deterioration in water quality. The Watershed Agreement is a legally binding memorandum of agreement between NYC, NY State, US EPA, and the Coalition of Watershed Towns (an organisation representing towns, villages, watershed communities, and non-profit environmental organisations) (Budrock 1997). The approach to the watersheds' inhabitants has been that the changes required for water quality protection will be partly voluntary, partly regulatory, and fully funded by NYC. Three programs have been accepted under the Agreement:

- *Land acquisition:* NYC is able to purchase land in the watershed but only where the landholders are willing to sell, i.e., 'willing buyer–willing seller'. There is a schedule of priorities for land purchases based on their likely impacts on water quality. Highest priority is given to intake areas to the water distribution system and land where water takes less than 60 days to travel from the point of falling as rainfall or snow and its entry into the distribution system. As alternatives to outright land purchase it is also possible for the City to purchase development rights in the form of conservation easements, or agricultural easements, that place restrictions on agricultural practices while the owners continue occupation. In its acquisition activities NYC will not avoid paying property taxes that would otherwise be paid.
- *Rules and Regulations:* The Agreement establishes acceptance of new rules and regulations by those in the watershed. These regulations address particularly waste-water treatment (sewage) plants, septic systems and storm water pollution.
- *Protection and Partnerships*: This program includes funding for new infrastructure for sewage plants, septic systems, sand and salt storages, stormwater, stream corridor protection, forestry management, public education, and a fund for environmentally friendly economic development.

The implementation of changes to on-farm practices is accomplished through a separate organisation, the Watershed Agriculture Council (WAC), established before the Watershed Agreement. WAC is also funded by NY City through its Department of Environmental Protection. This separation of agriculture from other sources of pollution in the watershed appears to be of historical origin and reflects the non-regulatory approach taken with agriculture, in contrast with the regulatory nature of the Watershed Agreement.

WAC implements on-farm practices and measures to improve water quality through its Watershed Agricultural Program (WAP). To date the program has given priority to reducing water contamination by the parasites *Cryptosporidium parvum* and *Giardia lambia* in their resistant forms (cysts or oocytes), which are closely connected with calf-rearing practices and farmyard construction and management. However, one of the major reservoirs, Cannonsville, is susceptible to phosphorus pollution causing serious eutrophication of the reservoir. This has significant consequences for the water supply in that there is a higher risk of disinfection by-products being created after the water is treated by chlorine. A high priority is given to this risk.

A committee composed of watershed farmers, agribusiness and a representative of the NYC Department of Environmental Protection comprises WAC. WAC manages the WAP. This program engages local extension services from Cornell Cooperative Extension, local Soil and Water Conservation Districts and USDA Natural Resources Conservation Services (NRCS) working with the watershed farmers. These planning and implementing agencies are supported by research and monitoring activities by the NY State Water Resources Institute and its collaborators at Cornell University, the research arms of the NYS Department of Environmental Conservation, USDA–NRCS, and NY City Department of Environmental Protection. Coordination of the efforts of at least seven major participants has been a feature of the program.

The WAP operates by implementation of whole-farm plans that are prepared by planning teams. The planning teams involve staff from the extension and planning agencies working with individual farmers with the dual objectives of improving water quality while maintaining farm economic viability. The whole-farm planning teams select BMPs on the basis of decision support materials (Environmental Review/Problem Diagnosis). A comprehensive watershed decision- support manual (Watershed Agricultural Council 1997) supports the program. Implementation with full funding occurs after review by the county Soil and Water Conservation Service and WAC approval of the whole-farm plans. The approach to selection of BMPs is based on three main barriers to the transport of pollutants to the streams — the on-farm sources of the pollutant, the farm landscape between the source and stream, and the stream margin as the third barrier (Porter et al. 1997).

Program progress is tracked by the number of farmers signed onto it, the number of whole-farm plans prepared, and the number of BMPs implemented. Since the start in 1994, 235 farms had implemented at least one BMP by the end of 1998. This rapid implementation reflects the effective cooperation between the extension services and local planners, and the full funding of on-farm implementation.

As noted above, the overall impact of the implementation of BMPs on water quality is difficult to determine at a scale relevant to large downstream water bodies. In the Cannonsville Reservoir watershed two brooks in one sub-watershed have been instrumented for long-term monitoring. One brook drains a catchment occupied by a single farm that has implemented BMPs according to WAP's whole-farm planning procedures. The other brook drains headwaters dominated by forest. This twinning allows a comparative assessment. It also permits the elimination of confounding factors in assessing the results of BMP implementation. Measurements of water flow and nutrient concentrations (particulate and dissolved), as well as benthic invertebrate communities, in the streams were started two years before BMP implementation and data are also available for the first year after BMP implementation on the farm (Longabucco et al. 1999). As pointed out by those authors, it is too early to conclude that there are any effects of BMP implementation on water quality in the brook draining the farm. There were, however, indications of reduced concentrations of dissolved phosphorus but increased concentrations of particulate phosphorus after BMP implementation. The increases in particulate phosphorus may have been due to site disturbance associated with the structural work required to improve the farmyard. Changes is benthic communities were consistent with improved water quality as indicated by increases in the abundance of species (mayflies, stoneflies and caddis-flies) associated with good quality water. These results are consistent with timeframes of several years to demonstrate the impact of the BMPs on the water of the nearby brook.

A particular feature of the WAP is its strong scientific support base and, in its first phase, an in-built research program (Porter et al. 1997). This reflects the early recognition of the need for a firm scientific basis for the implementation of the Program. The research and monitoring components, conducted by Cornell University and NYS Department of Environmental Conservation, accounted for about 10% of the cost of the whole program. The research projects directly supported the on-farm implementation, notably in the form of decision-making tools. Involvement of the Water Resource Institute (WRI) as an intermediary between the Cornell University and other researchers and WAP, and the formation of a multi-agency scientific support group, has served as a channel to capture and develop scientific outputs. These, in turn, may be available for rapid adoption during implementation of BMPs and monitoring overall impacts of the WAP on water quality. However, WAC has reduced the scientific work. This is regrettable because critical scientific work on pathogens has yet to be completed.

The range of institutions involved in the Cannonsville Reservoir watershed is shown in Table 2.2. While each has a distinctive role, and there are obvious natural alliances for cooperation, some problems between the agencies can be expected. There needs to be an agency that can synthesise results from all participants, preferably from a common and shared database. Some conflicts within the structure arise from the fact that WAC wishes to maximise the funds going into BMP implementation on farms, at the cost of research. Within and between the research groups there is competition for research funds that can lead to difficulties in cooperation. In addition, two of the regulating agencies, that are also responsible for dispensing government research and development funding, have their own research arms as potential competitors with outside research agencies. At present there appears to be undervaluation of the role of synthesisers of information.

To date, WAC has given emphasis to implementation of BMPs to reduce the transfer of parasites from young calves to streams. These BMPs include means of improving general calf health, such as enclosures that prevent calf-to-calf contact, redesign and construction of cattle holding yards, and other structures paid for by NY City. Farmers have readily accepted these inputs. Unfortunately, there is little direct scientific support for these practices. More recently the scientific support group has emphasised that priority should also be given to reducing phosphorus losses from farms to streams. The management of manure has emerged as a key issue in reducing phosphorus exports from farms. Progress has been made with reducing discrete sources of phosphorus on farms, such as milking parlour discharges. Some of the BMPs intended for parasite control could be effective in reducing phosphorus movement to streams. However, non-structural BMPs such as nutrient management planning and more controlled spreading of manure have not been so readily accepted.

Voluntary farmer participation and farmer leadership of the program, which is fully funded, appears to have resulted in rapid adoption of some of the BMPs most attractive to farmers. There appears to have been less adoption of BMPs that require changes in behaviour rather than once-off structural improvements. Unfortunately, the attractiveness of BMPs to farmers does not always correspond with their effectiveness in reducing the transfer of pollutants to surface waters.

Table 2.2 Potential participants in the Cannonsville Reservoir, Delaware County, watershed activities

Participant	Extension and/or implementation	Regulators and interest groups	Researchers
Federal Government	USDA–Natural Resources Conservation Service	EPA	US Geological Service
			USDA–Agricultural Research Service
State Government		NYS Department of Environmental Conservation	NYS Department of Environmental Conservation
		NYS Department of Health (water sources and final water treatment)	
	Cornell Cooperative Extension		Cornell University
	NYS Water Resources Institute		NYS Water Resources Institute
NY City Government and NY City water consumers		NY City Department of Environmental Protection	NY City Department of Environmental Protection
NY City and watershed communities	Catskill Watershed Corporation	NY City, EPA, Coalition of Watershed Towns and other community organisations	
Rural businesses and communities		Coalition of Watershed Towns	
Dairy farmers	Watershed Agriculture Program	Watershed Agricultural Council	
	Delaware Co. Soil and Water Conservation District	Delaware County	
	Watershed Environmental Assistance Program	Delaware County	

Table 2.3 Non-point-source abatement and control programs in New York State counties for 1997 and 1998

NYS county	Watersheds receiving NYS program funding for implementation	Watersheds receiving Federal grants
Albany	Foxenkill Onesquethaw	Onesquethaw Hannacrois Vlomankill
Allegany	Rushford Lake Upper Genesee River Basin	Upper Genesee River
Broome	Dudley Creek Part of Tioga Upper Susquehanna AEM	Dudley Creek
Cattaraugus	Cattaraugus Creek	
Cayuga	Cayuga Lake Little Sodus Bay	Cayuga Lake
Chautauqua	Clymer Valley Nutrient Management	Clymer Valley
Chemung	Part of Tioga Upper Susquehanna AEM	Big Flats Aquifer
Chenango	Otselic Part of Tioga Upper Susquehanna AEM	Chenango River
Clinton	Little Ausable	
Columbia	Four large whole-farm plans Hudson R. Estuary/Kinderhook Cr. Subbasin	
Cortland	Otselic Watershed Cincinnatus Wellhead Part of Tioga Upper Susquehanna AEM	Upper Tioughnioga
Delaware	Part of Tioga Upper Susquehanna AEM	Charlotte Creek
Dutchess	Wappingers Creek Ten Mile River /Long Island Sound	
Erie	Buffalo River Great Lakes/18 Mile Creek	
Essex	Lake Champlain	

Table 2.3 (cont'd) Non-point-source abatement and control programs in New York State counties for 1997 and 1998

NYS county	Watersheds receiving NYS program funding for implementation	Watersheds receiving Federal grants
Franklin	County-wide	Salmon River
Fulton	Cayudatta Creek	
Genesee	–	–
Greene	County-wide	Pepacton Watershed
Hamilton	–	–
Herkimer	West Canada Creek Winfield Creek Part of Otsego & Canadaigua Lakes	North Winfield Creek
Jefferson	Sandy Creek	Sandy & South SandyCreeks
Lewis	Great Lakes/Upper Black River (1998)	Upper Middle Black River
Livingston	–	Middle Genesee River
Madison	Oneida Creek (w/ Oneida Co.) Otselic River (w/ Chenango Co.) Otselic River (w/ Chenango Co) Susquehanna AEM	
Monroe	–	–
Montgomery	Canajoharie Creek Otsquago Creek	Canajoharie Creek Otsquago Creek
Nassau	Long Island Sound / Oyster Bay / Cold Spring Harbor	
New York City	–	–
Niagara	Part of Orleans Co. Johnson Creek	Johnson Creek
Oneida	Nine Mile River Oneida Creek Oriskany Creek Watershed	
Onondaga	Skaneateles Lake	Otisco
Ontario	Canandaigua Lake	Canandaigua Lake
Orange	Wallkill River	Wallkill River
Orleans	Johnson Creek Oak Orchard	Oak Orchard
Oswego	–	–

Table 2.3 (cont'd) Non-point-source abatement and control programs in New York State counties for 1997 and 1998

NYS county	Watersheds receiving NYS program funding for implementation	Watersheds receiving Federal grants
Otsego	Otsego Lake Part of Tioga Upper Susquehanna AEM	Upper Susquehanna
Putnam	–	–
Rensselaer	Tomhannock Reservoir	Hoosic–Mill Hollow Brook–Walloomsac
Rockland	County-wide	
St. Lawrence	Grass River	–
Saratoga	County-wide	–
Schenectady	Great Flats / Mohawk River Hudson River Estuary /Normanskill	Mohawk River
Schoharie	Cobleskill Creek	Cobleskill Creek
Schuyler	Part of Tioga Upper Susquehanna AEM Finger Lakes / Catherine Creek / Seneca Lake	
Seneca	Finger Lakes / Seneca Lake	
Steuben	Part of Yates Co. Keuka Lake Part of Tioga Co. Upper Susquehanna AEM Chemung River Basin	
Suffolk	Peconic Bay / Peconic Estuary	Peconic Bay Special Ground Water Protection
Sullivan	Callicoon Creek	Callicoon Creek
Tioga	West Branch Owego Creek Upper Susquehanna AEM 10 Counties	Owego Creek
Tompkins	Fall Creek Six Mile Creek	
Ulster	Lower Esopus Creek Wallkill River	Lower Esopus Creek
Warren	–	–

Table 2.3 (cont'd) Non-point-source abatement and control programs in New York State counties for 1997 and 1998

NYS county	Watersheds receiving NYS program funding for implementation	Watersheds receiving Federal grants
Washington	White Creek Champlain / Mattawee Indian River	
Wayne	–	–
Westchester	–	–
Wyoming	–	Wiscoy & East Koy Creeks
	Great Lakes / Silver Lake	Silver Lake Wolf Creek (1997)
Yates	Keuka Lake Seneca Lake	Keuka Lake

3 Government and regulatory aspects of agricultural watershed management for water quality in the United States

3.1 Brief overview of the Federal regulatory system relating to agriculture and water quality improvement

The US Government passed the *Clean Water Act* in 1972 with the overall aim of improving the minimum quality of all US surface waters to meet the standards for 'fishable and swimmable'. The Act is implemented following a fairly standardised approach by each of the States. Initial emphasis was given to point sources of pollution. The National Pollution Discharge Elimination System set water quality standards for point sources of effluents, which are implemented by State Pollution Discharge Elimination System regulation and permitting activities. State licences are required for all point discharges within water quality standards approved by EPA. They apply to inland and coastal waters.

Amendment to the *Clean Water Act* in 1987, reflected increased attention to non-point sources of pollution, and consequently, much greater attention to agriculture. Success with abating point sources has unveiled the importance of non-point sources in achieving further improvement to water quality. Watersheds are considered the basic management units throughout the US Environmental Protection Agency's approaches to improving water quality (EPA 1996a).

Section 303 of the Act set a framework for each State to follow:

- A comprehensive assessment strategy resulting in priority watershed listing and ranking, which is dependent on the designated use of the water. The EPA emphasises public consultation during this process.
- Setting standards for water quality, with the aim of all US surface waters being of the standard corresponding with 'fishable and swimmable', with uniform standards across the individual States.
- The EPA sets effluent guidelines for point sources through the National Discharge Elimination System, which are executed by State environment departments. Most States have a State Pollution Discharge Elimination System (SPDES), which is the means of issuing permits for discharges of point-source effluents.

The EPA has introduced the total maximum daily load (TMDL) approach to determine the capacity of individual water bodies to accept additional, specific pollutants. The TDML process leads to an allocation of pollutant loads to background load, point and non-point sources. It also builds in a safety margin to allow for errors and an 'anti-backsliding' element. EPA provides grants to States for non-point-source pollutant control, with additional resources for coastal States. TMDL development is briefly described in Section 4.2.

Implementation for improved water quality is usually in the form of the introduction of best management practices (BMPs) to reduce the entry of pollutants into water bodies.

The TMDL process also sets the foundations for the introduction of pollutant trading. Trading programs are still in their infancy (Section 4.3).

In addition to the *Clean Water* and *Safe Drinking Water Acts*, several others are relevant to water quality, including those administered by the USDA. The Acts that could affect agriculture are briefly summarised in Table 3.1, and Table 3.2 presents examples of the potential impacts of the legislation on agricultural activities. It may be noted here that the only agricultural activities now requiring SPDES permits are some of those with large, concentrated, animal-feeding operations (CAFOs). CAFOs are defined as operations with more than 1,000 animal units (approximately 700 dairy cattle), or more than 300 animal units with the potential for discharging directly into waterways. In practice a voluntary approach is being taken and only about 5% of CAFOs are subject to SPDES permits (USDA/EPA 1998). Regulations for CAFOs continue to be developed.

In addition to its regulatory role, the EPA provides materials and supports models for watershed planning and implementation activities. It is also a major source of funding for research and implementation activities. Additional Federal support for closely related watershed hydrology and water quality work is conducted by the US Geological Survey, which has an extensive network of gauging stations and water sampling devices throughout the country.

Table 3.1 Summary of US Federal environmental laws that could affect agricultural activities[a]

Law	Law's major objectives
Clean Air Act (CAA)	Objective is to protect human health, welfare, and the environment by maintaining and improving the quality of the air through the development of standards.
Clean Water Act (CWA)	Objective is to restore and maintain the chemical, physical, and biological integrity of the nation's waters by preventing point and non-point pollution sources, providing assistance to publicly owned treatment works to improve waste-water treatment, and maintain the integrity of wetlands.
Coastal Zone Management Act (CZMA)	Controls sources of non-point pollution sources that affect coastal water quality.
Comprehensive Environmental Response, Compensation, & Liability Act CERCLA/Superfund	CERCLA's goal is to clean up uncontrolled releases of specified hazardous substances.
*Emergency Planning & Community Right to Know Act (*EPCRA*)*	Objective is to: (1) allow State and local planning for chemical emergencies; (2) emergency release notification; and (3) toxic and hazardous chemical right to know.
Endangered Species Act (ESA)	Designed to protect endangered and threatened species from federally funded or directed activities {? meaning} (e.g. pesticide usage, wetlands destruction).
Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)	Requires all pesticides sold or distributed in the U.S. (including imports) to be registered by EPA, although unregistered pesticides or pesticides registered for other uses can be used when approved by EPA and the State to address emergencies and special local needs. Use of each registered pesticide must be consistent with use directions contained on the label or labelling.
Resource Conservation & Recovery Act (RCRA)	Controls the treatment, storage and disposal of hazardous waste as well as the disposal of municipal solid waste. Also regulates storage of petroleum and other products in underground storage tanks.
Safe Drinking Water Act (SWDA)	Object is to protect public health by establishing safe limits (maximum contaminant limits) based upon the quality of water at the tap for contaminants that may have an adverse effect on human health, and to prevent contamination of surface and ground sources of drinking water.
Toxic Substances Control Act (TSCA)	Allows EPA to regulate new commercial chemicals before market entry and existing chemicals (1976) when they pose an unreasonable risk to health or to the environment, and to regulate their distribution and use.

[a] Source: <http://es.epa.gov/oeca/ag/aglaws/lawsumm>.

Table 3.2 US Federal environmental laws that could affect small farms[a]

Operation	Agricultural activities	Potential environmental impact	Laws (abbreviations spelt out at foot of table)
Bring land into production	Clearing wood lot Removing vegetation Digging out trunks, shrubs Burning unwanted vegetation Converting wetland	Destroy wildlife habitat Soil erosion via wind, water Soil erosion, silting in streams, change course of waterways Air pollution Facilitate flooding, destroy wildlife habitat	ESA CWA, SDWA, CZMA CWA, SDWA, CZMA CAA CWA, ESA
Constructing / maintaining buildings	Services for water/ sewage Old transformer present	Contaminate ground- or surface water Polychlorinated biphenyls contamination	CWA, SDWA, CZMA TSCA
Demolishing structure	Asbestos disposal	Soil, groundwater contamination	RCRA
Underground storage tanks	Petroleum leakage	Soil, groundwater contamination	RCRA
Disposal of used motor oil	Spills	Soil, groundwater contamination	RCRA
Land preparation	Tilling soil No-till practised Fertiliser leaching from storage/application	Soil erosion from wind and rain, Silt in waterways Herbicide contamination Surface and groundwater nitrogen contamination	CWA, SDWA, CZMA FIFRA CEA, SDWA, CZMA
Crop protection	Pesticide highway spills Improper pesticide storage Improper pesticide handling/application Drift, over-application Improper pesticide and container disposal Excessive or improper cultivation	Soil and water contamination Soil and water contamination, well head contamination Soil and water contamination Endangered species, off-target species injury Soil and water contamination Soil erosion	FIFRA, CWA, SDWA, CZMA EPCRA, FIFRA, CWA, SDWA, CZMA FIFRA, CWA, SDWA, CZMA ESA, FIFRA RCRA, FIFRA, CWA, SDWA, CZMA, CERCLA/superfund CWA, SDWA, CZMA
Irrigation / Chemigation Drainage ditches, farm ponds	Backflow Run-off Herbicide application for weed control	Groundwater contamination Surface, groundwater contamination, soil erosion Surface, groundwater contamination, off-target species injury	CWA, SDWA, CZMA CWA, SDWA, CZMA FIFRA, CWA, SDWA, CZMA
Plant growth control	Improper plant growth regulator applications Burning unwanted vegetation	Soil and water contamination Air pollution	FIFRA, CWA, SDWA, CZMA CAA

[a] Table derived from the University of Delaware web page <www.udel.edu/pesticides/publications/smallfarm2.html>. Acts related to direct exposure of farm workers to pesticides protected by worker protection standards are not included here. The web site also gives a brief description of each Act. Details are available at <http://es.epa.gov/oeca/ag/aglaws/>. A summary for NY State appears at <http://www.cce.cornell.edu/ag/environmental-mgt/> (under 'Regulations' then 'New York State Regulations').

Table 3.2 (cont'd) US Federal environmental laws that could affect small farms[a]

Operation	Agricultural activities	Potential environmental impact	Laws (abbreviations spelt out at foot of table)
Harvest	Treating stored grain	Soil and water contamination	FIFRA, CWA, SDWA, CZMA
	Silage storage	Run-off	CWA, SDWA, CZMA
Preparing fields for dormancy	Crop residue removal, autumn tillage	Soil erosion from bare land	CWA, SDWA, CZMA
Animal Production		Water contamination from nitrate and bacteria run-off or leaching	CWA, SDWA, CZMA
		Water contamination from nitrate and bacteria	CWA, SDWA, CZMA
		Water contamination from bacteria	CWA, SDWA, CZMA
		Run off, fly control problems	CWA, SDWA, CZMA
		Soil and water contamination	FIFRA, CWA, SDWA, CZMA
		Soil and water contamination	CWA, SDWA, CZMA
		Soil erosion	CWA, SDWA, CZMA
		Water contamination from run-off, livestock allowed to enter water bodies	CWA, SDWA, CZMA
Aquaculture	Water system not closed	Escaped fish upset balance of nature	ESA
	Discharge water from system	Surface and groundwater contamination	CWA, SDWA, CZMA
	Disposal of dead fish	Surface and groundwater contamination	CWA, SDWA, CZMA

SDWA	*Safe Drinking Water Act*
CWA	*Clean Water Act* and the National Pollutant Discharge Elimination System (NPDES)
FIFRA	*Federal Insecticide, Fungicide, and Rodenticide Act*
CERCLA/Superfund	*Comprehensive Environmental Response, Compensation, and Liability Act*
ESA	*Endangered Species Act*
TSCA	*Toxic Substances Control Act*
CAA	*Clean Air Act*
EPCRA	*Emergency Planning & Community Right to Know Act*
CZMA	*Coastal Zone Management Act*
RCRA	*Resource Conservation and Recovery Act*

[a] Table derived from the University of Delaware web page <www.udel.edu/pesticides/publications/smallfarm2.html>. Acts related to direct exposure of farm workers to pesticides protected by worker protection standards are not included here. The web site also gives a brief description of each Act. Details are available at <http://es.epa.gov/oeca/ag/aglaws/>. A summary for NY State appears at <http://www.cce.cornell.edu/ag/environmental-mgt/> (under 'Regulations' then 'New York State Regulations').

The United States Department of Agriculture (USDA) has a range of programs to provide cost-share incentives for adoption of agricultural practices designed to improve water quality. These are briefly summarised below:

Farm Bill Act 1996 — introduction of Environmental Conservation Reserve Program, consisting of:

- Conservation Reserve Program — funding for retirement of land
- Wetland Reserve Program — cost sharing for wetland conservation
- Environmental Quality Incentives Program — technical, financial and educational assistance for priority areas.

Farmland Protection Program — enables purchases of State or local government lands for protection purposes by USDA.

Wildlife Habitat Incentives Program — cost sharing and technical advice for wildlife conservation.

Conservation Farm Options — one-off grants for conservation works in selected cropping systems in lieu of the above options.

At the Federal level, promotion of improved water quality appears to be a two-pronged effort of regulation supported by technical and financial support for the States, Territories and Tribal Nations, and other (multi-state) authorities, to meet the regulations. The Federal Government (through the EPA, USDA, and USGS) is therefore a major driver in bringing about improved water quality in the United States.

The legislation provided by the Clean Water Act provides the basis for 'citizen suits' in which environmental groups stand in for the EPA to prosecute particular polluting industries for environmental damage. More recently it has been reported (Glaberson 1999) that prosecutions have been curtailed as courts now require plaintiffs to have been physically injured by the pollution, rather than to only identify a particular case of environmental degradation. In addition, the intent of the original legislation may have changed in a recent trend of imposing only small penalties when the polluter remedies problems during the legal proceedings.

3.2 Regulations and agricultural management for water quality improvement in New York State

States, Territories and Tribal Nations implement the Federal Acts. In NY State the Department of Environmental Conservation complies with the EPA planning framework by:

- priority listing of the State's surface water resources, with public participation emphasised
- priority ranking of water bodies
- defining the use of the State's surface waters
- adopting standards of water quality that are acceptable to the EPA
- implementation of the State Pollution Discharge Elimination System — the permitting system for point-source discharges
- identification of surface waters where present effluent controls are not sufficient to improve water quality, i.e. those waters where pollutant inflows exceed the assimilation capacity of the water body
- TMDL development

These processes identify water bodies in which water quality is already impaired, or is under threat, identifies where agriculture (amongst other human activities) is likely to be a significant contributor to water quality problems, and the substances causing pollution. For those water bodies recognised as priorities and subject to TMDL development, an estimate of the reduction in pollution loading will be made (Section 4.2). Reductions in loadings may be relatively readily achieved for point sources of pollution (sewage treatment plants, industrial plants and CAFOs) by the State Pollution Discharge Elimination System regulation. Abatement of non-point-source pollution associated with agriculture has proven much more difficult.

Practical agricultural implementation to reduce non-point sources of pollutants (particularly nitrogen, phosphorus and pesticides) traditionally depends upon outreach and education programs, technical assistance to farmers, on-farm planning, and the implementation of BMPs. The programs are mostly directed through NY State Departments of Agriculture and Markets, and Environmental Conservation. Support for the programs is obtained by the State Environmental Protection Fund, *Clean Water/Clean Air Bond Act*, and the Agricultural Non-point Source Abatement and Control Program to the Soil and Water Conservation Districts established in each county of the State. The adoption of agricultural practices by farmers to reduce water pollution is encouraged in voluntary programs involving cost-sharing arrangements. In practice, the Soil and Water Conservation Districts work in groups involving the USDA–NRCS, Cornell Cooperative Extension, and other groups, as described for the AEM Program (Section 2.4.1). With the exception of large CAFOs, farmer participation in water quality programs is voluntary in New York State.

3.3 New York City watersheds

The New York City water supply is located outside the city limits, in five counties of NY State. The State Government granted NY City some authority over the watershed areas in 1905. In the period from the 1930s until the mid 1960s the City developed a large and complex water supply system of six major reservoirs and associated tunnels and aqueducts. In more recent times further City intervention, particularly in the Catskills and Delaware River watersheds west of the Hudson River, has intensified as the City seeks to avoid mandatory drinking water filtration as specified by EPA's Surface Water Treatment Rule (1989) under the *Safe Drinking Water Act Amendments (1986)*. When the City's Department of Environmental Protection proposed a regulatory approach to watershed protection, and a land acquisition plan, the watershed communities expressed strong opposition on the basis that the plans would stifle agriculture and inhibit economic development. The farming community was especially incensed by the draft regulations released by New York City. In response to the public clamour, New York City requested the New York Water Resources Institute (WRI) to assist as a mediator. An Inter-agency Taskforce on Agriculture was established with the assistance of WRI. This taskforce successfully forged an agreement creating the Watershed Agricultural Council. Broader community opposition in the watershed area evolved into the Coalition of Watershed Towns (CWT) in 1991. Originally, the purpose of the CWT was to oppose the watershed plans of New York City by legal actions. However, the CWT eventually entered into negotiations with the City producing after much effort the remarkable Watershed Agreement. Section 2.4.2 provides a brief outline of the resolution of the differences across the local juridical boundaries and the Coalition of Watershed Towns.

3.4 State regulatory approaches for reducing agricultural non-point pollution

In the 1970s Wisconsin introduced a voluntary regulatory program to reduce agricultural non-point-source pollution largely to protect surface water bodies from nitrogen and phosphorus arising from intensive animal production. Only farms with more than 1000 animal units were subject to State Pollutant Discharge Scheme regulations. The program consisted of the selection of priority watersheds across the State, comprehensive watershed planning with specification of water quality improvement goals, and generous cost sharing for introducing BMPs on farms. Some twenty years later it was concluded that voluntary participation rates, at below 40% of the farmers, were preventing the achievement of water quality goals. It appeared that the farms that were most polluting were those that were also least likely to voluntarily participate. In 1993 the State introduced an enforcement component to its non-point-source programs in the form of the Critical Site Legislation (Stevenson 1995). Critical sites are those that are identified and designated as requiring implementation of BMPs with a reasonable likelihood of achieving water quality improvements in designated priority watersheds. Landholders are given three years to voluntarily participate in watershed projects. If they fail do so they become subject to corrective orders (with cost sharing of BMPs) enforced by penalties. The main disadvantage is the legislation is cumbersome and a substantial backlog has accumulated while agricultural practices that degrade water are still pervasive (Stevenson 1995).

Initial voluntary programs have also evolved into regulatory programs in southern Florida to protect Lake Okeechobee. In order to protect the largest lake in the State from phosphorus arising from dairy farming State legislation introduced regulations aimed at a 40% reduction in the phosphorus load over a 6-year period (Goldstein and Ritter 1993, 1995). Responsibility for this rests with the South Florida Water Management District, which developed a resource management plan and a regulatory program for Lake Okeechobee. The regulations are based on meeting performance standards in the phosphorus discharges to surface waters but do not specify the measures to be used. All land parcels greater than 0.5 acres are subject to permits and are monitored for compliance by water quality monitoring. Those land parcels not in compliance are required to implement BMPs. By 1995, 640 permits had been issued covering 336,840 ha. Water quality monitoring, by biweekly grab sampling for at least one year, showed that about 3% of farmers exceeded their permitted discharges. Those found to be exceeding the permitted load are required to enter into a legally enforceable agreement to implement and utilise corrective measures. The BMPs selected usually involved improved field management such as fertiliser control and livestock rotation rather than capital intensive structural BMPs (Goldstein and Ritter 1995), although earlier implementation of structural BMPs in high intensity farmyards resulted in dramatic and rapid decreases in total phosphorus in nearby streams (Havens et al. 1996). The overall direct economic consequences of the mandatory program included a 26% reduction in the number of dairy cows and a 17% reduction in milk production in the affected areas (Bogess et al. 1997). The overall impact was a 4% decline in income and 4% decline in jobs. On the remaining farms, milk production increased by 13% and more than offset the farmers' costs (with cost sharing).

3.5 The application of environment programs by Native Americans[1]

About one half of the 2 million United States' Native Americans live in reservations. Tribes are recognised as sovereign nations within the US. In 1990, the Federal Government recognised 278 Indian land areas as reservations ranging in size from less than 100 acres to the Navajo Reservation of some 16 million acres in Arizona, New Mexico, and Utah. About half of the land on contemporary reservations belongs to tribes, with the rest owned and inhabited by non-Indians.

The EPA works with Tribes on a government-to-government basis. Because there are so many tribes it often works with inter-tribal organisations. Amendments were made to the environmental statutes (Table 3.1) explicitly authorising the treatment of Tribes in the same manner as States. Tribal governments are therefore responsible for setting standards, making environmental policy decisions, and managing programs within their reservations. Tribal governments establish the regulatory framework by passing tribal environmental codes, and drafting the necessary regulations. They also establish a body, if one does not already exist, that can ultimately seek tribal administrative or judicial sanctions to enforce the tribal law.

Specific watershed planning tools, that take account of the varying technical capacities of Tribes, have been developed (Williams 1996). They are intended to take account of subsistence life styles, including traditional foods and medicines. The protection of fish resources is of particular importance to many Tribes for cultural, as well as food, purposes. Environmental restoration is considered as part of cultural and sovereignty restoration by some Tribes (Long 1996).

3.6 Public policy mechanisms for water quality improvement

This section summarises the characteristics of the range of public policy mechanisms that can be applied to improve water quality. It is based on the discussion presented by Bogess and Cochran (1995) who provide further details and an outline of the economic aspects.

3.6.1 Public actions to facilitate private solutions

Characteristics

- Minimum government involvement
- Government-funded research to provide new technologies to private producers
- Cost sharing to introduce best management practices
- Educational programs and 'moral sessions'
- May be acceptable to farmers and other producers
- Publicising 'bad actors'

Disadvantages

- Low participation in voluntary programs unless there are clear economic advantages, or subsidisation

1. This section is based on web based material provided by the American Indian Environment Office at <http://www.epa.gov/indian/resource/resource.htm>, unless otherwise stated.

3.6.2 Public establishment of economic incentives

Effluent charges

Characteristics

- Moderate government involvement
- Pricing of pollution discharges leading to adjustment of production practices that reduce water pollution in response to additional costs
- Can be readily applied to point sources, but monitoring requirements are too expensive for non-point sources
- Rapid and measurable impacts can be expected for point sources
- Generates income that can be used for research and cost sharing of best management practices

Disadvantages

- Difficulty in setting prices, in practice is done by trial and error (first iteration may involve low pricing for rapid but small improvement)
- Difficult to apply to non-point sources

Marketable Permits

Characteristics

- Provision of economic incentives without setting prices on pollutants
- Government sets fixed quantity of pollution permits that can be traded
- Where pollutant abatement costs are not uniform trading will occur

Disadvantages

- Dependent on technical and cost-effective ability to quantify effluent discharges
- Setting standards and quantifying the basis for the permits may be fraught with technical difficulties

3.6.3 Government regulation

These policies involve maximum government involvement.

Technology design standards

Characteristics

- Specification of technologies that must be implemented by producers
- Is the basis of State Pollution Discharge Elimination System
- They can be readily monitored and enforced
- Some impact on water quality is assured
- Low-cost monitoring
- The regulated community knows its position with reasonable stability in the application of regulations

Disadvantages

- Inflexible and applies to all producers regardless of their present pollutant discharge

- The resulting reduction in the pollutant may not meet the need for reduction
- They inhibit innovation and improvements
- No specific incentives to ensure proper operation of new technologies

Performance standards

Characteristics

- Specify maximum levels of allowable effluent but not how they are met
- Are dependent on cost-effective monitoring
- They are flexible and polluters can make choices in their responses

Disadvantage

- Not readily monitored or enforced for non-point-source pollution
- May introduce inequities between dischargers in requiring different levels of treatment according to location and local conditions etc.

3.6.4 Judicial Options

Characteristics

- Low government involvement
- Based on liability litigation in common law
- Emitters prosecuted if they do not show 'due standard of care'
- Can result in rapid changes, but with increasing difficulty being imposed by courts (Section 3.1)

Disadvantages

- Compensates rather than prevents pollution
- Expensive in legal costs, and burden of proof can be difficult
- May be excessively time consuming and may encourage bad practices given an expectation of long delays in decision-making

In general, farmers fiercely resist regulation of their industry, and avoidance of regulations may be a major motivation to make voluntary changes in farm management to protect water quality. Nevertheless, the examples from Wisconsin and Florida show that State legislatures are willing to enact regulations where the protection of water bodies is of sufficient priority. It some parts of the US it has been claimed by environmental groups that government authorities have been reluctant to enforce existing regulations, purportedly under pressure from (non-agricultural) developers, despite general community support for enforcement (Kennedy 1997). In practice it appears that in most cases polluters are given time to take corrective action before legal proceedings are initiated.

In general a government regulatory approach is taken to reduce point-source pollution based on the well-established State Pollution Discharge Elimination System, and its technology design standards. In contrast the approaches to reducing non-point sources of pollution are based on the public establishment of economic incentives by the further development and introduction of marketable permits and trading programs (Section 4.3).

4 Estimating loads to water bodies, and pollutant trading

4.1 Introduction

The required reduction of a pollutant in a water body can be expressed as the difference between the present pollutant status and the level that is considered unpolluted for the designated purpose of the water. The accumulation or depletion of pollutants in a water body will depend on the difference in the inflow and the outflow. The inflowing pollutant is usually expressed as a load (mass/time). This simple mass balance approach is complicated by several factors, including the fact that pollutants enter water bodies in different forms. One of the major factors will be whether the pollutant is dissolved or associated with suspended solid phases. The latter may settle out on entering a water body only to be resuspended again later. The settled material may release the pollutant to the dissolved form under the changed chemical conditions of the bottom sediment. There are numerous examples of this type and models of the chemical, physical and biological processes to describe the resulting concentrations in the water have been devised. More recently models of estimated loads to water bodies have been coupled with models of the dynamic changes within water bodies.

The practical and regulatory implementation of water body protection programs, and watershed protection, are usually based on the total loading of a particular pollutant and average concentrations of the pollutant in the water over a specified interval of time. The definition of the average concentration in the water needs to take into account areal, depth and temporal variations. The average concentration may be restricted to only part of year, for example, the concentrations of excess nutrient may be confined to the summer growing season. The desirable target concentration in the water body may be based on numerical standards set by the EPA or a narrative description of desired outcomes. For example, there is no set standard for phosphorus concentration but a guidance value of 20 $\mu g\ L^{-1}$ is being used as a concentration above which algal growth is likely to be excessive in the growing season in water designated for drinking supplies.

The desired loading of a substance to a water body is normally determined following the total maximum daily load (TMDL) approach, which is endorsed and supported by the EPA (EPA 1991). The TMDL is an estimate of the maximum amount of pollutant that can be safely added to a water body over a specified period. It can be applied against a background of seasonal variations, and considers both point and non-point sources, and incorporates a margin of safety.

The responsibility for determining TMDLs for particular water bodies is devolved to each of the States[2] under the regulations of the *Clean Water Act* (Section 303), and involves the following steps:

- identification of water-quality-limited waters still requiring TMDLs
- identification of causes and sources of pollution
- documentation and rationale for listing
- identification and scheduling of targeted water bodies
- TMDL development

Additional requirements include formal reporting to EPA, and approvals.

2. American Indian Tribes have this responsibility for Indian Country. In 1998 EPA would not approve State plans including Indian country, and is still developing a policy for this land <www.epa.gov/OWOW/tmdl/lisgid.html#j>

4.2 Applications in New York State

As a means of understanding the application of the TMDL process its application to Cannonsville Reservoir, a part of the New York City's watershed, is briefly described[3]. In New York State the Department of Environmental Conservation (DEC) oversees the TMDL process. DEC is undertaking a rotating program to review the water quality of the State's water resources, with inputs from the public and county water quality coordinating committees, resulting in the selection of water bodies for TMDL development. In 1998, most of the 27 water body segments in the NY City watershed showed that phosphorus was a pollutant of concern. Excess phosphorus is deleterious because it favours excess production of algae, which leads to low oxygen concentrations, undesirable odour, taste and colour, and can result in carcinogenic disinfection by-products (trihalomethanes) after chlorination.

The DEC and the City's Department of Environmental Protection have worked together in a phased approach to develop the TMDL for Cannonsville Reservoir. Initial estimates were based on Vollenweider's (1968) equation that relates total phosphorus concentration in water to the lake's shape, water replacement rate and annual phosphorus load. The shape and water replacement rate terms in the equation account for phosphorus that settles with sedimentary particles. Only three terms — phosphorus concentration, lake shape and water replacement rate — are required to estimate the annual phosphorus load. However, the model does not account for re-suspension or dissolution from bottom sediment, or differentiate between dissolved and particulate P. This simple approach does not directly account for variation in rainfall in the watershed, and is therefore static. Early TMDL estimates, as the annual phosphorus load, for Cannonsville were calculated by using the annual mean of the measured phosphorus concentration.

In order to estimate phosphorus contributions from different land uses in the watershed, the Reckhow land use model (Reckhow et al. 1980) was applied to the watershed. This model requires the identification and determination of the areal extent of specified land uses (by aerial photography and GIS). Each land use has a coefficient of export of phosphorus so loads are calculated as the sum of the products of the areas of the land use area and their export coefficients. The results give a rough estimate of the sources of non-point-source phosphorus in a watershed. When combined with results for point sources, a total load can be estimated. Both agricultural and non-agricultural sources are included, resulting in categories for waste water treatment plants, urban run-off, septic on-site disposal, as well as estimates for forest, grass/shrub, bare soil and corn/alfalfa land uses.

Further development of TMDL took the form of accounting for precipitation and the consequent run-off by application of the general watershed loading function (GWLF) model. GWLF requires estimates of the areas of defined land uses, soil type and slope. The model uses USLE 'C' factors, USDA–NRCS curve numbers, inputs for run-off concentrations for each defined land use and weather data for several years. The combined results, including point sources, are an estimate of annual loads. By combining GWLF estimates with Vollenweider's equation and a factor to account for phosphorus settling, average phosphorus concentrations were estimated. A comparison of the modelled estimates with field data showed good agreement for years with 'normal' weather, but was inaccurate in a drought year and a very wet year.

GWLF is relatively simple to use and has been applied by community-based organisations with some technical support from extension services (e.g. Keuka Lake Foundation 1996), at least in

3. This section is based on the recent review by Porter et al. (1999).

northern New York State where its creator at Cornell University originally applied the model. The process should at least result in a comparison of the relative contributions of potential sources of pollutants into water bodies, and allow managers to target those.

The TMDL process and models to estimate loads are still under development. More recent hydrologic models for watersheds, although not yet applied directly to TMDL development, are based on determining the water balance of small cells within watersheds. These are referred to as distributed models, as opposed the 'lumped parameter' type models such as GWLF. The Cornell soil moisture routing model (CSMR) was developed for shallow soils on steep slopes (Frankenberger et al. 1999; Zollweg et al. 1996). The model is based on the coupling of a hydrologic water balance model with the geographic information system 'GRASS'. Water balances are determined in 10 to 30 m cells that are coupled to downstream cells. This type of model has the advantage of identifying areas within a land-use unit that are likely to produce run-off and transport pollutants, and which are likely to be only a fraction of the total land, a fact that is ignored in the lumped parameter models. Application of the model in parts of the Cannonsville watershed has allowed the identification of areas that produce run-off and their extent throughout the year. The model has found ready application in developing whole-farm plans in the Watershed Agriculture Program, for example in best management practices for manure applications that minimise run-off of phosphorus and parasites (Porter et al. 1997). Watershed modelling is dependent on computer development. As computing power increases it is likely that watershed modelling will allow the application to whole watersheds of distributed models with cell sizes appropriate for agricultural management. This could lead to more accurate means of estimating annual loading rates to water bodies. Work along these lines is now progressing well at Cornell coordinated by WRI.

4.3 Pollutant trading and water quality improvement

The concepts of market-based pollutant trading received high level political support in the US in 1995 after a period of some 30 years of discussion in the resource economics literature (Kerns and Stephenson 1996). At that time the EPA developed a framework (EPA 1996b) doubtless influenced by analogous experiences of the *Clean Air Act*. The concepts and implementation strategy for trading are rooted in the EPA's watershed approach and TMDL development. TMDL development results in estimation of all sources of a pollutant in a particular watershed. Pollutant discharges from point sources are likely to be well defined in terms of their loadings of pollutants and the costs of applying engineering technologies of treating water to remove them. In comparison, the quantification of pollutant loads from non-point sources is difficult, and the effects of introducing (even widely adopted) best management practices uncertain.

The costs of removing pollutants varies between point and non-point sources, between different point sources, and between different non-point sources. At the watershed scale, water quality improvement may be achieved more economically and rapidly if the most cost-effective means of pollutant removal are applied. It is possible that some operators may be able to remove pollutant on behalf of polluters that are less cost effective in removing the pollutant. Table 4.1, from Kerns and Stephenson (1996) gives estimates of costs of practices to remove nitrogen from water and therefore indicates the scope for trading in the nutrient. This table does not show the certainty of the effectiveness of the various practices in removing nitrogen, which must be greater for engineered structures at point sources in waste water treatment plants and in farmyards, compared with those that are implemented for non-point sources in the field. There appears to be no relationship between the cost and certainty of the various practices in removing nitrogen.

In watersheds where point sources of pollutant are already being treated, the costs of further treatment may be high, as the marginal cost of treatment increases with the quality of the treated water. In the Dillon Reservoir watershed, Colorado, it was estimated that the minimum unit cost of point-source removal of phosphorus was $1,816/kg. In comparison, the control of non-point source pollution by best management practice implementation on farms was only $262/kg (Griffin et al. 1991). At the watershed scale it was more cost effective to fund changes to on-farm practices than to further upgrade waste-water treatment plants.

Table 4.1 Examples of costs of removal of nitrogen from effluent waters in the Potomac Basin (Kerns and Stephenson 1996)

Management practice	Cost of nitrogen removal (US$/lb)
Biological removal in waste-water plant	20–50
Urban nutrient management	85
Urban storm water retrofit	1
Erosion and sediment control	254
Septic tank pump out	38
Animal confinement run-off control	6
Livestock waste management	28
Agricultural nutrient management	1
Stream protection from livestock	11
Grazing land protection	11
Conservation tillage	19
Highly erodible land	11
Cover crops	3
Grass buffers	20
Forest harvesting	4
Forest buffers	8
Shoreline erosion protection	54

Programs have been introduced to facilitate the trading of pollutants. The process is still being developed and there are only a few examples where it is operating. Trading is approved only within current government regulations and existing water quality standards, and is permitted only within a single watershed, or segment of a specific hydrological unit.

The EPA (1996b) has categorised the types of trading as follows:

- *Point/point-source trading.* A point source arranges for another point source to undertake greater-than-required reductions in pollutant discharge in lieu of reducing its own level of pollutant discharge, beyond the minimum technology-based discharge standards, to achieve water quality objectives more cost-effectively.
- *Intra-plant trading.* A point source allocates pollutant discharges among its outfalls in a cost-effective manner, provided that the combined permitted discharge with trading is no greater

than the combined permitted discharge without trading and discharge from each outfall complies with the requirements necessary to meet applicable water quality standards.

- *Pretreatment trading.* An indirect industrial source that discharges to a publicly owned treatment plant arranges for greater-than-required reductions in pollutant discharge by other indirect sources in lieu of upgrading its own pretreatment beyond the minimum technology-based discharge standards, to achieve water quality goals more cost-effectively.
- *Point/non-point-source trading.* A point source arranges for control of pollutants from non-point source to undertake greater-than-required pollutant reductions in lieu of upgrading its own treatment beyond the minimum technology-based discharge standards, to achieve water quality objectives more cost-effectively.
- *Non-point/non-point-source trading.* A non-point source arranges for more cost-effective control of other non-point sources in lieu of installing or upgrading its own control or implementation of pollution prevention practices.

To date point/non-point trading has been most common in relation to nitrogen and phosphorus that are associated with both agricultural and urban water, and in one instance, to water quantity and salt. Point/point and pretreatment trading have been applied to metals associated with industries (Podar et al. 1996).

Kerns and Stephenson (1996) noted the following conditions necessary for trading:

- A binding constraint with definitive assignment of responsibility (either at the State or local level) is needed on the amount of pollution discharge and the responsibility must be enforced. Some entity must place a cap on nutrient loads and also impose some mechanism to account for future growth in loads.
- The geographic area in which trades will be effective must be specified. Trades can be allowed across the entire watershed or within small segments of a watershed. Trading will not be accepted if the trading scheme results in localised water quality problems.
- A credit such as an emission reduction credit or a nutrient credit must be established to allow for buying and selling of credits.
- Transaction costs, whether faced by the government or individuals, must not be too expensive.
- For trades between different sources, each source must contribute a substantial share of the pollutants.
- There must exist a sufficient number of relatively major dischargers. The potential is limited for trading if traders are too small or too few in number. If that is the case, transaction costs are too high or the opportunity to trade does not exist.
- A difference in the marginal cost of control (the additional cost of controlling an addition unit of pollutant) must exist (as shown in Table 4.1).

A trading ratio has been introduced in water quality programs. The ratio is the number of units of a non-point-source pollutant loading that a discharger must purchase in exchange for a single unit of pollutant loading. The value of the ratio is usually set to greater than 1:1 to compensate for the uncertainty associated with non-point sources (Griffin et al. 1991). Values of 3:1 are common in an effort to bring about water quality improvement. Letson (1992) discussed the economic consequences of setting the value of the ratio.

The acceptance of pollutant trading has been slow, not least because of the institutional arrangements to meet the needs of the above list. There are also significant technical constraints such as:

- the uncertainty in the estimates of non-point sources (by the TMDL or other approaches);
- how to deal with pollutants that decay with time (e.g. pesticides);
- differences in the forms of the chemical elements between sources (e.g. particulate phosphorus from non-point sources will not have the same environmental consequences as dissolved phosphorus from a waste-water treatment plant); and
- interactions between excess nutrients.

A concern in small or lightly populated watersheds is the domination of trading ('market power') by a single or a few large dischargers (Letson 1992).

In their analysis of the suitability for point/non-point phosphorus trading in the Cannonsville basin, Porter et al. (1999) noted the resistance to the idea from both urban and agricultural dischargers, who were concerned about additional regulations and administrative burdens, while environmental groups were inclined to want increased regulatory control.

5 Agricultural research at the watershed scale

The watershed approach focuses attention on a particular geographic location, and brings involvement of a wide range of interested parties, of which researchers are only some of many. However, researchers have crucial roles in each step (Table 2.1) of watershed work from identifying priority watersheds, characterising watersheds and water bodies, identifying particular problems that require correction, supporting implementation, and evaluating the impact of watershed implementation programs. While it is possible to distinguish between the application of scientific or economic work (for example routine monitoring of water quality) and research, the approach taken here is that of a continuum between the two.

5.1 Research in association with watershed implementation projects

The applications of multiple disciplines to a particular watershed, which will be unique in character and problems, may be sufficient to classify it as research, and researchers at the watershed scale are often dependent on data produced for more routine, perhaps regulatory, purposes. At least, researchers can be brought into contact with practitioners from watershed implementation projects, and through them, representatives of watershed inhabitants. The researchers will be influenced and their work is more likely to be of greater relevance to the practitioners. From the viewpoint of the watershed residents, their participation in the research is important if they are to readily accept its results. In the New York City watershed, this is expressed as a need for local ownership of the research program. Local extension staff in a watershed implementation project thereby can have a key role. It is they who can advise what could be done on farms within the watershed. Communication must be bi-directional between watershed leaders and the researchers.

In urban parts of the watershed, and on roads and stream banks, county-level staff are charged with specifying and implementing improvements. Progressive extension staff, and their non-farm equivalents, will turn to researchers for answers, and so influence the researchers' own work. In some cases, the watershed implementation project teams and their management will include extension staff and farmers. They may be influential in the allocation of funding to the researchers, and can directly influence the research. Associating and involving researchers with particular active watershed implementation projects appears the most straightforward approach for external research funding agencies that want to maximise the short-term application of land and water research.

Figure 5.1 presents an idealised and generalised outline of linkages between a watershed implementation project and researchers (agricultural aspects only, based on the first phase of the New York watershed's WAP). By its nature, the implementation project will have existing linkages to the watershed inhabitants, both by their representatives, and by direct interactions with individual farmers if they are appointed to a scientific support group. The scientific support group is proposed here to facilitate the two-way flow of information. It may be noted that farmer representation can occur at all levels. Formal direct linkages between farmers and all individual researchers may not be necessary with this structure, although it is bound to occur informally.

Specialists in particular disciplines will conduct individual research projects. It is suggested that a research coordinator take a key role in running the scientific support group and synthesising and communicating results through it. An important role for such a coordinator would be to foster collaboration and teamwork amongst a group of scientists with diverse backgrounds and, probably, limited experience with working within a project involving a wide range of disciplines. Maintaining cooperation and communication between the disciplines involves high transaction costs that the individual scientists may themselves be reluctant to accept.

5.2 Research to support watershed planning

A planning period, often of about two years, is likely to precede actual implementation or extension of best management practices in a watershed development project. Education and outreach activities and pre-implementation monitoring should also be established well in advance of implementation. The planning period could be a period of research, with prospects for the research results finding applications in the short term, once the implementation gets under way. This period also presents researchers with opportunities to be involved in the community educational activities, and this may be particularly appropriate for universities. Pre-implementation monitoring conducted during the planning period could also be used to build links between the agricultural research agencies and others responsible for monitoring (for example routine stream gauging). In addition, on-farm experimental work can be used for educational purposes. Although the planning period is an integral prelude to watershed implementation work, and should ideally be funded as part of it, it is possible for research funding agencies to assist only in the planning period. External research funding agencies could bring together an appropriate research team to cover the disciplines required, and select a research coordinator/project leader, particularly where individual research institutions do not have the full range of disciplines required. It would be important to involve the research group in the implementation project, with their roles changing from planning to advisers, conducting targeted research when necessary, and continuing with the evaluation of impact.

5.3 Research of general applicability to watersheds

In addition to research directly linked to existing or planned implementation projects at specific sites there is a clear role for research to develop generic, non-site specific tools and models in support of watershed related research. It is preferable to support this type of research in institutions that are also directly involved with particular watersheds as this will assist in keeping the researchers in contact with those who may use their outputs for specific applications. Although the researchers will be seeking outputs with general applications, they will always need field data from particular instrumented watersheds. There are mutual benefits to be gained by linking researchers involved in this kind of work with those active in fieldwork.

5.4 Research to support the watershed approach

This section does not attempt to develop a research agenda, or provide a list of priority research projects. Rather, it provides a framework on how various natural resource research activities fit in the watershed approach. The third column of Table 2.1 already indicated the kind of activities that may be expected.

Research at the large scale, that corresponding with satellite imagery or a large river basin, has direct application to the watershed approach. At the planning phase large scale remotely-sensed information and derived maps and models will find applications in identifying and setting

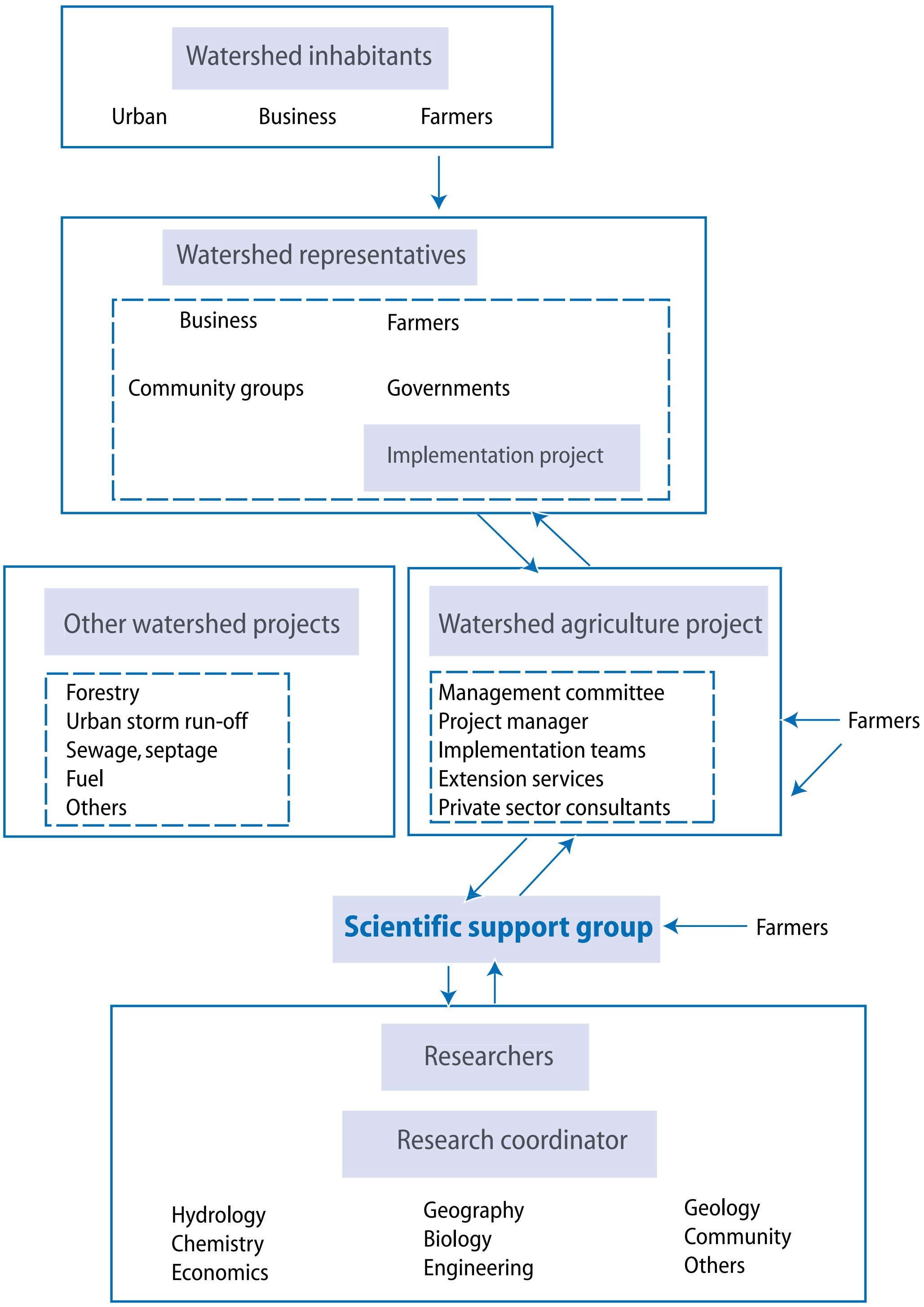

Figure 5.1 Generalised organisation chart for implementation and agricultural research for surface water management in watersheds.

priorities for watersheds that require more detailed work. At the watershed scale, up to hundreds of thousands of hectares, or county scale, a wide range of techniques requires further research and development as practical tools for watershed management. At large scale, research is still required on means of identifying and grouping land uses within watersheds for their characterisation. This will involve methodologies for managing large and diverse kinds of data, as well as geographic information systems. The development of models to predict the consequences of changes in land management on water quality will continue as major research subjects. Models also have a vital role in evaluating the effects of management decisions. The reason for this critical role is because of the normal extended time lag between watershed actions and benefits in water quality. It is necessary to interpret the likely high degree of variations observed. This is especially important in watersheds where there are significant confounding factors. Models provide valuable feedback to leaders after decisions have been made. It is important to recognise that both agricultural and non-agricultural activities in the watershed must be considered. In the watershed approach focused on protection of water, it can be expected that there will be instances where on-farm agricultural practices are not the major cause of problems in comparison with, say, road or urban run-off in causing sedimentation in water bodies.

Research at the large scale will be important to policy-makers and regulators. Within the watershed approach applied in the US, the EPA, USDA, and State departments of environmental conservation and agriculture can be readily identified as potential users of the research with policy implications. For example, successful technological or modelling research to reduce the uncertainty of estimating non-point sources of sediment or other pollutants in the TMDL process could have direct impacts on policies and regulations, as well as future plans to drive future environmental improvements by trading programs.

At the farm-scale research focuses on management practices that will abate losses of soil, nutrients and pesticides. Enormous research effort has gone into agricultural practices that reduce losses from fields and farmyards. Research on individual practices in isolation from practical farm management may be at a point of diminishing returns. Farm decisions influenced by the narrow perspective of a specialist may in fact be adverse to the broader interests of the farm. What is still required is research on practical combinations of practices for farms that prevent losses in long-term farm productivity and do not result in off-farm impacts to downstream water resources. This purpose is the basis of so-called 'whole-farm planning'. As this requires changes in farmers' practices, while maintaining economic viability, it is obvious that social and economic factors will be prominent. In general, successful corrective measures to reduce losses in farm productivity (e.g. preventing soil erosion) and identifying the need to protect large water bodies (e.g. from excessive sedimentation) have been devised from a successful research effort. However, the weak link in the chain is that the relationship between practices on farms and their impacts on water bodies is still very uncertain. Farm decisions may be multi-purpose, multi-factorial, and non-linear in their combined effects. Where the linkage from farm scale to water body scale has been made, where there are large sets of data and information, the effects of extreme weather events, in which a large proportion of the transport of materials from farms to water bodies occurs, are still poorly predicted. This uncertainty may result in over-cautious target setting leading to inefficient use of funds for implementing abatement activities. For example, the TMDL process incorporates an additional 'load' as a margin of safety, and trading programs set trading ratios greater than 1:1 partly because of uncertainty.

At the implementation level over-cautiousness resulting from uncertainty (a result of insufficient research) may also lead to unnecessary expense or inefficient allocation of funding. Uncertainty is at least partly responsible for the implementation of BMPs at three levels — barriers to prevent the transport of pollutants are applied to the original source, the over-land transport route, as well as immediately next to watercourses. The three barriers have in-built redundancy but this creates a safety margin to accommodate uncertainties.

The overall impact of a watershed project will be measured by the long-term measurements of water entering a water body, and in chemical and biological (ecological) measurement in the water body itself. As indicated earlier, it can be expected that several years' data will be required to detect changes brought about by the widespread adoption of new agricultural practices. However, this sort of long-term monitoring will be essential, not only for assessing the impact of one particular watershed project, but also for accumulating understanding of the linkages between on-farm practices and downstream impacts. During this period models play an important role in providing feedback.

The watershed approach is still evolving and it is impressive that many concepts have been adopted and implementation started. However, it is clear that the processes for assessing the target load reductions and trading schemes to drive improvements by market forces, have not been completed with scientific research or economic analysis.

5.5 Research in less-developed countries

This report has described work focused on water quality in the US, but what are the applications of the watershed approach elsewhere? In general the watershed approach is universally applicable, in that it orientates land and water management to natural units that can act as a focus for a diversity of interested parties. However, particular problems in land and water management vary widely. Data and information available vary markedly within a highly developed country and are likely to be scarcer in less developed countries.

Some applications where the watershed approach may be applied are outlined in Table 5.1. The watershed approach can be applied to varying degrees. It may form a framework for assessing the environmental impact of project ideas, a strategic framework for structuring a research program, or be adopted in part until funding for a comprehensive project can be obtained.

In Asia, most watershed development projects have been concerned with flooding and downstream sedimentation while improving the economic conditions of the inhabitants of upper watersheds. Projects in less-developed countries have multiple objectives and are not restricted to the main natural resources management problems (Doolette and Magrath 1990). Despite their original focus on upstream–downstream linkages World Bank economists concluded that downstream impacts of land use changes in large river basins are marginal (Magrath and Doolette 1990). This conclusion was based on the long time lag (decades) at river basin scale between the implementation of improvements in land and water management in the upper watershed and the time it takes for measurable changes in sedimentation in downstream structures. This is related to sediment storage in the basin. Magrath and Doolette (1990) considered that short-term reliance on dredging and infrastructure design for high sedimentation rates were the correct approaches. In seeking shorter-term impacts, it would appear that smaller scales should be considered, for example the catchment of a smaller unit such as an important reservoir.

Land-tenure issues in watershed development in Asia have been of particular concern. In particular, tenure may affect the profitability and adoption rates of new practices, and changes to land use have had unintended negative consequences for upland farmers. In addition, the failure to understand tenure systems may had led to the overlooking of opportunities for land management by multiple users (Molnar 1990). Molnar describes a wide range of tenancy and common property resource management arrangements in upland Asia. Short-term security leads to the lack of interest in resource conservation. However, there are several examples of arrangements that are acceptable to landholders and tenants, which lead to longer-term management and organised group management of common areas. In some instances it may be possible to link increasing the security of tenure with participation in the implementation of resource management improvements. It is clear that watershed development projects will always require study of tenure in the target area.

The introduction of economically attractive changes is the key to adoption, and improved local community resources have proven to encourage participation and on-going maintenance of systems. Molnar (1990) cites the case of small-scale water harvesting structures in upland areas, which provide very limited supplementary irrigation and reduce downstream sedimentation, but were of greatest benefit in improved forage and animal production.

Morgan and Ng (1990) suggested that watershed development projects should include a component for planning, monitoring and evaluation. Such a component would take responsibility for establishing information systems to integrate both technical and economic information, establish GIS facilities, and undertake watershed planning activities and site development plans. Such a group could also be responsible for reporting, and ensuring that lessons learnt from implementation activities are made available to others. These activities are closely aligned to those of recent US watershed projects outlined in Table 2.1, and could form the basis of a scientific support group (Figure 5.1). Evaluation, in particular, implies that external agencies should be involved. Such a component, which Morgan and Ng (1990) suggest would represent a few percent of an implementation project's costs, could form the basis of a research component to support the project. While a planning, monitoring and evaluation component should be part and parcel of a watershed implementation project, the absence of one could represent an opportunity for research agencies to become involved.

Table 5.1 Potential applications of the watershed approach to land and water problems

On site land and land-use issues	Related water issues	Note
Soil erosion	Sedimentation, turbidity, biological productivity, filtration	Soil erosion may directly reduce on-farm productivity as well as have off-site impacts
Nutrient losses	Excess nutrients in water	Excess loss of nutrients from land to water are usually of much greater consequence for the water than the loss of nutrient from the farm
Salinity	Salinity, ground- and surface water	Changes in management at the large scale are the only feasible long-term solution
Pesticides	Contamination of surface and groundwater, fisheries and wildlife protection	Groundwater is particularly difficult to remediate, prevention of contamination is paramount
Acidification	Acidification, fish habitats	Both are impacted by aerial deposition. Also caused by imbalances of nutrients in poorly buffered soils
Toxic metals	Toxic metals	Usually caused by industrial or mining activities, waste disposal
Forest activities	Decreased water quality, flooding or decreased water supply	Clearing and road making have serious off-site effects. Extensive clearing may result in increased frequency or extent of downstream flooding
Floodplain and riparian land and vegetation	River regulation Water supply Seawater intrusion	Impacts of river regulation at large (basin) scale
Concentrated animal production systems	Serious point sources of oxygen-depleting organics, nutrients and pathogens	Increased efficiency of nutrient use by confined animals has a key role
Extensive animal systems. Overgrazing, rangeland vegetation, wind erosion	Increased run-off and decreased infiltration	
Human waste disposal	Sewage plants impact directly on water, excess sludge disposal can contribute to non-point sources, septic tanks	Aim for beneficial reuse of nutrients without accumulation of excess. toxic substances.
Agricultural product processing	Point sources of pollutants	Numerous small industries my act more like a non-point source

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