CHAPTER 11

RESTORING HYDROLOGIC FUNCTION OF ALTERED LANDSCAPES: AN INTEGRATED WATERSHED MANAGEMENT APPROACH

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More than a century and a half of agricultural development in the Upper Midwest of the United States has resulted in one of the most productive agricultural areas in the world. Through technological advances on rich prairie soils, the corn–soybean cropping system has become a production centrepiece and is practised on more than 20 million ha in the Upper Midwest. Today, however, questions are being raised about its sustainability in terms of profitability and its impact on human and environmental resources. To expand production in the Upper Mississippi River basin, and particularly in the Minnesota River basin (MRB), wetlands have been drained and converted to croplands. Extensive tile drainage networks and ditch systems have been developed to move water more efficiently off the land and into stream channels. Annual crops have largely replaced tall grass prairie species in the uplands and native riparian forests along stream banks and in floodplains. Stream channels have been modified to convey floodwater in an effort to reduce flood damage to crops and farming communities.

A major environmental consequence of our enhanced agricultural productivity is non-point pollution of water bodies in the Upper Midwest. The Minnesota River is one of the most polluted water bodies in the state (Magner, Johnson and Larson, 1993; MPCA, 1994; State of the Minnesota River, 2001), and among the most polluted rivers in the United States, largely the result of agricultural non-point sources. Intensive agriculture is common in much of the Minnesota River basin. One of its tributaries, the Blue Earth basin, is more than 85 percent cultivated in corn–soybean, and although it represents only 20 percent of the area of the MRB, it contributes between 40 and 50 percent of the annual pollutant load in the Minnesota River (BERBI, 2003).

A serious concern in the basin is that nutrients are largely exported to streams through drain tiles and ditches that effectively by-pass riparian vegetation. More than 6 370 000 acres (2 325 000 ha) of Minnesota cropland is artificially drained (Ohio State University, 1998) and agricultural runoff is thus largely discharged directly into channels. This results in substantial nitrate loading because as much as 50 percent of nitrogen fertilizer applied to crops can be lost from agricultural fields in the form of nitrate (Neely and Baker, 1989).

The Minnesota River basin has also experienced frequent damaging floods, and many of the tributary streams and sections of the main stem river channel are considered to be in a degraded condition. These effects have been exacerbated by the loss of hydrologic storage on watersheds and in floodplains through the loss of wetlands, tile drainage, ditching and perennial riparian vegetation (Magner, Johnson and Larson, 1993). As a result, flow rates of water have increased (Miller, 1999), contributing to unstable stream channels and greater sediment delivery downstream. The importance of perennial vegetation on the landscape is apparent when satellite imagery of the Upper Mississippi River basin is examined in spring and early summer (see: www.nass.usda.gov/research/avhrr/avhrrmnu.htm). The spring period typically exhibits the highest runoff and stream flow of the year, a time when the annual cropping areas can be seen as expansive brown areas. In contrast, areas with perennial vegetation during this same period are a bright green, suggesting active uptake of soil moisture and soil protection from rainfall impact. Shifts towards more perennial cover on the basin, therefore, have the potential to reduce flow and sediment rates during the most active runoff season.

The cumulative watershed effects of current land use described above can be considered in terms of increased flow rates, increased channel instability and increased loading of pollutants to the river; all contribute to degradation of water quality of the river. These effects are recognized throughout much of the Upper Mississippi River basin and are reported to be contributing to the hypoxia problem in the Gulf of Mexico (Goolsby and Battaglin, 2000).

This paper describes an interdisciplinary and participatory watershed management programme in the Minnesota River basin. A research and education approach is taken to guide the identification, evaluation and development of alternative cropping and management strategies that incorporate trees, woody vegetation and herbaceous perennials into the landscape, with the purpose of improving water quality and the hydrological services of the Minnesota River and its tributaries. Alternatives are being considered to provide farmers with options that can compete financially with current production systems on their own or through payments for the environmental services that such practices provide.

We have developed the following five objectives to accomplish these goals:

1. Promote the creation of, or support existing mechanisms that place leadership with local landowners and existing stakeholder groups in the identification, evaluation, promotion and implementation of alternative production systems, with support from universities and local, state and federal agencies as appropriate.
2. Through changes in cropping and increased perennial vegetative cover on watersheds and riparian areas of the Minnesota River basin, improve the hydrologic condition of the Minnesota River, reduce the magnitude of peak flow rates associated with the more frequently occurring storms, and reduce nutrient and sediment transport downstream.
3. Estimate the economic consequences of changes in cropping and increased perennial vegetation cover in watersheds and riparian areas, considering both the financial benefits to farmers and the economic impact of hydrologic and water quality improvements that can result.
4. Identify agronomic, economic and policy constraints and key knowledge gaps to crop diversification with agroforestry and perennial crop systems.

5. Develop information for landowners, citizen groups, government agencies, policy-makers, industry and researchers in a format (materials, meetings, conferences and learning groups) that is appropriate for aiding stakeholders in the decision-making process and furthers management consistent with improving water quality.

RATIONALE FOR CHANGE

The issues summarized earlier point to the need for change on the agricultural landscape. However, immediate and widespread change from current farming practices is not possible; furthermore, many potentially viable land-use alternatives have yet to be identified and tested. Therefore, incremental change is a more realistic approach, using pilot projects to demonstrate which changes are most effective and acceptable to farmers. A fundamental question that will be addressed in this programme centres on determining the scale and landscape positions for agroforestry and other perennial cropping systems that are most effective in improving water quality and the hydrologic condition of the river. It has been shown, for example, that scale and placement of restored wetlands and perennial vegetation will govern the magnitude of hydrologic response and nutrient export to water bodies (Almendinger, 1999; Ahn and Mitsch, 2002).

What we are suggesting in this programme is that some major changes are needed, at least on portions of the agricultural landscape. The reasons for these changes, in contrast to modifying the existing corn–soybean farming, are many. For one, conversion from annual cropping to perennial and woody crops will, in most cases, reduce the application of fertilizers and other chemicals on watersheds. This alone can reduce nutrient and other chemical loading to wetlands, lakes and rivers. Where sufficient proportions of watershed areas are converted to perennial vegetation, which eliminates the need for artificial drainage, water flow rates may return to levels closer to those associated with the original prairie–savannah ecosystems within which the Minnesota River was formed.

Improving water quality

Replacing annual crops with perennial cover crops such as switchgrass and hybrid poplars has been shown to reduce chemical export to receiving watersheds in northwestern Minnesota (Baskfield, Magner and Brooks, 1996; Perry *et al.,* 1998; Stockhaus, 2000; Shank *et al.,* 2001). Randall *et al.* (1997) report that nitrate-nitrogen (NO_3-N) loading from tile drains was 45 times higher under row crops than perennial crops and native grasses in the Minnesota basin. Restoring perennial vegetation in riparian areas, including cottonwoods (*Populus* spp.) and willow (*Salix* spp.), has important water quality and hydrologic implications for the river, including reduced nutrient export to rivers, improved stream channel stability and improved aquatic habitat. Denitrification and uptake are the major processes by which NO_3^--N is removed in floodplains and associated riparian areas (Burt *et al.,* 1999; Gold *et al.*, 2001). Riparian forests and associated communities are effective in removing nitrate-nitrogen and also in trapping excess sediment and phosphorus (Thornton *et al.*, 1998; Whigham, 1988; Addy *et al.*, 1999).

Phosphorus (P) is a limiting plant nutrient in most freshwater systems of Minnesota. As a result, even small quantities of P can cause serious eutrophication of lakes and rivers (Lüderitz and Gerlach, 2002). Significant algae blooms and a corresponding increase in turbidity result.

Because P is most often adsorbed to soil particles, soil erosion and sediment transport influence the export of phosphorus and, consequently, the retention of phosphorus on the watershed. Basins in which more than 50 percent of the land is in agricultural cultivation can experience suspended loads that account for 56 to 59 percent of total P export (Cooke *et al*., 1993). Phosphorus farming in wetlands is possible, but because P removal in natural wetlands is often poor (results vary from 0 to almost 100 percent removal), with a mean removal of 29 percent (Lüderitz and Gerlach, 2002), reducing P loading to receiving waters is greater where there is uptake of P by vegetation in the watershed and where that vegetation is periodically harvested and removed from the site. Ornamental willows and other willows thus have potential to reduce P and provide income through periodic harvesting.

Reducing excessive stream flow

To grow corn and soybeans in much of the basin, wet soils are a major obstacle, hence the proliferation of drainage systems. Perennial crops that are adapted to these conditions provide an alternative for wet sites and, furthermore, can reduce excessive water flow in the river, a trend that has been observed from 1938 to the present (State of the Minnesota River, 2001).

Many independent studies have shown that areas with trees and other woody plants have higher annual evapotranspiration and generate lower amounts of runoff and stream flow than do herbaceous plants, including annual crops (Bosch and Hewlett, 1982; Whitehead and Robinson, 1993; Brooks *et al.,* 2003). Conversion from annual agricultural crops to hybrid poplar in northwestern Minnesota reduces soil moisture and water yield (Kaster and Brooks, 2001; Perry, Miller and Brooks, 2001; Shank *et al.,* 2001). Hybrid poplar and natural forest remnants also experience less concrete soil frost than annual crops, yielding lower snowmelt runoff in the spring. In contrast, conversion of native perennial vegetation to annual crops and the accompanying wetland drainage in the Minnesota River basin has been shown to more than double the magnitude of peak flows associated with recurrence intervals of 1.5 to more than 20 years (Miller, 1999; Mickelson, 2001). Changes in average annual peak flows contribute to degradation in the river channel (Rosgen, 1994) and these effects can be exacerbated by loss or degradation of riparian vegetation (Dwyer, Wallace and Larsen, 1997; Burckhardt and Todd, 1998; Bendix and Hupp, 2000; Tabacchi *et al*., 2000; Riedel, Verry and Brooks, 2002, and others).

The cumulative effects of increased and more diversified perennial crops in the basin can *restore storage* to Minnesota’s watersheds that have been lost through decades of: 1) wetland drainage; 2) conversion from native prairie and savannah ecosystems to annual crops; and 3) loss of riparian forest corridors in floodplains and along streams and rivers. Hey (2001) suggested that through restoration of riparian and associated wetland storage alone, we might experience significant reductions in flood peaks and hence flood damages. Hey and Philippi (1995) suggested that 13 million acres of restored wetland/riparian areas would have reduced flood damages caused by the 1993 flood in the Upper Mississippi River.

Opportunities for farmers and other landowners

As is the case with many watershed management benefits, those benefits derived from replacing annual crops with perennials can be many but may not all be reflected in the market.

Innovative mechanisms that will allow landowners to capture the value of the benefits they provide to downstream communities are needed to encourage land use that is consistent with improving water quality. Both financial (landowner) benefits and economic (societal) benefits can be obtained by implementing woody and perennial crop systems. Buffers around wetlands have also been shown to provide both economic and important water quality benefits when enrolled in the Conservation Reserve Program (CRP) (Rickerl, Janssen and Woodland, 2000). Growing short-rotation woody crops in Minnesota with incentives similar to CRP benefits provides a financially attractive option for rural landowners in areas of the state where markets exist for pulpwood or bioenergy. The current CRP programmes do not allow for productive use of the lands enrolled in the cost-share programme.

There are many opportunities to expand the use of woody and herbaceous perennial crops in floodplains and riparian corridors with agroforestry systems such as living snow fences, windbreaks and timber belts. Markets exist for woody biomass, either as an energy feedstock or as fibre for the wood products industry (Center for Rural Policy and Development, 2001). However, current fuel/fibre prices are too low for farmers to be willing to risk land conversion and the loss of short-term income, without additional incentives such as CRP (Streed, 1999). The bewildering array of federal and state policies and programmes that affect the management of farmland add to the need for effective risk-reduction strategies (Schertz and Johnson, 1997; Kuch and Crosswhite, 1998).

At present, CRP is essentially a set-aside programme that does not allow for the cultivation of marketable biomass crops on enrolled land. However, in 2001 the United States Department of Agriculture (USDA) approved the enrolment of land in the Minnesota River watershed as part of a pilot programme to evaluate the production of biomass fuels within the CRP framework (Johnson, 2001). Other types of incentives have also been considered. Hey (2001) suggested that credits might be given to individual landowners for increasing “storage” in upper watersheds and along main reaches of the river that translates into reduced downstream flood losses. He further indicated “Perhaps a futures market in flood storage credits could be established at the Board of Trade in Chicago”. If non-point source (NPS) pollution were regulated, a permit trading programme might encourage the implementation of agricultural best management practices (BMPs) such as riparian buffer zones. The difficulty of monitoring NPS pollution makes design-based incentives (such as agricultural BMPs) more feasible to implement than performance-based incentives such as can be applied to point source polluters (Horan and Ribaudo, 1999). Ultimately, basin-wide total maximum daily load (TMDL) standards may provide the mechanism for instituting watershed-based performance incentives (Ribaudo, Horan and Smith, 1999).

Perennial crops and agroforestry configurations provide opportunities to combine environmental services with productive and profitable crops. These options may be of particular importance to enhance the survival of smaller-scale farms with a greater diversity of production and markets. The status of these farmers is particularly threatened because they lack the resources to expand and adopt the new competitive technology necessary for economic survival. The complex forces that have an impact on farming in the Upper Midwest corn belt have local, regional, national and global origins and have created substantial barriers to farmer implementation of perennial crop/agroforestry options.

Given the recent poor market conditions for corn, soybeans and other grain crops, the problems of non-point agricultural pollution, pressure to establish TMDLs and other concerns about downstream impacts, such as the hypoxia issue in the Gulf of Mexico, opportunities for diversifying farm income and improving the condition of Minnesota's watersheds and rivers are attractive. Nonetheless there are a number of issues that limit our ability to take advantage of the potential opportunities that exist.

OBSTACLES TO CHANGE

The challenge in this programme is to develop and implement perennial cropping systems that are hydrologically effective, financially attractive to landowners and can be directed to appropriate landscape positions at a scale that provides both viable economic alternatives to farmers and the environmental benefits necessary to improve the condition of Minnesota watersheds. Not surprisingly, there are several obstacles to implementation that must be overcome in this programme, as summarized in the following:

- ***Lack of information on the aggregate impact of landscape changes on hydrologic storage and water quality.*** Although many studies have shown field-level effects of different land-use practices and vegetative conversions, the dearth of information about the aggregate watershed response to such land-use change has made it difficult to convince those who make decisions about land use.

- ***Understanding constraints to and motivations for farmer adoption of soil and water conservation options.*** Such options have been available to farmers for many years, but despite the potential benefits of these practices, they are often not adopted. The reasons for this lack of adoption include financial, technical and other constraints that are very real and well understood by the landowner. To motivate landowners to adopt sustainable practices, we need to understand the constraints they face, and together identify options that overcome constraints and offer productive and profitable opportunities.

- ***Institutional and policy constraints.*** Those factors and policies that influence farmers' use of the land need to be analysed; barriers to innovation and diversification of the agricultural landscape need to be identified so that better policies can be developed to support practices that provide benefits to society as a whole. Financial safety nets for farmers, rules for obtaining loans and crop insurance benefits, all are being examined for an array of different cropping systems and land-use practices.

- ***Lack of financial information on costs and benefits of alternative cropping and land management systems.*** Information about financial opportunities provided by diversified production systems, such as agroforestry practices, living snow fences, tree farms and alternative perennial crops, must be presented to farmers. Knowledge of production, processing and marketing is necessary so that farmers can make informed decisions.

- ***Internalizing externalities – valuing the benefits of improvements in water quality and storage.*** Many of the watershed measures that reduce peak flows and the amount of nutrients and chemicals entering water courses provide economic benefits for society or downstream users, which are not reflected in the market. The external and cumulative benefits and costs of land-use change need to be quantified and valued. This information is needed by policy-makers to make decisions about government programmes that may help finance practices that provide benefits to society.

- ***Lack of understanding and communicating of the adverse impacts of past land use and the benefits of land-use change to stakeholders.*** Farmers, other landowners, local communities and policy-makers, although aware of environmental problems related to land-use practices, may not understand how historical and cumulative changes in land use, and practices such as field and wetland drainage have affected stream flow peaks, channel erosion, sedimentation and water quality. In addition, there is little understanding of the hydrologic and water quality benefits that can be derived from restoring perennial woody vegetation on watersheds and in riparian areas.

AN INTEGRATED APPROACH

This multifaceted programme is a participatory approach that involves people from different sectors and with different backgrounds and disciplines. It incorporates demonstration projects, monitoring and research, educational programmes, hydrologic and economic modelling, market and policy analysis together in a way that invites expansion and continuity of successful outcomes.

Participation of stakeholders

Stakeholders are involved in this project in a number of ways. Programme objectives emerged largely from meetings, conferences and other activities involving a diverse group of stakeholders (landowners, local citizen groups, local, state and federal government agencies) in the Minnesota River basin. Partnerships have been formed with concerned citizen groups, agency personnel, agroforestry cooperatives, university faculty and individual farmers. One such partnership is the "3rd crop" initiative led by a local watershed group, the Blue Earth Basin Initiative (BERBI), which was formed to develop alternatives to intensive corn–soybean farming with the aim of improving water quality. Another group, Clean Up the River Environment (CURE), has been an active proponent of improving water quality and, together with the Minnesota River Joint Powers Board, has sponsored activities that bring together a broad range of landowners, citizen groups, government agencies and university researchers in the development of a Minnesota River Basin Action Plan. One of the top three recommendations in this plan is the improvement of land management practices, which this programme directly addresses.

Because the changes in land use and management practices to be evaluated in this programme are meant to be adopted by farmers and other landowners in the Minnesota River basin, the projects rely on "learning groups" that include some who have already implemented agroforestry and perennial cropping systems. These learning groups, patterned after the model of Jordan *et al.* (2000), provide the vehicle for stakeholder interaction to exchange and share ideas with the objective of designing sustainable and profitable land management options that can easily be adopted by landowners

Project activities

Through learning groups and workshops with stakeholders and project collaborators, scenarios of potential cropping changes are being identified in pilot project watersheds, the Chippewa and Blue Earth watersheds in the Minnesota River basin. Through a series of meetings with farmer learning groups, acceptable perennial cropping systems are being identified that have the potential for both financial opportunities for landowners and hydrologic/water quality benefits.

Demonstration areas of 10 to 20 acres (4 to 8 ha) are being established as pilot projects within small watersheds, and are accompanied by field research and monitoring to quantify production outcomes and hydrologic and water quality changes that are associated with the different cropping systems. These pilot projects are complemented by a series of plot studies in which seven perennial crops of interest to farmers are being studied to determine differences in soil moisture regimes, runoff and the export of sediment and nutrients. The results of this research and monitoring effort have important implications for the federally mandated TMDL process, which requires all states to identify and mitigate all impaired waters. Furthermore, the resulting data allow for testing and validating models to be used to extend field results across the basin.

Changes in vegetative cover and related changes to wetlands, stream channels and ditches will be simulated for upland watersheds and for riparian areas; different scenarios of change will be investigated to determine the effects of scale and landscape position on project objectives. The Hydrologic Simulation Program – Fortran Model (HSPF), as described by Bicknell *et al.* (1997), has been calibrated and will be used to simulate hydrologic, hydraulic and water quality changes due to project activities. Areas of upland watersheds that undergo conversion would not require drain tiles; therefore, where such changes occur, the removal of tile drainage would be a component of the simulation. In addition, changes in seasonal evapotranspiration, including interception, would be major hydrologic changes that would be reflected in model parameters, which would result in different soil moisture storage. Changes in the stream channel/riparian corridors, restoration of selected wetlands and riparian forests on floodplains and along stream banks will also be simulated. Field studies on ditch redesign that can create a functioning riparian vegetative buffer will provide empirical data to test and validate models. Furthermore, restored wetlands have been and continue to be monitored; their storage and water quality benefits can thus be better quantified and the data used to model the effects of expanded wetland restoration in the basin.

The output from the hydrologic modelling provides critical information for economic evaluations of downstream impacts. Stream flow volumes, peak flows, dry season (summer) base flows and sediment export will be examined under current land-use conditions. These same hydrologic variables will be simulated for conditions associated with perennial vegetation in uplands and riparian areas. Comparisons of these two conditions form the basis for further economic analysis. Hydrologic analysis considers how changes in stream flow pattern will affect bank full flow conditions and the resulting impacts on river stability and sediment-nutrient export. In addition, land-use effects on low flow conditions and the implications for water quality, aquatic habitat and diversity are all of interest.

Economic analyses will be performed using field monitoring data and hydrologic modelling results using the framework of FAO Conservation Guide No. 16 (FAO, 1987). On-site and off-site costs and benefits are being examined from both the perspective of individual farmers and that of the broader stakeholders in the river basin (externalities). Farmers may have to change their farming approach in some cases, requiring new equipment costs. Such costs must be compared with benefits derived from new crops. In terms of externalities, downstream impacts need to be quantified and valued. For example, if peak flow discharges associated with two to 20 year recurrence intervals are reduced, to what extent would such changes translate into reduced flood damages (benefits)? Any reductions in sediment levels in the channel and nutrient loading may be translated into sediment removal costs in ditches, effects on aquatic (fish) productivity, reduced water treatment costs and so forth. Valuing externalities represents a challenge and will depend, to a large extent, on the results of ongoing non-market valuation research. In some cases, only a rough estimate of potential downstream benefits can be obtained; regardless of whether all such externalities are valued, they will be identified as project outcomes. For example, the Minnesota River has good recreational potential and we will attempt to estimate the recreational value of a cleaner river.

An assessment of markets (current and future) for the variety of products derived from agroforestry and other perennial cropping systems is an integral component of the project. For example, there is now a planned bioenergy project proposed in the basin, which will require more than 25 000 acres (9 100 ha) of short rotational woody crops, such as willow, to be located near the site. This new market is in an area that is primarily under corn and soybean cultivation at present.

Workshops are planned for land managers and farmers to discuss economic and policy issues that constrain implementation. Discussions will be held to determine steps needed to provide necessary incentives and technical support to farmers, as well as explaining how the various land-use changes affect the flow and quality of water in the river. Topics covered will range from farming methods for perennial cropping systems, to hydrologic principles and examples of how improved riparian conditions, wetland conditions and uplands benefit stakeholders in the basin.

Educational materials will be prepared that are appropriate for different audiences (landowners, citizen groups, local, state and federal agencies, and policy-makers). The format for these materials will be determined through interaction with the various constituents in learning groups, workshops and more general meetings. Ultimately, the information will be distributed and evaluated through this same strategy. This participatory process should yield educational materials that support viable land-use options that have financial vitality and environmental benefits that can help shape agricultural and environmental policy in the state and region.

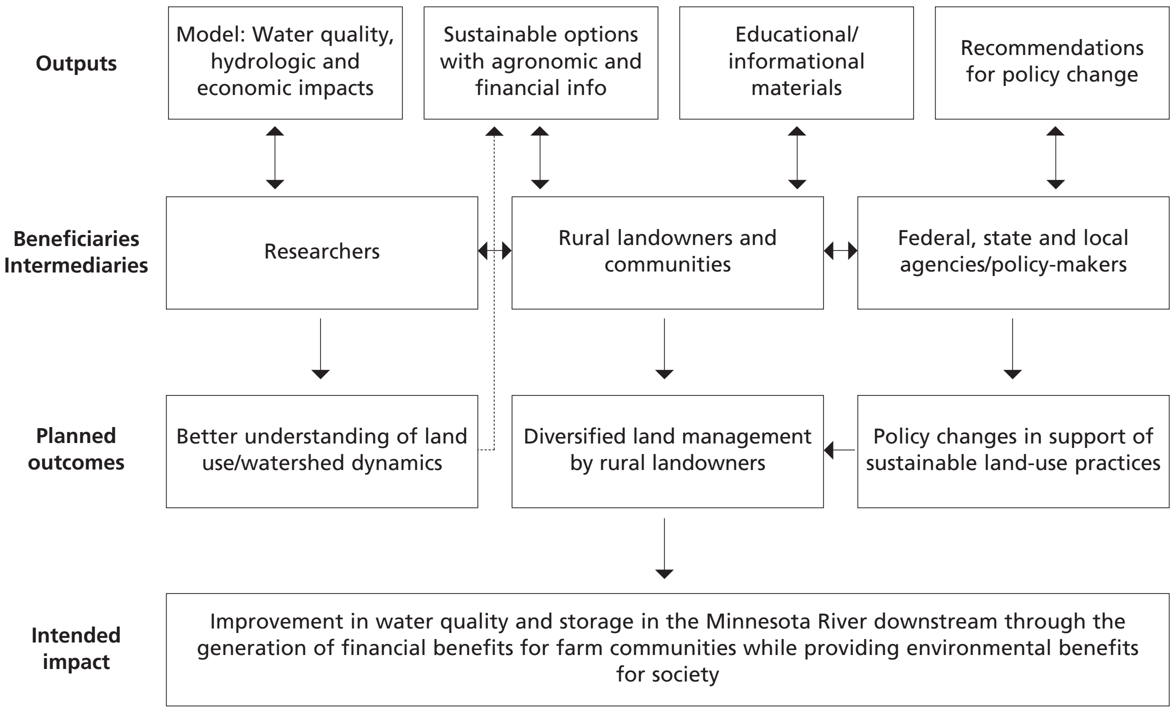
Programme summary and expected outcomes

This programme is expected to promote desirable land-use changes that will diversify the agricultural landscape, sustain the rural economy, enhance hydrologic storage and function and improve water quality in the Minnesota River basin (Figure 1). Prospects for broadening the agricultural production base can lead to more sustainable financial benefits to landowners while enhancing the environmental benefits to both local communities and downstream communities as well. All these objectives can only be achieved when individual landowners adopt more sustainable land-use practices in sufficient numbers to generate the desired impact.

To promote the adoption of alternative systems, the programme will identify options with benefits sufficient to convince rural landowners to make the change. Therefore, this integrated approach must develop the technology, markets and policy changes necessary to make those systems attractive to landowners. The key to this approach is that landowners, technical service providers, policy-makers and other interested parties/stakeholders have been involved from the outset. We expect that our initial learning groups will expand into an ongoing network of groups working to improve and adapt management practices for using perennial crops and agroforestry options, as has occurred with our earlier groups that addressed annual cropping systems. What should emerge from the programme is an expanded and continuing diversification of land use and management, a better understanding of watershed benefits that are derived from improved land use, more involved and informed citizens, and ultimately policy changes that are needed to support sustainable land-use practices.

FIGURE 1

Programme outputs



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