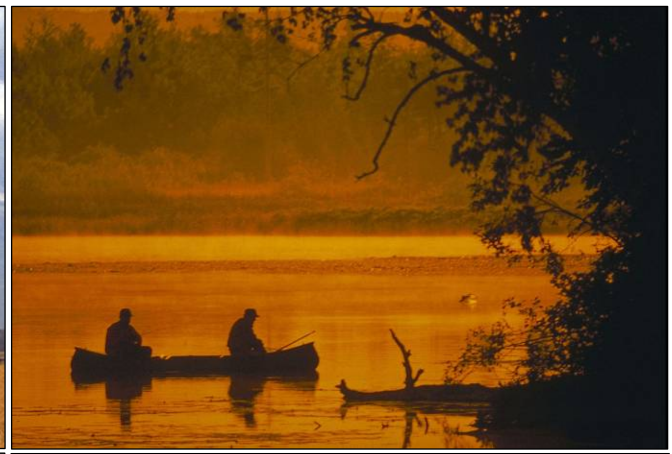
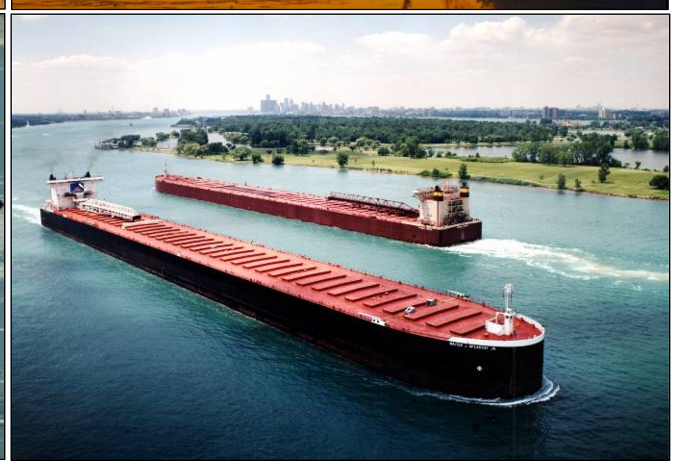
The Economics of Soil Erosion and Sedimentation in the Great Lakes Basin



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Executive Summary

The purpose of this report is to present the current state of knowledge on the economics of soil erosion and erosion control in the Great Lakes basin. Soil is defined as the unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants. Sediment is eroded soil from the landscape, which is generally transported by river systems and eventually deposited into a lake, reservoir or larger body of water. Estimating the economic costs associated with soil erosion and the benefits of erosion control can be very difficult. To understand the full picture, one must recognize the linkages between soil erosion and its impacts, which are not always clear or well-documented, and be able to assign an economic value to these impacts, which can also be complex. This report describes what is known about: 1) the status of erosion and sedimentation in the Great Lakes basin; 2) impacts from erosion and sedimentation on environmental resources, beneficial uses, and market goods; 3) monetary damages from erosion and sedimentation and the benefits of erosion control; and 4) the cost-effectiveness of erosion control programs and practices. It is anticipated that this information will be useful in assessing the monetary damages of erosion and sedimentation for the Great Lakes basin.

The first section of the report describes the status of soil erosion and sedimentation in the Great Lakes basin. In order to understand the economics of soil erosion and erosion control, it is important to understand the rate of erosion and soil deposition in the basin. There is currently a lack of good data on sediment loads and their impacts. In fact, there are few direct measurements of loadings to help assess the effectiveness of control measures. In order to conduct a realistic assessment of the costs and damages of erosion and sedimentation in the Great Lakes region, the following information is needed: 1) a more accurate measurement of the total soil loss in the basin, including all sources of sediment (not just agriculture); 2) a better understanding of how sediment is transported through watersheds in order to better predict its impacts throughout the system; and 3) a more accurate measurement of sediment delivery ratios and sediment loads to the Great Lakes.

The second section of the report describes the process of soil erosion, soil transport and soil deposition, as well as the land-use activities which have the potential to exacerbate soil erosion. Understanding the movement and storage of sediment in rivers is a key to understanding its impacts on the watershed system. However, there are many factors that influence the rate at which soil erodes and the types of problems sediment can create downstream. The linkage between sediment and its potential impacts is neither distinct nor simple.

The third section of the report describes the impacts of sediment on aquatic environments, beneficial uses, and market goods and resources. Sediment can cause a wide array of damages as it erodes from the land, is transported by water or other means and eventually settles out in a lake, reservoir, or other location. These impacts are diverse and are influenced by complex hydrological, physical, chemical and biological factors. Sediment pollution also impacts environmental systems, such as rivers, streams, lakes, reservoirs, wetlands and fisheries as well as resource uses such as recreation, drinking water, navigation, flood control, drainage, and property values.

There have been very few comprehensive studies that have examined the monetary impacts of erosion and sedimentation in the Great Lakes. One of the most comprehensive studies to examine this issue in Great Lakes basin is the 1970s Pollution from Land Use Activities Reference Group (PLUARG) study by the International Joint Commission. PLUARG was the first study to document in detail the water quality impacts associated with land use, including impacts from sediment. Many problems identified by PLUARG remain today, including excess nutrient loads and contaminants, both of which can be tied either directly or indirectly to sediment.

Another seminal study on the impacts of erosion and sedimentation was conducted by Clark, Haverkamp and Chapman for the Conservation Foundation in 1985. This national study, entitled *Eroding Soils: The Off-farm Impacts*, looked at the impact that sediment has from the time it erodes from the land to the time it accumulates in a lake, reservoir, or other location. The study researchers found that many types of damages are weakly documented, and that even for those damages that are well-documented, the direct linkage between these damages and sediment is not well-understood.

The fourth section of the report describes what is known about the monetary costs associated with erosion and sedimentation, and includes a literary review of nearly 75 economic valuation and impact studies. Determining the monetary costs associated with erosion and sedimentation – or the benefits from reduced sediment load – is difficult for three key reasons. First, an estimation of impacts requires an understanding of ecosystem health and the status of environmental resources, which often are not very well documented or monitored. Second, even if environmental impacts are identified, the linkage between soil erosion and these impacts is not always clear. Third, if the impacts are identified and the linkage between sediment and the impacts is determined, an economic value must still be assigned to these impacts and is often difficult to assess.

In short, the total monetary costs of damages from erosion and sedimentation are largely unknown for the Great Lakes basin and no comprehensive studies to document these costs have been conducted. Most of the research in this area is site-specific and focuses on prescribing an economic value to a particular ecosystem good or service. The most comprehensive study to date that documents the monetary impacts of soil erosion and sedimentation was the Clark, Haverkamp and Chapman study, *Eroding Soils: The Off-Farm Impacts.* This study concluded that, in 1985, the total nationwide off-site damages of erosion from all sources totaled $7.0 billion per year. Monetary damages are provided for several specific categories, such as recreation, navigation, water supply and habitat. In 1989, M.O. Ribaudo conducted a national study of sediment damages resulting from agricultural erosion, entitled *Water Quality Benefits from the Conservation Reserve Program*, and found damage estimates to be between $2 billion and $8 billion per year. These estimates include damages or costs to navigation, reservoirs, recreational fishing, water treatment, water conveyance systems, and industrial and municipal water use.

In order to assess the costs of soil erosion and sedimentation, it is also important to look at the cost-effectiveness of soil erosion and sedimentation control programs and practices. The fifth section of the report provides an introduction to the current state of knowledge on the cost-effectiveness of sediment control programs, policies and practices, with summaries of nearly 35 studies and reports. Erosion control practices help keep soil on the land and reduce the amount of sediment that accumulates in rivers and lakes, but they can be costly and time-intensive to implement. Understanding the economic benefits of intervention strategies can help determine if these practices are worth the time and money.

Economists have developed methods by which to quantify the economic benefits of environmental programs. However, there are serious limitations to choosing the most cost-effective strategies, due to the complex nature of erosion and sedimentation. First, erosion is difficult and expensive to measure because it is diffuse and is impacted by random natural events such as weather. Also, the process by which sediment is transported to and through rivers and lakes is influenced by a number of factors, some of which are unpredictable. Therefore, the random and unpredictable nature of the erosion and sedimentation process imposes serious limitations when crafting programs and policies that are cost-effective. Another issue to consider is the scale of application. Erosion and sedimentation depend on many site-specific factors. Thus, the more site-specific that policies and programs are, the more efficient they will be. However, designing and implementing site-specific programs can be very costly as they require the collection of site-specific data and information, which can be expensive to acquire.

In recent years, there has been pressure to expand the scope of estimating costs and benefits in national policymaking, including proposals to require federal regulatory agencies to address costs and benefits of legislation. Furthermore, there also appears to be growing pressure to incorporate nonmarket values in economic analysis and decision-making. This trend will likely spur research into new methods of applying economic valuation to policy and decisionmaking. In addition, an accurate measurement of the total amount of soil loss in the Great Lakes basin (as opposed to state-wide data for each entire Great Lakes state) is sorely needed, as is an accurate measurement of sediment delivery ratios and sediment loads to the Great Lakes and a better understanding of how sediment is transported through the basin.

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Introduction

Soil erosion and sedimentation are serious problems in the Great Lakes basin. Erosion, the detachment of soil particles by wind, rain and other forces, diminishes the productivity of agricultural lands. Sedimentation, the deposition of eroded soil from the landscape, clogs harbors, navigation channels and water treatment plant pipes, fills streams and lakes, and degrades water quality by introducing suspended solids and pollutants into water systems. Sediment also increases turbidity in water and can transport other pollutants such as pesticides and fertilizers that adsorb to the sediment particles. Combined, erosion and sedimentation reduce the productivity of agricultural cropland; adversely affect fish and wildlife habitat; negatively impact the recreational quality of streams and lakes; and cause federal, state and local governments to incur tremendous costs through increased dredging, ditch and stream channel maintenance, and damage to water treatment and conveyance facilities.

Soil erosion control programs help keep soil on the land and reduce the amount of sediment that accumulates in rivers and lakes. The public costs of soil erosion control programs can be significant, but these programs bring measurable public benefits that will be realized through improvements in water quality, protection of fish and wildlife habitat, and enhancement of recreational opportunities. Effective erosion control programs will also reduce the need for increased dredging, stream and ditch channel maintenance, and may reduce maintenance costs to water treatment and conveyance facilities. Comparing the costs required to implement prevention measures with the economic benefits associated with reduced sediment load, is critical to understanding the value of these intervention strategies.

Estimating the economic benefits of soil reduction measures is difficult for several reasons. First, it involves understanding the linkage between soil erosion and its impacts, which is not always clear or well-documented (Waddell, 1985). Second, it requires assigning an economic value to these impacts. Sometimes this is straightforward, as is the case with increased dredging or water treatment costs. Sometimes this is more difficult, such as assigning monetary values to clear streams or healthy fish habitat.

In order to understand the economics of soil erosion and erosion control, it is important to assess the status of erosion and sedimentation in the basin; damages from erosion and sedimentation and the benefits of erosion control; and the cost-effectiveness of erosion control programs and practices. This report describes the current state of knowledge in these three areas.

Soil Erosion and Sedimentation in the Great Lakes

Recent modeling data suggests that more than 65 million tons of soil may be eroding annually in the Great Lakes basin (Ouyang et al., 2003). That rate is equivalent to more than 2 tons of soil per second. Agricultural land is by far the largest known contributor to soil erosion in the basin, contributing between 65 to 77 percent of erosion (Ciaglo 1989, Great Lakes Commission 1987, U.S. EPA 2000 as cited in Ouyang et al., 2003, NRI 1997). The remainder of soil erosion in the basin comes from forests, pastures, streambanks, urban areas and other sources. Estimates for shoreline erosion are not available for the whole basin. However, the International Joint Commission (IJC) estimates that shoreline erosion accounts for a higher percentage of sediment than agricultural cropland (Ciaglo, 1989).

There are no precise measurements for how much soil is eroding in the basin and depositing in the Great Lakes and their tributaries. The only comprehensive soil erosion data available for the region is from the National Resources Inventory (NRI), and is included in a nationally-consistent statistical data set on erosion resulting from water and wind processes on cropland for the period 1977 - 2001. The NRI is a statistically-based survey that is used to assess conditions and trends of soil, water, and related resources on nonfederal lands in the United States. It is conducted by the U.S. Department of Agriculture's Natural Resources Conservation Service (USDA NRCS). Erosion on cropland is of particular interest to NRCS because of potential offsite impacts on water and air resources, as well as its relationship to productivity and long-term cropland sustainability.

NRI data shows that rates of erosion losses and sedimentation for the eight Great Lakes states have declined over the past twenty years, paralleling national trends. However, it should be noted that these data refer to the Great Lakes states entirely and not just the portion of the states that fall within the Great Lakes drainage basin. Based on the 1997 NRI data (revised in 2001), erosion on cropland, Conservation Reserve Program (CRP) land and pastureland within the region had been reduced by 27 percent since 1982 (compared to a 38 percent reduction nationwide). In 1982, 610 million tons of soil were eroding annually in the Great Lakes states from agricultural land. By 1997, this figure had dropped to 443 million tons.

Declining erosion rates on agricultural lands are due in part to the successful implementation of the Food Security Act of 1985 and the Food, Agriculture, Conservation, and Trade Act of 1990, both predecessors to the current Farm Security and Rural Investment Act of 2002 (and commonly known as the Farm Bills). The Farm Bills helped to create numerous programs, such as the CRP, aimed at reducing erosion rates and implementing best management practices (BMPs). However, erosion rates appear to be leveling off in recent years with little change since 1992 [1] (see Figure 1).

The NRI survey is an excellent source of data on erosion, covering more than a 20-year time period. From this data, it is

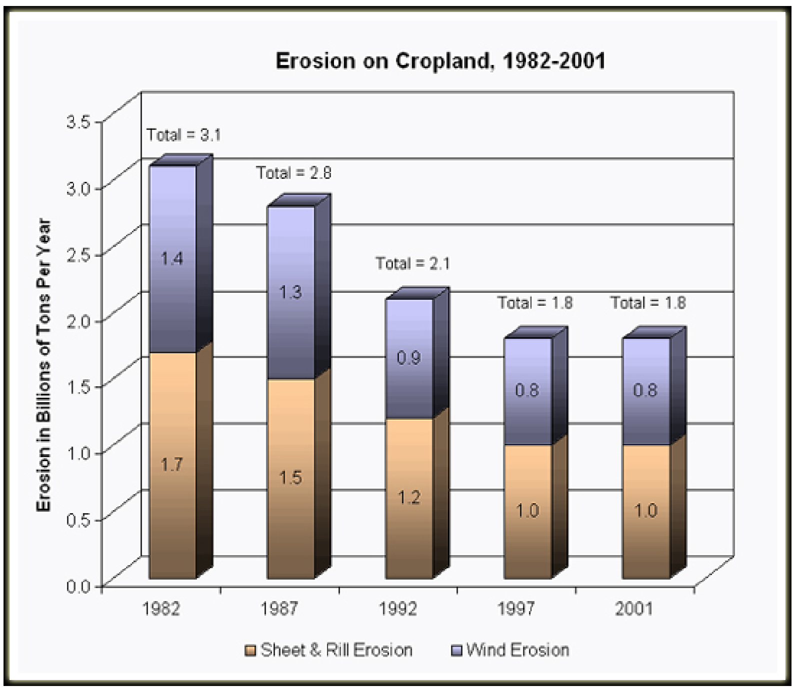


Figure 1. Erosion on Cropland, 1998 – 2001 [1]

[1] Estimates presented here are based upon the latest information from the National Resources Inventory (NRI). The NRI is a longitudinal sample survey based upon scientific statistical principles and procedures. Erosion rates computed from NRI data are estimates of average annual (or expected) rates based upon long-term climate data, inherent soil and site characteristics, and cropping and management practices. The 2001 data are suitable only for analysis at a national scale. Current estimates cover the contiguous 48 states.

possible to examine trends in erosion rates and sediment losses from 1977 – 2001. However, there are some significant limitations to this data. First, it is available only for agricultural lands and not from the numerous lesser sources, such as forest lands, streambanks, construction sites, and coastal areas. Second, this data is not statistically significant below the state scale. Thus, it is difficult to get an accurate picture of erosion for the Great Lakes drainage basin, as Michigan is the only state that lies almost entirely within the basin. Finally, the NRI data only tells part of the erosion story; it does not inform our understanding of sediment transport, deposition or yield.

The sedimentation process consists of soil erosion, soil transportation and sediment deposition. Some of this dislocated soil is deposited in ditches and stream channels, while the remainder passes through the system and empties at the mouth of the channel into a lake, reservoir or other large water body, contributing to the "sediment delivery" or the total amount of sediment per year that reaches the watershed outlet. Sediment yield is defined as the amount of eroded soil from the landscape which reaches the channel at a specified location. Both sediment yields and delivery figures are usually not available as a direct measurement; but rather are estimated using various localized factors and equations. Thus, the NRI data can describe, at the national and state levels, how much soil is eroding from agriculture land, at what rate it is eroding and whether these figures are increasing or decreasing. But the NRI data cannot tell us what happens to that soil once it is eroded and how much of it is ultimately deposited in the Great Lakes.

Researchers at Michigan State University (MSU) are currently using advanced modeling techniques to calculate potential soil erosion, sediment delivery ratios, and sediment loads for tributary watersheds of the Great Lakes. As monitored sediment data is not readily available in many cases, modeling of erosion and sediment delivery ratios is an important and effective approach for estimating sediment loadings. Using Geographical Information System (GIS) technology and GIS data such as digital elevation models (DEM), land use/cover and soils layers, models can be efficiently used to simulate soil erosion, sediment delivery and loadings to identify high-contributing areas in a large basin. MSU researchers are developing a "broad-brush analysis" of Great Lakes watersheds to assess and compare their relative loadings of sediments, the state of conservation practices, and their potential for further reductions to sediment and contaminant loadings.

Preliminary results estimate that potential total soil loss is 68.0 million tons per year from agricultural cropland under conventional tillage farming practices in the Great Lakes basin, 31.1 million tons per year under reduced tillage practices and 11.3 million tons per year under no till (soil that is left undisturbed from harvest to planting). The results show that conservation tillage practices (reduced tillage and no till) can reduce soil erosion significantly. Reduced tillage practices have the ability to cut soil loss by half and no till practices can reduce soil loss by up to 80 percent. Similar results show that conservation tillage can also reduce sediment loads significantly, with estimated total sediment loads of 15.6 million tons per year from agricultural croplands under conventional tillage, 7.1 million tons per year under reduced tillage and 2.6 millions per year under no till practices.

Figure 2. Estimated Total Soil Loss from Agricultural Croplands with Different Tillage Practices in the Great Lakes Basin (Ouyang, et al., 2003).

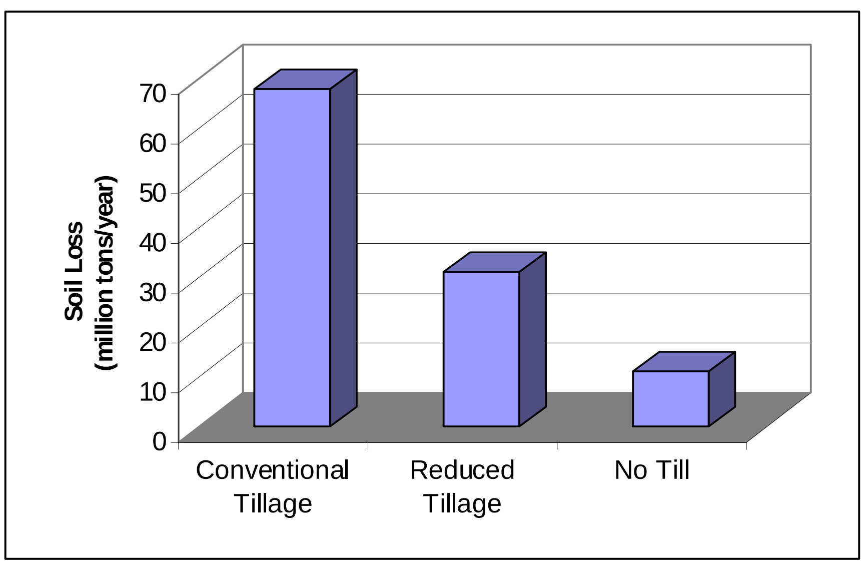
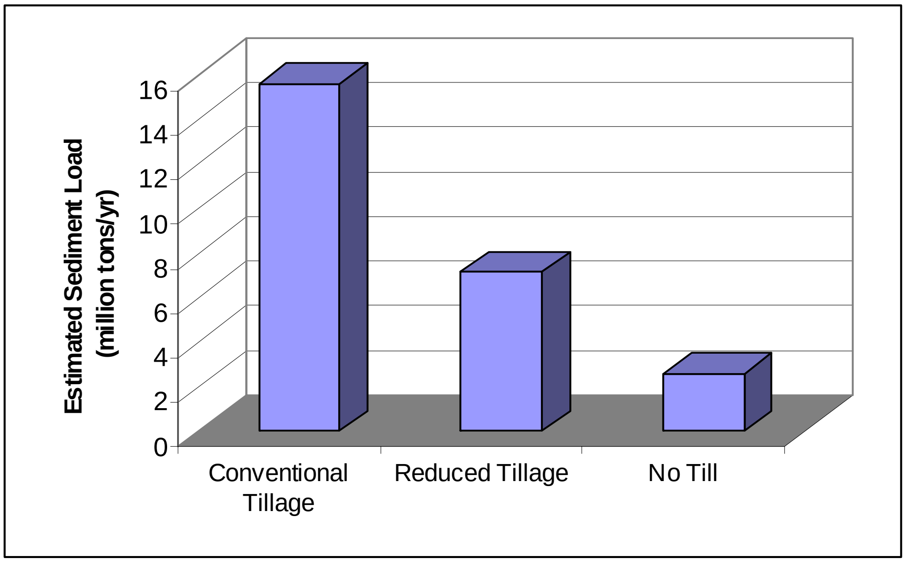


Figure 3. Estimated Total Sediment Load from Agricultural Croplands with Different Tillage Practices in the Great Lakes Basin (Ouyang, et al., 2003).



The preliminary findings of the MSU study are very valuable, as this is the only study that has estimated potential sediment loss, sediment delivery ratios and sediment loads for the Great Lakes basin. However, there are limitations to the MSU data that should be noted. The MSU findings are intended to help assess and compare relative loadings of sediments from Great Lakes watersheds in order to prioritize potential high-risk areas, as well as to compare the effects of different tillage practices on soil erosion and sediment loading. The data was not intended to provide actual figures on sediment loss and sediment load for the basin. In addition, as is the case with the NRI data, the report focuses only on agricultural land and does not address sediment loading from other sources, such as construction sites, forested lands, or coastal areas.

A 1998 workshop conducted by the IJC to review progress in addressing nonpoint source pollution concluded that, while progress was significant through the 1980s, it had stalled over the previous decade**.** Soil erosion remains a significant problem in some areas and practitioners may be approaching the limits of acceptance and/or effectiveness of control practices. In addition, participants found that there is a lack of good data on sediment loads and their impacts. General information exists about the nature and importance of sources, but most of this information is derived from inference and not from direct measurement. In fact, there are few direct measurements of loads that may be relevant in assessing the effectiveness of proposed controls. As governments scale down their monitoring and surveillance efforts, these data are becoming scarcer and older.

The impacts of sediment on the environment and the economy occur throughout the system. As sediment moves through a system, it can smother habitat and degrade water quality. Further down the system it can clog water treatment plants and reservoirs. Eventually, the sediment may be deposited in harbors, adding to dredging costs and impairing recreational boating and navigational use of the waters.

Thus, in order to conduct a realistic assessment of the costs and damages of erosion and sedimentation in the Great Lakes region, the following information is needed: 1) a more accurate measurement of the total amount of soil loss in the basin, including all sources of sediment (not just agriculture); 2) a better understanding of how sediment is transported through watersheds to better predict its impacts throughout the system; and 3) a more accurate measurement of sediment delivery ratios and sediment loads to the Great Lakes.

The Basics of Soil Erosion and Sedimentation

The linkage between sediment and its potential impacts is neither distinct nor simple (Clark, Haverkamp and Chapman, 1985). First, sediment is not a homogenous substance. It is usually a mix of different particle sizes, including clays, silts, sands and gravels, which may be densely or loosely packed together. Soil is also a combination of different mineral particles and contains a variety of bacteria types and other organisms. There may also be additional man-made chemicals, such as fertilizers and pesticides, that bind to the soil particles and are transported by sediment. All of these factors influence the rate at which soil erodes and what types of problems it creates downstream. The following section describes the physical processes of soil erosion, transport and deposition, and the primary land-use activities that lead to increased erosion and sedimentation.

Physical Process

Soil erosion is the process by which soil is worn away from the land through various geomorphic processes, including soil detachment caused by rain and overland or sheet flow, rill erosion and transport, gully erosion, channel degradation and bank erosion, surficial gravity erosion and wind erosion. Sheet erosion is the uniform removal of soil in thin layers by the force of raindrops and overland or sheet flow. Rill erosion occurs when the flow of water over the land (i.e., sheet flow) is concentrated into small channels called rills. Gully and channel erosion occurs mostly during or immediately after heavy rains or melting snow when several rills combine and flow together, eroding a larger channel. In the Great Lakes basin, sheet and rill erosion account for approximately two-thirds of total erosion, while the remainder is caused by gully and channel erosion (Wade and Heady, 1976).

Soil erosion is a regular occurrence in agricultural areas, where farmers till the soil to plant seeds. It can also occur when vegetation is removed for construction purposes for new roads and buildings. Clear-cutting forests can also expose soil to erosion, as can forest fires. Dislocated soil is then carried – or transported – by wind, water or human activities. Some of the dislocated soil is deposited in ditches and stream channels, while the remainder passes through the system and empties at the mouth of the channel into a lake, reservoir or other large water body, contributing to the “sediment delivery” or the total amount of sediment per year that reaches the watershed outlet (usually measured in tons/acre/year).

There are many factors that affect the rate at which soil erodes from land, including 1) rainfall intensity and duration, 2) soil erodibility, 3) land topography and 4) type of land use. For cropland, the type of vegetative cover and tillage practices also impact the rate of soil erosion.

Not all of the soil that erodes off the land ends up in our waterways. It may be deposited along the way at the edges of fields or in areas where the slope of the land has leveled off. The difference between the amount of soil that erodes off of the land and the amount of soil (or sediment) that is eventually deposited in a waterway is known as the “sediment yield,” usually expressed as average tons/acre/year. Sediment yield is usually not available as a direct measurement, but rather is estimated by using a sediment delivery ratio, for which there is currently no precise estimation procedure (Ouyang, et al., 2003). The sediment delivery ratio is affected by a variety of factors, including soil characteristics, proximity to the waterway, channel density, watershed size, slope, length, land use, land cover, and rainfall intensity and duration.

Sediment moves through a river system in response to specific events and changing conditions in the drainage basin. The movement of sediment is usually not continuous, but rather is separated by periods of storage that can range from less than a year to more than 1,000 years (USGS, 2005). Understanding the movement and storage of sediment in rivers is a key to understanding its impacts on the system. A more detailed discussion of sediment transport through streams is provided in the section on Sediment Impacts.

Land-Use Activities that Lead to Excessive Erosion and Sedimentation

Increased erosion and sedimentation are often directly related to land use changes or to poor land management. Land use activities that can exacerbate erosion and sedimentation problems include agriculture, rangeland and pastureland, forestry, industrial, urban, and water resource management. These are described below.

Agriculture

Agriculture increases the risk of erosion through land use conversion and tilling of fields. Traditionally, farmers have prepared their fields by tilling or plowing to produce a smooth soil surface with no vegetation or previous crop material to interfere with the seeding equipment. This process creates a soil surface that is very vulnerable to erosion, thereby allowing wind or rain to detach soil particles and to allow water to flow overland at a more rapid rate. Water runoff not only picks up sediment, but eroded topsoil may also transport agricultural chemicals that are bound to the soil particles. Conservation practices and technologies exist that can help prevent erosion from agricultural production; however, these practices and technologies can be expensive and are often underutilized. Even though debris basins, settling ponds, and other structures may be used to catch sediment and filter runoff before it enters a stream or river, keeping the soil on the land is generally the best option, both ecologically and financially.

Another impact of agricultural land use is the historic removal of riparian vegetation to increase arable lands. Floodplain soils are usually very fertile, relatively level and in close proximity to water. These qualities have helped to promote the conversion of riparian vegetation in floodplains to cropland. However, because of the proximity to water, sediment delivery ratios tend to be high. Restoring streams and riparian areas can help to reverse this impact.

Range and Pasture

Grazing can lead to increased sediment moving into rivers and streams. Grazing animals can cause compaction of the soil, as well as a reduction in soil cover, both of which lead to increased runoff and less infiltration of water into the soil. Increased runoff can also lead to increased stream bank erosion.

Often, grazing animals will drink water from rivers and lakes, trampling down vegetation and destabilizing banks. Livestock spend more time in riparian areas than in upland areas; consequently the riparian areas are more intensively grazed (Armour, Duff and Elmore, 1991 as cited in Castro and Reckendorf, 1995). Bank erosion can also lead to increased turbidity in the waterways, which negatively impacts the aquatic habitat.

Forestry

There has been a great deal of research on the impacts of harvesting activities (Castro and Reckendorf, 1995). One interesting finding is that logging roads, rather than the harvesting practice itself, are responsible for a large percentage of the excess sediment delivered to our waterways (Everest et al., 1987). The roads act as tributaries, creating an efficient sediment delivery system through which sediment is easily transported directly to streams through a series of ditches and culverts. Consequently, practices that prevent sediment from entering streams, such as riparian buffers, are not sufficient when a significant road network is in place. Forest roads also increase erosion through the removal of riparian vegetation. The removal of vegetation destabilizes the banks and may result in bank erosion.

Timber harvest practices, such as clear-cutting and selective cutting, directly impact sedimentation rates in a stream system. When vegetation is removed, soils are destabilized, increasing erosion and sedimentation. Many state and federal forestry regulations minimize or prohibit timber harvesting in riparian zones.

Industrial

Industrial uses include large manufacturing companies, open pit mining and sewage treatment plants, among others. There has been a great deal of research focusing on the effects of industrial sediment pollution (Castro and Reckendorf, 1995). This research has been conducted primarily in the eastern United States as a result of heavy industry along many of the eastern rivers, and in the Great Lakes region. Mining, for example, not only increases the amount of sediment delivered to streams and lakes, but also contributes toxins such as heavy metals. These toxins are bound to the sediment which is eroded and washed into waterways.

Urban

Urban land use intensifies erosion and sedimentation in two major ways. First, urban development and increased impervious surfaces cause increased stormwater runoff and peak flows. Ultimately, this increases stream water velocities and can cause erosion of the stream channel. Floodplain and channel filling also leads to stream bank erosion problems. Second, the construction of buildings and roads can result in temporary sediment “pulses” as vegetation is removed and soil is exposed.

Water Resources

In-stream structures designed for water storage, diversion and flood control are among the largest impacts on sedimentation and ultimately, aquatic systems.

Dams are one of the most severe alterations to a stream; peak flow quantity and intensity is reduced, as is the stream’s capacity to carry sediment. Dams also restrict or prevent the flushing effect often caused by large storm events. All this can result in a buildup of tributary sediment in the channel over many seasons, rather than a dry-season buildup with periodic flushing. Downstream scour as a result of long-duration clean water releases from dams is also a problem because there is often high sediment recruitment directly below the dams.

Stream diversions for agricultural water or hydroelectric generation also diminish the stream's capacity for sediment transport. The reduced tractive stress results in the accumulation of sediment in the stream channel.

The Impacts of Sediment

Sediment can cause a wide array of damages from the time it erodes from the land to when it comes to rest in a lake, reservoir or other location. These impacts are diverse and are influenced by complex hydrological, physical, chemical and biological factors.

There have been very few comprehensive studies that have examined the impacts of erosion and sedimentation in the Great Lakes. Arguably, the most comprehensive study to examine this issue in Great Lakes basin is the 1970s Pollution from Land Use Activities Reference Group (PLUARG) report by the IJC. PLUARG was the first study to document in detail the water quality impacts associated with land use, including impacts from sediment. This was one of the first significant acknowledgements of the need to move beyond point sources of pollution to consider nonpoint sources, with sediment as the leading nonpoint source pollutant in the basin. Before this, few studies had addressed pollution in coastal areas from land-use activities, and even fewer had taken a holistic approach to examining water quality. The PLUARG study and associated reports remain the standard on nonpoint source pollution issues in the Great Lakes basin.

Even though this study is now more than 25 years old, it is still said to represent "a state-of-knowledge that has remained unchallenged in the intervening 20 years" (IJC, 2000). In 1998, the IJC coordinated a workshop as a follow-up to the PLUARG reports to assess the status of nonpoint source pollution control in the Great Lakes basin and review progress toward addressing nonpoint source pollution. The workshop participants concluded that the original recommendations were still valid and appropriate, but should be reevaluated and adapted, where necessary, to address emerging issues and changing land-use patterns.

The 1998 IJC workshop participants also concluded that progress in the control of nonpoint source pollution (including sediment) was significant through the 1980s but had flagged over the previous decade**.** Soil erosion, leading to high sediment loadings to watercourses, remained a significant problem in some areas. And with the exception of conservation planning and conservation tillage adoption, there had been little significant implementation of PLUARG recommendations. Findings also showed that while conservation tillage implementation has had a significant impact on sediment and total phosphorus loads, adoption of this practice may be reaching saturation. Practitioners may be approaching the limits of acceptance and/or effectiveness of available soil conservation technology in some regions where nonpoint source pollution is still not adequately controlled.

Types of Impacts

Environmental Impacts

- Rivers and Streams
- Lakes and Reservoirs
- Coastal Wetlands
- Fish and other Aquatic Species

Beneficial Use and Other Market Impacts

- Recreation
- Drinking Water
- Reservoirs and Water Storage
- Navigation and Dredging
- Flood Control
- Drainage and Irrigation
- Aesthetics and Property Values

In addition, the 1998 IJC participants found that the paucity of good data on nonpoint source loads (including sediment) and their impacts on environmental decisions has contributed to confusion about appropriate actions and endpoints, and is a major obstacle to further progress meeting water quality goals. Although there is much better general information about the nature and importance of sources, most of this information is derived from inference and not from direct measurement. In fact, there are few direct measurements of loads that may be relevant in assessing the effectiveness of proposed controls. As governments scale down their monitoring and surveillance efforts, these data are becoming scarcer and older. Without strong data there is a lack of proof of cause-and-effect relationships, which therefore limits our ability to make sound management decisions with confidence. Computer models of agricultural systems, for instance, too often rely on inadequate data to make predictions that are influential in guiding management decisions.

Many problems identified by PLUARG remain, including excess nutrient loads and contaminants. Over the last decade, renewed emphasis has been placed on issues that PLUARG considered to be of only minor importance, such as microorganisms and sedimentation (IJC, 2000). It is now known that sediment is the largest contaminant of surface water in the nation (Koltum, et al., 1997), and is the leading pollution problem in rivers and streams (U.S. EPA, 1998). In 2003, the Science Advisory Board of the IJC called for a major binational investigation and research effort to update and expand the PLUARG reports. Efforts are currently underway by the IJC to address key issues related to urbanization, though this will not be on the scale of a reference study such as PLUARG due to insufficient funds. While erosion is related to urbanization issues, it is not the key focus of this initiative.

Another seminal study on the impacts of erosion and sedimentation was conducted by the Conservation Foundation in 1985. This national study, entitled *Eroding Soils: The Off-farm Impacts*, looked at the diverse impacts that sediment has from the time it erodes from the land to when it accumulates in a lake, reservoir or other location. These impacts are diverse and are influenced by many complex factors. Researchers found that many types of damages are weakly documented, and even if they are well-documented, the linkage between these damages and sediment is not.

Environmental Impacts

This section describes the impacts of sediment on the aquatic environment and associated species. Specifically, this section discusses sediments impacts to:

1) Rivers and streams;
2) Lakes and reservoirs;
3) Estuaries and marshes; and
4) Fish and other aquatic species.

While there are many problems associated with sediment in the aquatic environment, it should be noted that it is very difficult to study the impacts of sediment on aquatic systems. Because these systems are so complex and integrated, the isolation of the effects of sedimentation on an aquatic system has not yet been effectively accomplished and is likely not a reasonable expectation for a natural interactive and responsive system (Castro and Reckendorf, 1995). The following section describes what is known about the types of impacts sediment has on these systems.

Rivers and Streams

Suspended sediments (or sediments suspended within the water column) impact rivers and streams in diverse ways, including the physical aspects of the stream channel and flow and the aquatic habitat. An excellent summary of these impacts and the current state of research in this area was conducted in 1995 by Janine Castro and Frank Reckendorf for the Natural Resources Conservation Service in their paper, entitled *Effects of Sediment on the Aquatic Environment*. The following section provides a brief summary of their findings.

Physical Impacts

Maintaining the health and function of stream channels is an important concern. Changes in the balance between flow and sediment load can alter channel size and configuration. To understand the impacts of sediment on streams, several issues must be considered: 1) natural watershed sediment yields; 2) temporary versus chronic sediment problems; 3) localized alterations such as construction sites; 4) type of sediment; and 5) cumulative effects of sedimentation. In addition, it is necessary to know how fast the sediment is moving and its effects. It is useful to analyze individual streams to determine if high sediment yields are a natural phenomenon or if the sediment yield is higher than the natural or “background” rate for that stream. Another factor of importance in determining sediment impacts is the temporal variations of sediment yield.

Sediment can be divided into three categories that are helpful in the evaluation of aquatic systems: framework bedload, matrix bedload and suspended load. Framework bedload refers to the larger particles that are moved only during large-flow events. They create the structure of the river bed. The matrix bedload refers to that part of the bed material that is small enough to be pulled by low to moderate flows but is large enough to settle out of the water column in lower velocities. The matrix bedload is often referred to as “sediment” by fisheries biologists and poses the greatest interest and concern in fisheries studies. The suspended load is the smallest size class of the total sediment load of a stream system. It is held in the water column as suspended material for extended periods of time. When this material is finally deposited, conditions are usually slow-moving water resulting in deposition in higher parts of the stream bed or deposition in bars and on floodplains.

To understand the impacts that sediment has on a river system, it is necessary to understand why and how sediment moves through the system. The particle size and weight of sediment is important but does not entirely control its movement. Forces that drag and pull on a sediment particle, surrounding particles and even the shape of the particle can all affect its transportability. Sediment supply, along with transport capacity and capability, controls the character of the bed. Transport capacity refers to the amount of material that a stream can transport, and capability refers to the largest particle size class that a stream can transport.

Currently, there is no precise method for measuring bedload transport. Several methods are in use but results of sampling vary widely. Furthermore, it is difficult to quantitatively describe the fluvial geomorphology and sediment transport of all streams because of the lack of information to fully describe stream behavior. However, there are hydraulic functional relationships between some stream variables that can be used to describe what occurs within rivers in general terms. For example, if sediment transport capacity exceeds the sediment supply, streambed erosion becomes the negative feedback mechanism that can work to restore stream channel stability by lowering channel gradient and increasing bed material size. Conversely, if the sediment load is suddenly increased (e.g., through forest clear-cutting and/or new road construction), the slope of the channel tends to increase to accommodate the additional sediment load. This usually results in the stream channel more vigorously attacking the stream banks (which can result in channel migration), as the stream cannot transport the entire sediment load entering the stream channel. The additional sediment load from the stream banks worsens the transport problem and causes the stream to widen further. Obviously, changes in both discharge and sediment load may lead to conflicting responses, so it is not easy to precisely predict channel changes and the associated effects on habitat. (Castro and Reckendorf, 1995)

Aquatic Habitat Impacts

Erosion and sedimentation can adversely impact aquatic habitat and the species that depend on it in three key ways. These are increased turbidity, increased sedimentation and degradation of water quality through conveyance of adsorbed pesticides and nutrients. All of these impacts lead to degradation of aquatic habitat for aquatic species.

Stream turbidity refers to the transparency of the water or the amount of light that can penetrate the water. Increased sediment generally increases turbidity and reduces the amount of light that penetrates to the deeper layers of the stream. This can also increase the temperature stratification and interfere with the normal mixing between the more oxygen-rich layers at the surface of the stream and the deeper layers of the stream. This depletes the amount of dissolved oxygen in the stream, which fish and other oxygen-dependent organisms depend upon. High fish populations are generally associated with low turbidity streams.

Increased turbidity also decreases the productivity of aquatic plants by limiting their ability to photosynthesize. This leads to a reduction in the quantity of phytoplankton (microscopic plants such as algae) and benthic macrophyites (rooted aquatic plants). This reduction of aquatic plants impacts the entire aquatic system, as many organisms depend on these plants for their food.

There are many other ways that turbid waters can directly impact the viability of aquatic communities. Reduced visibility can make it difficult for fish to find prey. Turbidity can affect reproduction by impacting fish courtship and spawning behavior. It can also affect the timing of reproduction by delaying spawning. Certain organisms, such as some snail species, simply will not lay eggs in turbid water. Turbid water may also interfere with egg hatching, due to decreased dissolved oxygen levels and decreased light penetration. It can also make it difficult for newly hatched fish larvae to find food. Suspended sediment can also directly harm aquatic species, through gill damage and abrasion on fish, reduced growth rates and decreased resistance to diseases.

Increased sedimentation may be even more devastating to aquatic communities than increased turbidity. Large deposits of sediments can completely wipe out rooted aquatic plants. Many plants require firm soil in which to root, not the soft, unstable sediment from erosion that can cover the bottom of a stream. Sediment can also settle on the leaves of plants and reduce their capacity to photosynthesize. As discussed above, this reduction in plant production has negative impacts on the entire system.

Sedimentation destroys habitat by filling the spaces between rocks where organisms live and spawn. Some organisms, such as caddis flies or mayflies, can easily move to another area. But benthic – or bottom-dwelling – organisms cannot relocate as easily. Once their habitat is degraded, they often die off. Some organisms, such as clams, attach themselves to the bottoms of streams that are firm and free of mud. Increased sedimentation muddies the bottom of streams, thereby destroying this important habitat. Sediment can also kill submerged vegetation and fill in pools and deep channels that fish use for protective cover, both for themselves and for their eggs, which can also be damaged through abrasion and damage to the outer cover.

Sediment also transports chemicals through aquatic systems. Nutrients and pesticides are the primary contaminants of concern associated with sediment transport. The fate and transport of these contaminants is inherently difficult to measure, and their impacts can be difficult to assess.

The cumulative effects of sedimentation are well-documented. Many species of Great Lakes fish have experienced significant declines in their population due in part to increased sediment (Muncy, 1979). Evaluating the health of a stream system is difficult, and it is not possible to do an in-depth and thorough investigation each time an evaluation is necessary. This requires other, less intensive techniques for monitoring. For example, fish have been used as indicator species to assess the health of a stream. As the number of fish declines, a system is thought to be degrading; however, it takes at least a season to monitor and compare differences in populations of fish. Because of the number of factors that influence fish (e.g., dams, fishing, and pollution), it is difficult to evaluate the effects of a single component on the system.

Separating the effects of sediment from other environmental factors can be impossible in a natural system. Sometimes the effects are obvious when there are excessive amounts of fine sediment, but often they are not apparent and unfortunately, fish are not great indicators of excess sedimentation. A slight decline in the fish population may be attributed to sediment but may actually be the result of dams in the stream system. To eliminate this problem, other indicator species should be found. For example, species that are more sensitive to very small changes in sediment quality and quantity, less mobile, and have shorter life cycles are preferred. This would allow more frequent monitoring, which would produce information about sediment in a limited geographic area.

Lakes and Reservoirs

The focus of research on sediment impacts to lakes is different from that of studies of stream environments. Because lakes are essentially closed systems in many respects, they often act as sediment sinks. As such, toxins pose a great concern; once a lake has been polluted, it is difficult to clean. As with streams and rivers, sediment can impact lakes and reservoirs in a variety of ways. However, a great percentage of lake sediment literature is aimed towards sediment toxicity. Two excellent papers describe the impacts of sediment on lakes and reservoirs: *Effects of Sediment on the Aquatic Environment* (Castro and Reckendorf, 1995), and *Planning and Management of Lakes and Reservoirs: An Integrated Approach to Eutrophication* (United Nations Environment Program, 1999). The following section provides a brief summary of their findings.

Physical Impacts

The introduction of excess sediment can be addressed in lake tributaries or in the watershed, and sediment traps such as filter dams and desilting basins can be used in the tributaries above a lake to reduce the amount of sediment that is delivered to the lake (Muncy, 1979). However, once sediment is in the lake, it is hard to remove. Therefore, research focusing on the physical effects of sediment in lakes and reservoirs is somewhat limited.

Dredging of lake bottoms is often considered as a remedial technique to remove excess sediment, increase lake depth, or remove toxic or nutrient-rich sediment from the lake environment. Yet, there are many problems associated with dredging lake bottoms. Dredging temporarily increases turbidity in the lake and can cause environmental degradation because of the decrease in primary productivity. The sediment may be a nutrient sink and dredging may reintroduce the nutrients back into the lake. The interstitial (pore) water associated with dredged materials may also be high in nutrients or toxins, and removing this water is very difficult and expensive. The loss of shallow zones may result in the loss of large macrophyte beds, resulting in an increase in the algal population. Lakes and other bodies of water are also often used for the disposal of sludge, which can contain high levels of toxins.

Sediments play a significant role in the process of the eutrophication of lakes and reservoirs through the accumulation and regeneration of nutrients and contaminants. Eutrophication is the process by which lakes gradually age and become more biologically productive. The evolution of natural lakes is normally from oligotrophic (lacking in plant nutrients and having a large amount of dissolved oxygen) to eutrophic (rich in mineral and organic nutrients that promote plant life, which in turn reduces the dissolved oxygen content and often causes the eradication of other organisms). Lakes in transition between oligotrophic and eutrophic states are mesotrophic. Normally, this process takes hundreds or thousands of years to occur; however, humans have greatly accelerated this process through the addition of phosphorus, nitrogen and carbon to streams and lakes in various ways. Consequently, much of the research on lakes and sediment has been on quantifying the eutrophication process (Leach and Herron, 1992).

The delivery of sediment can also cause the lake to slowly fill in and become shallower, which can lead to an increase in temperature and biologic productivity. This process accelerates the eutrophication process because of nutrients that bind to fine sediments. Organic matter produced by algae in the lake settles to the sediment and decomposes, leading to the production of different carbon, nitrogen and phosphorus compounds. Decomposing organic matter also affects changes in oxygen concentrations and can generate anoxic (no oxygen) conditions. This, in turn, affects nitrogen and phosphorus release from the sediments to the water. Under these conditions, iron and manganese coatings can become soluble, ultimately leading to a significant release of accumulated elements and compounds, particularly phosphorus. Contaminants are elements and compounds which are toxic to aquatic plants and animals. Most persistent contaminants have low solubility in water, and can bio-accumulate easily in animals. This characteristic is further enhanced by biomagnification as contaminants become more concentrated up the food chain.

There are limitations to the current feasibility of lake sediment studies. One limitation is freezing. Constant monitoring is impeded in lakes that freeze over during the winter. This applies to a significant portion of the lakes in North America and is a particular problem for the Great Lakes region, where most lake studies are conducted in this country. Another limitation is water depth. Spawning grounds in the Great Lakes are often 10 to 15 meters below the surface of the lake, which requires special equipment for sampling and monitoring (Manny, Jude and Eshenroder, 1989).

Methods for monitoring sediment have become more sophisticated with the technological advances of the past 20 years. Remote sensing (satellite imagery) can be used to monitor surface water color. This provides data about the amount and distribution of fine sediments in larger lakes. However, more basic data on lake sedimentation are needed (Castro and Reckendorf, 1995), as well as long-term, well-monitored projects. There has been a strong emphasis on sediment/toxin relationships and the effect of sediment toxicity on lake habitats, but the actual effects of the sediment, alone, have been neglected (Castro and Reckendorf, 1995). A significant amount of work has focused on aquatic insects and sediment (Resh and Rosenberg, 1984) and their interaction, but this work does not address the effects of excess fine sediment. A review by Minshall (1984) strongly supports the need for more research in lake environments and the identification of indicator species. In the field of freshwater benthic invertebrate ecology, the insect/sediment relationship has been intensively studied (Minshall, 1984). This knowledge base should be utilized for future studies in aquatic ecosystem dynamics.

Aquatic Habitat Impacts

Aquatic habitats within lakes can be very diverse and complex and may require detailed analysis to describe the lake characteristics accurately. To a large extent, the history of the lake formation, combined with its hydrology, controls biologic suitability.

Under normal environmental conditions, benthic invertebrates can move quickly enough to keep ahead of fluctuations in natural sedimentation. Artificial dumping and/or accelerated sedimentation introduce sediment too quickly for benthic invertebrate organisms to avoid it (Herdendorf, et al., 1992). Loss of benthic communities may also occur if an increase in wave action erodes the substrate (Herdendorf, et al., 1992). Macroinvertebrate species generally survive well in areas of rapid sedimentation because of the decrease in competition and their ability to escape the sediment (Wiederholm, 1984).

Preferred spawning habitat in lakes can be similar to that in streams, but because of the diverse and relatively more stable environment in lakes, spawning occurs in a large variety of substrates. However, areas that meet the size criteria for spawning grounds may not have the appropriate stability. Consequently, lag cobbles or gravels are often used for spawning while modern deposits may be avoided. This is because lag deposits are usually stable, while modern deposits may still be actively transported (Herdendorf, et al., 1992). The relative location of spawning grounds is also important in large lakes. Large substrate material combined with strong wave action is preferable. Spawning grounds are generally located near deeper water (more than 15 meters) (Nester and Poe, 1987) where wave action is the strongest. This provides an environment where the spawning grounds are flushed with water and are supplied with oxygen and nutrients. For example, lake trout in Lake Huron prefer cobble and rubble and generally do not spawn in coarse sands or gravels. Lake trout, like stream trout, cannot successfully spawn in areas that are blanketed with fine sediments (Nester and Poe, 1987). Other lake species prefer sand, rocks, inshore environments, logs, sticks, plants or vegetative nests (Herdendorf, et al., 1992).

The determination of important feeding and spawning grounds in lakes should be made consistent through sound sampling and monitoring methods. The identification of suitable habitat for feeding and/or spawning based on substrate characteristics is probably insufficient because of seasonal variability and the complex interactions between the physical and biologic environments.

Coastal Wetlands

Numerous coastal wetlands, which support a great diversity of plant and animal life, are located along the shores of the Great Lakes. Abundant aquatic and terrestrial organisms use these areas, either on a temporary or permanent basis, and wetlands are critical for anadromous fish that migrate from streams to the Great Lakes or oceans on their return to spawn. They also serve as a feeding ground and nursery for many aquatic species. Coastal wetlands have also been recognized for their large biomass production and pollution-filtering systems. Because of the physical, chemical and biotic diversity of wetland systems, they are among the most biologically diverse and richest systems found on earth. Thus, the concern for the health and survival of wetlands is growing, as is the urgent need for practical, useful data and management practices.

Because wetlands’ unique hydrology is affected by both river flow and lake fluctuations, the impacts of sediment transport and deposition on these systems are very different when compared with lakes and rivers. A summary of these impacts and the current state of research in this area was presented in a Natural Resources Conservation Service paper entitled *Effects of Sediment on the Aquatic Environment* (Castro and Reckendorf, 1995). The following section provides a brief summary of their findings.

Physical Impacts

Coastal wetlands and estuaries (in the Great Lakes, semi-enclosed areas in which lake waters become mixed with waters from rivers or streams) are extremely sensitive to human activity, including the dredging of wetland channels to keep shipping corridors open, dredging for sand and gravel for industrial and commercial use, and filling in coastal wetlands for development purposes. Now that the ecologic importance of marshes, wetlands and estuaries has been acknowledged, the preservation and restoration of these environments has begun.

A characteristic of estuaries is that their beds are constantly moving because of river inflow and lake fluctuations. The bedload is composed mainly of sand-sized particles, which are easily moved over long distances. However, the bed material is not always transported in a downstream direction. Depending on tidal influences, material may be moved up and down the channel.

The dynamics of sediment transport in and through coastal wetlands is extremely complex. Many studies have been done in the field of geophysics to gain an understanding of the transport processes; however, the equations and theories derived from stream studies are not directly applicable (if at all) to the estuarine environment.

Phillips (1991, as cited in Castro and Reckendorf, 1995) found that estuarine sediment is derived from fluvial (or river) sediment input, shoreline erosion and migration of sediments inland. Fluvial sediment inputs were the dominant process affecting these estuaries. Of the estuaries studied, a fluvial sediment delivery ratio of 4 percent was derived; that is, only 4 percent of the sediment eroded from the uplands and delivered to the stream ever makes it to the estuary. This implies that a large amount of sediment is being stored in and along these stream channels. Phillips also indicates that sediment storage is much more environmentally sensitive than basin sediment yield, and concludes that dramatic changes in the watershed would be required to alter the sediment budget in the estuary. However, processes that mobilize stored sediment would have a large effect on the sediment budget. Another important statistic discussed by Phillips is the storage capacity of the estuaries. He believes that 90 to 95 percent of all coastal sediment storage occurs in estuaries and coastal wetlands and that up to 95 percent of watershed-derived sediment is stored in the basin.

This has interesting implications for sediment management. Even though sediment delivery may be low, total sediment input can be high. Stopping sediment before it reaches the stream channel is important because once it becomes stored in the channel, it can be easily remobilized. Efforts to reduce sedimentation rates will be long-term because large quantities of sediment are already in stream channels due to agricultural and land-use practices of the early twentieth century. If sediment is in long-term storage in coastal wetlands, then sedimentation rates should be of great importance.

Aquatic Habitat Impacts

Coastal wetlands are utilized by specialized organisms that have adapted to fine sediments, high sedimentation rates and mobile substrate. However, basic research and baseline data are needed for coastal wetlands, including long-term monitoring and evaluation, to provide as much base information as possible and to study the effects of sedimentation. The lack of data about sediment transport into coastal wetlands from rivers makes it extremely difficult to develop an accurate sediment budget for coastal wetlands (Horne and Patton, 1989), and sediment budgets are necessary for long-term planning in coastal areas. Since coastal wetlands are one of the richest and most sensitive aquatic environments, restoration efforts will require more information and data about these environments and their dynamics.

Fisheries

Suspended sediments can impact fisheries in a variety of ways because so many aspects of the physical environment are affected. As discussed briefly above, the effects of sediment on aquatic environments ultimately impact aquatic species, including fish. These impacts are both indirect (increased turbidity, increased temperature, reduced productivity) and direct (gill abrasion, egg abrasion, reduced bivalve pumping rates, and direct mortality.) There has been extensive research on the impacts of sediment on fish and other aquatic species. The report entitled *Biological Effects of Suspended Sediments* (Wilber and Clark, 2001) provides a detailed discussion of these impacts.

Beneficial Use and Other Market Impacts

This section describes the impacts of sediment on various beneficial uses and other market impacts in the basin. These impacts are diverse and this list is not intended to be exhaustive. These impacts include:

- Recreation
- Drinking Water
- Reservoirs and Water Storage
- Navigation and Dredging
- Flood Control
- Drainage and Irrigation
- Aesthetics and Property Values

Most of the impacts described in this section are market resources, or commercially traded goods with clear monetary value. Nonmarket resources are goods and services that are not traded in markets and have no clear monetary value, such as clear streams or healthy fish habitat. The impact that sediment has on market resources is primarily monetary in nature. For this reason, the bulk of the discussion describing the impacts on these beneficial uses will be provided in a subsequent section, Monetary Impacts of Sediment. This section provides a very brief overview of the ways in which sediment can impact these use types.

Recreation

Sediment has both direct and indirect impacts on the suitability of water for recreational use. For example, boating and fishing are affected by increased water turbidity and subsequent increased weed growth. Turbidity can reduce the pleasure of swimming and boating activities, and may lead to dangerous conditions by obscuring submerged hazards such as rock outcrops. Turbidity and sedimentation can also diminish the quality of recreational fishing activities by reducing the populations of desirable fish species and creating conditions more favorable for low-value species such as carp. It is also harder to catch fish in turbid waters because the fish have a harder time seeing the lures.

Increased sedimentation can affect hunting because many waterfowl depend on aquatic plants and animals for food; if aquatic plants and animals are impacted by increased sediment, it can lead to negative impacts on wildlife populations. Sediment can also impact other water-related recreational activities, such as canoeing and picnicking, by reducing the aesthetic appeal and attractiveness of the resource.

Navigation and Dredging

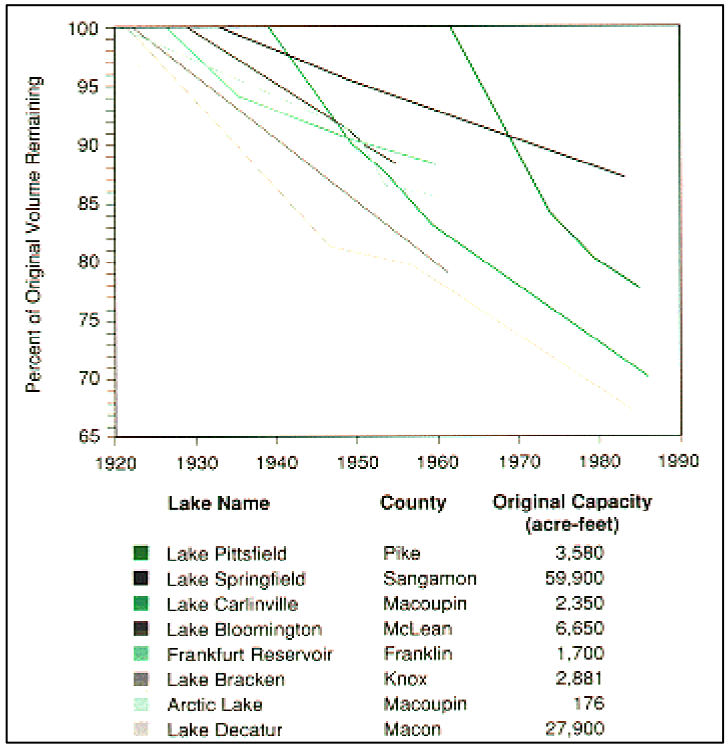
Sedimentation fills harbors, bays and navigation channels. This can impact navigation in many ways. First, it reduces the capacity of waterways to accommodate commercial and recreational watercraft, which may lead to accidents and shipping delays. Sediment also adds costs to the maintenance dredging that is required to keep these waterways open. Furthermore, dredged sediment must be stored or disposed of once it is removed. Finding appropriate ways to dispose of sediment can sometimes be as costly as dredging itself. If the sediments are contaminated with toxic substances, the cost of storage can become extremely costly.

Dredging costs have three components: 1) the cost of dredging material from the lake bottom, 2) the cost of transporting the material to a confined disposal facility, and 3) the cost of confining the material. The first two, dredging and transportation, are annual costs related directly to the total quantity of sediments dredged. Confining costs, however, are capital costs. As capital costs, they depend on additional variables, such as interest rates, and they must be treated differently. According to the U.S. Army Corps of Engineers, there are approximately 35 projects dredged in the Great Lakes each year. Combined, these projects remove approximately 3.8 million cubic yards of sediment, which the Corps estimates to cost around 20.6 million (Ouyang, et al, 2003).

Reservoirs

Reservoir sedimentation is one of the consequences of soil erosion. Survey data collected by U.S. Department of Agriculture (USDA) and U.S. Department of the Interior (USDI) indicated that in the 1970s and early 1980s sedimentation eliminated slightly more than 0.2 percent of the nation's reservoir capacity each year (Crowder, 1987). Lake Pittsfield in Illinois, for example, lost nearly a quarter of its volume to sedimentation in only 24 years (Illinois Natural History Survey, 1994*).* And as a result of lost capacity since the mid-1930s, the City of Springfield removed sediments from a small arm of Lake Springfield in 1988 at a cost of $10 million.

Figure 4. Storage Capacity Loss for Eight Illinois Reservoir Lakes. Source: Illinois Natural History Survey, 1994



Sediment and nutrients can also affect the rate of evaporation and transpiration from reservoirs. Evaporation is a particularly serious problem in arid regions because more than an acre-foot of capacity has to be constructed to provide an acre-foot of yield. Here, suspended sediment and algae may provide a benefit since they can reduce evaporation by reflecting the much of the solar energy that would otherwise warm the water in lakes and reservoirs. However, sediment and nutrients can increase the rate of evapotranspiration by stimulating the growth of water consuming vegetation on lake borders.

Flood control

Sedimentation can increase the risk of flooding through aggradation, a process by which sediment deposition fills and raises the level of a streambed. This reduces the capacity of a stream to carry water, which can lead to an increase in the frequency and depth of flooding. Sediment also increases the volume of the water in a stream, which leads to an increase in the volume of the floodwater. Furthermore, when flooding does occur, sediment can exacerbate the damages by settling out of the water onto the floodplain. In agricultural areas, this sediment can smother crops or grassland for cattle. In urban areas, it can settle in streets and between houses where it can be costly to remove. Table 1, below, provides the flooding costs for the eight Great Lakes states combined, averaging $1,576,330,000 per year.

Table 1. Average Costs of Flooding Per Year for the Eight Great Lakes States.

State	National Rank	Av/Yr (millions 1999 US$)
Illinois	8	$218.7
Indiana	18	$113.4
Michigan	37	$35.56
Minnesota	15	$144.9
New York	9	$218.2
Ohio	22	$102.4
Pennsylvania	1	$682.3
Wisconsin	30	$60.87
Total		$1576.33

Source: Extreme Weather Sourcebook (National Center for Atmospheric Research et al., 1999);
Information based on flood damage data from 1955-1999, and has been adjusted for inflation and wealth.

Drainage and Irrigation

Sediment can impair the capacity of irrigation channels and other canals to carry water to its destined point of use, resulting in increased flooding along ditches and maintenance costs for the removal of sediment. Sediment may also increase the cost of pumping water from these channels as well as increase the wear on pumps.

Drinking Water

Sediment must be removed from water before it can be used as drinking water or for industrial use. Sediment is also a source of chemical contamination as it often carries with it fertilizers, pesticides and other chemicals. Sediment ponds are constructed to let the coarse sediment settle to the bottom. The water is then passed through a filter to remove any remaining sediment and chemicals can be added to treat or remove other dissolved contaminants that may have desorbed from sediment. Operation and maintenance costs of water treatment facilities increase as the amount of sediment increases.

Aesthetics and Property Values

Property values can be lowered by polluted waters and sediment deposits. Preservation values represent the value that people place on clean water, even though they may never make direct use of the water body. Studies have shown preservation values to be higher than recreational and other user values.

Contaminants

Even if land has not been impacted by human development, it naturally contains a variety of chemical particles that, once eroded, can impact water quality. These particles, once deposited in streams, can result in excessive concentrations of nutrients and reduced levels of dissolved oxygen, both of which impact the stream's aquatic habitat. Human land disturbances exacerbate this problem by increasing the levels of chemicals and nutrients in the sediment. The same processes that transport sediment apply to these particles, and many of them are carried off the land along with sediment – either as distinct particles, chemically bound to sediment, or dissolved in water. However, the fate and transport of these contaminants is inherently difficult to measure, and their impacts can be difficult to assess. The primary contaminants of concern associated with sediment include nutrients and pesticides.

Nutrients

Nutrients – primarily nitrogen and phosphorus – are the most significant contaminants in eroded soil and runoff (Clark, Haverkamp and Chapman, 1985). Each year, approximately 11 million tons of nitrogen and 4 million tons of phosphate are applied to agricultural cropland in the United States (USDA ERS, 1997 and Ribaudo, 1999). Excess nutrients, and especially phosphorus, can result in eutrophication – or over-enrichment – of streams. Eutrophication can result in algal blooms, which can sometimes lead to fish kills due to the excess algae using up the available dissolved oxygen. Nutrients and algae in the water also can cause stream electric power plants to operate less efficiently.

In addition, chemicals that do not dissolve in the waters may be consumed by organisms. These chemicals then bioaccumulate through the food chain, potentially endangering the health of animals and humans. The Environmental Protection Agency (EPA) reports that nutrient pollution is the leading water quality impairment in lakes and estuaries, and the second leading impairment in rivers (EPA, 1998 as cited in Ribaudo, 1999). Nitrates are also a concern for drinking water, especially for those areas where source water is groundwater (Ribaudo, 1999). The EPA has established a maximum contaminant level (MCL) for nitrate levels in drinking water (10 mg/liter). High levels of nitrates are a concern and can lead to "blue baby syndrome," which impedes the transport of oxygen in the bloodstream.

The cost of nutrients to the environment and water resource use has not been fully estimated (Ribaudo, 1999). However, the EPA has estimated costs of $200 million to upgrade water treatment plants to meet federal nitrate standards (Ribaudo, 1999). Crutchfield, Feather and Hellerstein (1995) estimated that consumers would be willing to pay about $350 million for reduced nitrate in drinking water in four areas of the United States (Ribaudo, 1999).

Pesticides

Pesticides can harm freshwater organisms and cause damage to recreational and commercial fisheries. They may also pose human health risks, as some commonly used pesticides have been identified as potential or probable carcinogens. Federal regulations are in place for pesticide levels in drinking water, and public water systems are required to provide additional treatment to ensure that these levels not exceeded. Reservoirs are particularly susceptible to pesticides and may serve as a form of sink for these contaminants (Ribaudo, 1999).

In their 1995 paper, *Environmental and Economic Costs of Soil Erosion and Conservation Benefits*, Pimentel *et al.* provided a conservative estimate that pesticides cause nearly $1 million in direct annual losses from fish kills. In 1997, the EPA estimated that it would cost about $400 million for additional water treatment plants to meet current pesticide regulations, with an additional $100 million required over the next 20 years.

Monetary Impacts of Sediment

Determining the monetary costs associated with erosion and sedimentation – or the benefits from reduced sediment load – is difficult for three key reasons. First, an estimation of impacts requires an understanding of ecosystem health and the status of environmental resources, which often are not very well documented or monitored. Second, even if environmental impacts are identified, the linkage between soil erosion and these impacts is not always clear. Third, if the impacts are identified and the linkages between sediment and the impacts are determined, it still requires assigning to the impacts an economic value, which can be difficult to assess.

No comprehensive studies have documented the monetary costs due to erosion and sedimentation in the basin. In short, the total monetary costs of damages from erosion and sedimentation in the basin are largely unknown. The Northeast-Midwest Institute (NE-MWI) recently published a guidebook to economic analysis of environmental benefits in the Great Lakes region (Cangelosi et al., 2001). This book, however, does not focus on any particular pollutant (such as sediment), nor does it provide actual economic values of environmental resources in the basin, except for site-specific case studies. Rather, this book is intended to provide guidance on conducting environmental valuation in the region, describing where economic benefits assessment comes into play in environmental regulations and decisionmaking in the Great Lakes region and nationally; the various methods available for accounting of environmental benefits; and case studies illustrating each method.

The most comprehensive study to date that documents the impacts of soil erosion and sedimentation was conducted by Clark, Haverkamp and Chapman (1985). This study, entitled, *Eroding Soils: The Off-Farm Impacts*, was conducted by the Conservation Foundation and looked at the impact that sediment has from the time it erodes from the land to when it comes to rest in a lake, reservoir or other location. It is a comprehensive study documenting the damages caused by sediment and the monetary costs associated with those damages. This study concluded that, in 1985, the total off-site damages of erosion from all sources totaled $7.0 billion per year. Monetary damages are provided for several specific categories, such as recreation, navigation, water supply and habitat.

In 1989, Ribaudo conducted a national study of sediment damages resulting from agricultural erosion and found that damage estimates are likely to be between $2 billion and $8 billion per year (Ribaudo, 1989). These estimates include damages or costs to navigation, reservoirs, recreational fishing, water treatment, water conveyance systems, and industrial and municipal water use. A later study estimated the benefit of soil not eroded in the Great Lakes States was $4.68 per ton (Hansen and Ribaudo, 2008).

Economic Valuation Terms and Techniques

Willingness to Pay (WTP) – the maximum amount of money people are willing to pay for a good or service that increases their utility

Willingness to Accept (WTA) – the minimum amount of money people would accept as compensation for an action that reduces their utility

Defensive Expenditure – expenditures made to clean up pollution or repair or compensate for environmental damage

Contingent Valuation – an economic technique that surveys people regarding their willingness to pay for a good or service (such as the preservation of water quality)

Travel Cost Method – the use of statistical analysis to determine people's willingness to pay to visit a natural resource (such as a river or wetland area)

Hedonic Price Method – the use of statistical analysis to explain a good's price or service as a function of several components (such as explaining the price of a home as a function of the surrounding water quality or proximity to natural areas)

Use Value – the value that people place on the use of a good or service

Direct Use Value – the value one obtains by *directly using* a natural resource

Indirect Use Value – ecosystem benefits not valued in markets (such as natural water filtration that occurs as waters pass through wetland areas)

Nonuse Value – values people obtain without actually using a resource; nonuse values include existence and bequest values

Existence Value – the value people place on the continued existence of a resource (such as the benefit one obtains from knowing that a natural area is preserved even though one will never visit it)

Bequest Value – the value people place on the knowledge that a resource will be available for future generations

Option Value – the value that people place on maintaining future resource use options

Source: Environmental and Natural Resource Economics: A Contemporary Approach (Harris, 2002)

While there is an abundance of research in the area of ecosystem valuation, most of these are case studies that focus on prescribing an economic value to a particular ecosystem good or service. There are relatively few studies that document the monetary costs from damaged ecosystems due to erosion and sedimentation, and fewer yet that are specific to the Great Lakes. The purpose of the following section is to describe 1) what is known about economic valuation in the Great Lakes; 2) what is known about economic impacts of erosion and sedimentation and benefits from erosion control; and 3) what is known about the value of environmental goods and services that have the potential to be impacted by erosion and sedimentation. This section provides an overview of the current state of knowledge in these areas.

National Comprehensive Studies of Economic Costs of Sediment

Clark *et al.* (1985) examined the impact that sediment has from the time it erodes from the land to when it comes to rest in a lake, reservoir or other location, and documented the damages caused by sediment and the monetary costs associated with those damages. This study concluded that, in 1985, the total off-site damages of erosion from all sources totaled $7.0 billion per year. Monetary damages are provided for several specific categories, such as recreation, navigation, water supply and habitat. The economic estimates provided by the Conservation Foundation report are indicative, not definitive, and provide for each category of impact a range of costs and a single “best guess” estimate that falls within that range. The authors note that the estimates should be considered only as order-of-magnitude estimates and actual costs are more likely to be within the estimated range than they are to be one-tenth as much or ten times as much. Some damages do not have economic estimates because they did not have appropriate methods to assign costs.

Hansen and Ribaudo (2008) conducted a national study of the per-ton values of 14 types of soil conservation benefits. The values are derived from models that capture the cause-and-effect relationships between agricultural erosion and environmental benefits. Values and methodology are described so that analysts can apply the data to calculate regional and national benefits of specific soil conservation projects. Analysts can also use the per-ton benefit estimates to determine where a 1-ton reduction in soil erosion might be most beneficial.

Ribaudo (1986) conducted a national study of water quality benefits of reduced soil erosion from conservation practices. This study concluded that erosion reduction from practices adopted under the 1983 soil conservation programs were estimated to produce $340 million in offsite benefits over the lives of the practices.

Ribaudo (1989) conducted a national study of water quality damages from soil erosion and the benefits from the CRP. Ribaudo found that damages to all uses totaled about $5.1 billion to $17.6 billion, with a best guess of $8.8 billion. Ribaudo estimated that reducing erosion through retirement of 40 million to 45 million acres of highly erodible cropland would generate $3.5 billion to 4.5 billion in surface-water quality benefits over the life of the program.

Pimentel *et al.* (1995) examined the ways in which soil erosion reduces soil fertility and crop productivity, assessed the environmental and economic costs of soil erosion and compared techniques to reduce erosion and conserve resources. The researchers estimated that erosion causes $44 billion in damages each year in the United States and that it would take an investment of $6.4 billion per year ($40 per hectare for conservation) to reduce U.S. erosion rates to a sustainable rate (from 17 tons/hectare/year to 1 ton/hectare/year). To reduce erosion on pastureland, the United States would have to spend an additional $2.0 billion per year ($5 per hectare for conservation). For every $1 invested, $5.24 would be saved.

Table 2: Summary of Findings for National Comprehensive Studies of Economic Costs of Sediment

Reference	Location	Subject	Findings
Clark II, E.H., Haverkamp, J.A., & W. Chapman. (1985). Eroding soils: The off-farm impacts. Washington, DC: The Conservation Foundation.	United States	Economic costs associated with erosion and sedimentation	Damages to all uses totaled \$3.2 - \$13 billion, with a "best guess" estimate of \$6.1 billion (1980 dollars).
Hansen, L., & Ribaudo, M. O. (2008). Economic measures of soil conservation benefits: Regional values for policy assessment. Resource and Rural Economics Division, Economic Research Service, U.S. Department of Agriculture, Technical Bulletin TB-1922.	United States	Benefits of soil saved in \$/ton by county, by 8 Digit HUC and by region	Benefits in \$/ton of soil saved in the Great Lakes States ranged from \$2.77 to \$4.68 (not counting the benefit to marine fisheries.)
Ribaudo, M.O. (1986). Reducing soil erosion: Offsite benefits. AER-561. U.S. Department of Agriculture, Economic Research Service.	United States	Water quality benefits of reduced soil erosion from conservation practices	Erosion reduction from practices adopted under the 1983 soil conservation programs was estimated to produce \$340 million in offsite benefits over the lives of the practices.
Ribaudo, M.O. (1989). Water quality benefits from the Conservation Reserve Program. AER-606. U.S. Department of Agriculture, Economic Research Service.	United States	Water quality damages from soil erosion	Damages to all uses: \$5.1-\$17.6 billion, "best guess" of \$8.8 billion. Agriculture's share of damages: \$2-\$8 billion. Reducing erosion via retirement of 40-45 million acres of highly erodible cropland would generate \$3.5-4.5 billion in surface-water quality benefits.
Pimentel, D., Harvey, C., Resosudarmo, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., & Blair, R. (1995). Environmental and economic costs of soil erosion and conservation benefits. *Science*, 267, 1117-1123.	United States	Damages from wind and water erosion	Damages to all uses causes \$44 billion in damages each year in the United States. It would take an investment of \$6.4 billion per year to reduce U.S. erosion rates to a sustainable rate on cropland, and an additional \$2 billion on pastureland. For every \$1 invested, \$5.24 would be saved.

Water Quality

Brox *et al.* (1996) conducted a large contingent valuation survey to estimate the social benefits of water quality improvements in the Grand River watershed, which is located in southern Ontario and drains into Lake Erie. Early results indicate a willingness to pay (WTP) for residential water quality improvements of up to \$4.50 per household per month (19 percent of the average water bill), with a somewhat lower value for preserving the environmental quality of parkland in the watershed. The narrowness of the estimated range of WTP values, and their similarity to values found in other studies, suggests that the estimates are a reliable measure of the monetary value of social benefits from water quality improvements in the region. The main socioeconomic determinants of WTP appear to be household income, number of children, perception of existing water quality, and awareness of environmental issues on the part of survey respondents.

Greenley *et al.* (1981) examined existence and bequest (nonmarket) values of water quality. Nonrecreationists in the South Platte River basin were surveyed to find the value they placed on improvements in water quality, related to salinity and suspended solids. Researchers found that each household placed a value of $95-$99 (1998 dollars) on water quality improvements.

Loomis (1987) also examined the nonmarket value of water quality improvement. He found that each household surveyed was willing to pay an increase of $131 on their water bill for improvement in lake level, visibility, and bird survival and diversity.

Magat *et al.* (2000) introduced an iterative choice procedure for valuing the quality of inland waters, which breaks valuation into a series of component tasks. Respondents in Colorado and North Carolina assessed the value of water quality rated "good" by EPA standards and it was found that the value of water increases with even a 1 percent increase in water quality. Study results noted differences in the valuation of water quality improvements specific to swimming, fishing, and a healthy aquatic environment, and for water that is cloudy, smelly, or polluted by toxins.

Table 3: Summary of Findings for Water Quality

Reference	Location	Subject	Findings
Brox, J.A., Kumar, R.C., & Stollery, K.R. (1996). Willingness to pay for water quality and supply enhancements in the Grand River watershed. *Canadian Water Resources Journal*, 21(3).	Grand River Watershed, Lake Erie basin	Willingness to pay for residential water quality improvements	Willingness to pay for residential water quality improvements of up to $4.50 per household per month (19 percent of the average water bill), with a somewhat lower value for preserving the environmental quality of parkland in the watershed.
Greenley, D.A., Walsh, R.G., & Young, R.A. (1981). Option value: Empirical evidence from case study of recreation and water quality. *The Quarterly Journal of Economics*, 96(4), 657-672.	South Platte River basin, Colorado, Wyoming and Nebraska	Existence and bequest values of water quality improvements related to salinity and suspended solids	Each household placed a value of $95-$99 (1998 dollars) on water quality improvements.
Loomis, J. (1987). Balancing public trust resources of Mono Lake and Los Angeles' water right: An economic approach. *Water Resources Research*, 23(8), 1449-1456.	Mono Lake, California	Nonmarket value of water quality improvement related to lake level, visibility, bird survival and diversity	Each household was willing to pay an increase of $131 on their water bill for improvement in lake level, visibility, and bird survival and diversity.
Magat, W.A., Huber, J., Viscusi, W. K., & Bell, J. (2000). An iterative choice approach to valuing clean lakes, rivers, and streams. *Journal of Risk and Uncertainty*, 21(1), 7-43.	Colorado and North Carolina	Valuing the quality of inland waters	Value of water increases with even a 1 percent increase in water quality.

<u>Additional References:</u>

Koteen, J., Alexander, S.J., & Loomis, J. (2002). Evaluating benefits and costs of changes in water quality. General Technical Report PNW-GTR-548. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Whitehead, J.C., & Groothuis, P.A. (1992). Economic benefits of improved water quality: A case study of North Carolina's Tar-Pamlico River. *Rivers*, 3(3), 170-178.

Rivers and Streams

Sanders *et al.* (1990) estimated total values of protecting rivers in the Rocky Mountains of Colorado. Respondents were asked to report the maximum amount they would be willing to pay annually for increases in the number of rivers protected. The per household WTP for river protection (annually) for: the three most valuable rivers totaled $39 (recreational use values = $8, preservation value = $32); seven most valuable rivers totaled $74 (recreation = $14, preservation = $60); 11 most valuable rivers totaled $95 (recreation = $18, preservation = $77); and 15 most valuable rivers totaled $101 (recreation = $82, preservation $19). Respondents were also asked to report their reasons for valuing river protection. Preservation motives appear more important than recreational use, as is reflected in the WTP values. In fact, option and bequest values rank highest, with recreational use values ranking fifth in importance for reasons to protect the river.

Clonts and Malone (1988) estimated the WTP for the protection of 15 rivers in Alabama. They found a total WTP of $57 per year (1987 dollars), including demand for recreation use value of $8, option value of $9.50, existence value of $22.50, and bequest value of $17.

Gramlich (1977) surveyed 165 families' WTP in the metropolitan area of Boston. He found that the costs and benefits of swimmable water in the Charles River are nearly equal. The range of estimates for benefits is $8.8 million to $21.9 million, with an average of $15.4 million. Total aggregate costs were estimated at $16.7 million.

Magat *et al.* (2000) introduced an iterative choice procedure for valuing the quality of inland waters, breaking valuation into a series of component tasks. Respondents in Colorado and North Carolina assessed the value of water quality rated "good" by EPA standards and it was found that the value of water increases with even a 1 percent increase in water quality. Study results noted differences in the valuation of water quality improvements specific to swimming, fishing, and a healthy aquatic environment, and for water that is cloudy, smelly, or polluted by toxins.

Whitehead and Groothuis (1992) conducted a contingent valuation survey to measure the economic benefits of reduced agricultural nonpoint source pollution in the Tar-Pamlico River in eastern North Carolina. Surveys showed respondents were willing to pay for improved water quality. Results suggested that aggregate benefits of improved water quality would be $1.62 million each year and the majority of voters would support a program that would raise up to $1.06 million annually for water quality improvements.

Gonzalez and Loomis (1997) used contingent valuation surveys of Puerto Rican households to estimate residents' WTP for preserving instream flows in the Mameyes and Fajardo Rivers. Results indicated that the annual base amount residents are willing to pay is $11.33 million for the Mameyers and $13.09 million for the Fajardo.

Lant and Roberts (1990) used contingent valuation methods to estimate recreational and intrinsic benefits of improved river-water quality in selected river basins of Iowa and Illinois. Findings indicated WTP for river-water quality was related to income and recreational participation, but not to other spatial or socioeconomic variables. Intrinsic values were found to be expressible as economic values similar to those of other public goods. In many instances, intrinsic and recreational values together were larger on a per-acre basis than the production of agricultural commodities. The authors concluded that the purpose of programs like the CRP should be enlarged from their present focus on soil conservation to include water quality, aquatic ecosystems, and intrinsic values.

The Ohio River Valley Water Sanitation Commission (1994) conducted a valuation survey of the Ohio River corridor. This report provides an overview of the role and impact of the Ohio River in its economic, cultural and environmental/natural resource dimensions. The authors estimated river-generated annual income, including the value of products shipped and income from events held along the river. Findings incorporate economic information on employment, tourism, urban benefits, recreation, and natural resources associated with the Ohio River.

Loomis (1994) detailed the economic benefits that natural stream channel restoration can provide, including flood damage reduction, cost savings and enhancement of the natural environment. Techniques for estimating flood damage reductions were identified.

Sanders, Walsh and Loomis (1990) used a statistical demand function to estimate Colorado residents' WTP for river protection in the Rocky Mountains. Results suggested that the 'total value' of a river should include direct consumption benefits such as onsite recreation, as well as offsite preservation benefits such as information consumption (interpretation and education) with regard to river activities and resources. A sample of the general population reported a WTP for (rather than forego) on or off-site uses. It is recommended that off-site values be included with the value of onsite recreation use when determining the total value of rivers to society.

Table 4: Summary of Findings for Rivers and Streams

Reference	Location	Subject	Findings
Sanders, L.D., Walsh, R.G., & Loomis, J.B. (1990). Toward empirical estimation of the total value of protecting rivers. *Water Resources Research*, 26(7), 1345-1357.	Rocky Mountains of Colorado	Willingness to pay for river protection and reasons for valuing river protection	The per household willingness to pay for river protection (annually) for: the three most valuable rivers totaled $39; seven most valuable rivers totaled $74; eleven most valuable rivers totaled $95; and fifteen most valuable rivers totaled $101.
Clonts, H.A. & Malone, J. (1988). Estimating natural resource values: The case of free-flowing rivers. Unpublished paper, Department of Agricultural Economics, Auburn University, Auburn, Alabama.	Alabama	Willingness to pay for river protection	Total willingness to pay of $57 per year (1987 dollars), including demand for recreation use value of $8, option value of $9.50, existence value of $22.50, and bequest value of $17.
Gramlich, F.W. (1977). The demand for clean water: The case of the Charles River. *National Tax Journal*, 30(2), 183-194.	Boston	Costs and benefits of swimmable water	Average estimate of benefits for swimmable water in the Charles River is $15.4 million. Total aggregate costs were estimated at $16.7 million.
Magat, W.A., Huber, J., Viscusi, W. K., Bell, J. (2000). An iterative choice approach to valuing clean lakes, rivers, and streams. *Journal of Risk and Uncertainty*, 21(1), 7-43.	Colorado and North Carolina	Iterative choice procedure for valuing the quality of inland waters	Value of water increases with even a 1 percent increase in water quality.
Whitehead, J. C., & Groothuis, P.A. (1992). Economic benefits of improved water quality: A case study of North Carolina's Tar-Pamlico River. *Rivers*, 3(3), 170-178.	Tar-Pamlico River in eastern North Carolina	Willingness to pay for improved water quality through reduced agricultural nonpoint source pollution	Study shows survey respondents are willing to pay for improved water quality. Aggregate benefits of improved water quality were $1.62 million per year, and majority of voters would support a program to pay for water quality improvements.

Gonzalez, C., & Loomis, J.B. (1997). Economic benefits of maintaining ecological integrity of Rio Mameyes, in Puerto Rico. *Ecology and Economy*, 21(1), 63-75.	Puerto Rico	Willingness to pay for preserving instream flows	Results indicate that the annual base amount residents are willing to pay is $11.33 million for the Mameyers River, and $13.09 million for the Fajardo River.
Lant, C.L., & Roberts, R.S. (1990). Greenbelts in the cornbelts: Riparian wetlands, intrinsic values, and market failure. *Environment and Planning*, 22(10), 1375-1388.	Iowa and Illinois	Willingness to pay for river-water quality	Willingness to pay for river-water quality is related to income and recreational participation. Intrinsic values are found to be expressible as economic values similar to those of other public goods.
Ohio River Valley Water Sanitation Commission, National Park Service, and The Ohio River Basin Commission. (1994). What's a river worth?	Ohio River corridor	Valuation of river corridor	Report provides estimate of river-generated annual income, including the value of products shipped and income from events held along the river.
Loomis, J. B. (1994). Determining Benefits and Costs of Urban Watershed Restoration: Concepts, techniques and literature review. Fort Collins, CO: Colorado State University, Department of Agricultural and Resource Economics.	NA	Economic benefits of natural stream channel restoration	Details the economic benefits that natural stream channel restoration can provide and provides techniques for estimating flood damage reductions.
Sanders, L.D., Walsh, R.G, & Loomis, J.B. (1990). Toward empirical estimation of the total value of protecting rivers. *Water Resources Research*, 26(7), 1345-1357.	Colorado Rocky Mountains	Willingness to pay for river protection	Results suggest that the "total value" of a river should include direct consumption benefits such as onsite recreation, as well as offsite preservation benefits.

Additional References:

Koberstein, P. (1997). What's a river worth? River values, 8-12. American Rivers.

Hitzhusen, F.J., Ayalasomayajula, R., & Lowder, S. Economic evaluation of a river corridor: Integration of natural resource and development economics. *American Journal of Agriculture Economics*, 77(4), 1999.

Wetlands

Bardecki (1998) summarized many of the values derived specifically for Great Lakes wetlands in *Wetlands and Economics: an Annotated Review of the Literature, 1988-1998*.

Amacher *et al.* (1988) established three requirements to produce accurate values for Michigan coastal wetlands: incorporation of ecology and economics, applicability to different regions and sites, and capability of addressing multiple sites simultaneously. In the article, attempts were made to apply six market and nonmarket valuation techniques for the purpose of valuing the biological and economic functions of Michigan's coastal wetlands. These methods are the environmental quality as input, implicit price hedonics, energy analysis, contingent valuation, travel cost and property hedonics.

Broower *et al.* (1999) presented a meta-analysis for the use and nonuse values generated by wetlands across Europe and North America. Results from the meta-analysis identified a number of distinct values for wetland functions. Interestingly, use values such as flood control, water generation and water quality attributes were found to exert a stronger influence over WTP than nonuse elements such as the biodiversity functions of wetlands, a result which agrees with the findings of recent mixed revealed and expressed preference studies of non-market goods.

Costanza *et al.* (1989) examined the value of wetland ecosystems in Louisiana. The researchers estimated the total value of an average acre of natural wetlands in Louisiana to be $2,429–$6,400 per acre (assuming an 8 percent discount rate) to $8,977–$17,000 per acre (assuming a 3 percent discount rate) (1989 dollars). At the lowest value, the current annual rate (1989) of loss of Louisiana wetlands (50 square miles per year) is worth about $77 million. At the largest value it is worth about $544 million. In this paper, they also explore fundamental theoretical and practical problems underlying natural resource valuation and detail some of the more difficult problems associated with applied natural resource valuation, including discounting and dealing with uncertainty and imprecision.

Mahan *et al.* (1997) estimated the value of urban wetland amenities in Portland, Ore. Results indicated that wetlands influence the value of residential property and that they do so differently than other amenities. Increasing the size of the nearest wetland to a residence by one acre increased the residence’s value by $24. Similarly, reducing the distance to the nearest wetland by 1,000 feet increased the value by $436.

Kreutzwiser (1981) used contingent valuation to measure the annual net recreational benefits received by Canadians who use the large wetlands around Long Point on Lake Erie in Ontario. The study also calculated the total expenditures made by recreational users of the wetlands and found that they spent a total of $119,000 ($215,906 in 1999 Canadian dollars) to receive wetland benefits that were estimated to have a contingent value of $213,000 ($386,000 in 1999 Canadian dollars) per year. This implies that for every dollar users spent, they received $1.79 in benefits, a return of 179 percent. Recreational use of the Long Point wetlands represents just one of the many benefits of these wetlands. Others benefits include wildlife production, nutrient retention, groundwater recharge/discharge, etc.

Table 5: Summary of Findings for Wetlands

Reference	Location	Subject	Findings
Bardecki, M.J. (1998). Wetlands and economics: An annotated review of the literature, 1988-1998. Ryerson Polytechnic University, Toronto, Ontario. Prepared for Environment Canada - Ontario Region.	Great Lakes	Summary of values derived for Great Lakes wetlands	NA
Amacher, G.S., Brazee, R.J., Bulkley, J.W., & Moll, R.A. (1988). Interdisciplinary approach to valuation of Michigan coastal wetlands. Michigan Institute of Water Research, East Lansing. Technical Report 88-G1429-02.	Michigan	Valuation of biological and economic functions of Michigan's coastal wetlands	Establishes three requirements to produce accurate values for Michigan coastal wetlands: incorporation of ecology and economics, applicability to different regions and sites, and capability of addressing multiple sites simultaneously.
Brouwer, R., Langford, I., Bateman, I., & Turner, R.K. (1999). A meta-analysis of wetland contingent valuation studies. Center for Social and Economic Research on the	Europe and North America	Meta-analysis for the use and non-use values generated by wetlands	Results from the meta-analysis identify a number of distinct values for wetland functions. Use values were found to exert a stronger influence over willingness to pay than non-use elements.

Global Environment, Working Paper.			
Costanza, R., Farber, S. C., & Maxwell, J. (1989). Valuation and management of wetland ecosystems. *Ecological Economics*, 1(4), 335-361.	Louisiana	Value of wetland ecosystems	Estimated the total value of an average acre of natural wetlands in Louisiana to be $2,429–$6,400 per acre (assuming an 8 percent discount rate) to $8,977–$17,000 per acre (assuming a 3 percent discount rate) (1989 dollars).
Mahan, B.L. (1997). Valuing urban wetlands: A property pricing approach. U.S. Army Corps of Engineers, Institute for Water Resources.	Portland, Oregon	Value of urban wetland amenities	Results indicate that wetlands influence the value of residential property. Increasing the size of the nearest wetland to a residence by one acre increased the residence's value by $24. Reducing the distance to the nearest wetland by 1,000 feet increased the value by $436.
Kreutzwiser, R.D. (1981). The economic significance of the Long Point marsh, Lake Erie, as a recreational resource. *Journal of Great Lakes Research*, 7(2), 105-110.	Long Point, Lake Erie, Ontario	Contingent valuation of annual net recreational benefits of wetlands and total expenditures made by recreational users of the wetlands.	Recreational users spent a total of $119,000 ($215,906 in 1999 Canadian dollars) to receive wetland benefits that were estimated to have a contingent value of $213,000 ($386,000 in 1999 Canadian dollars) per year. This implies that for every dollar users spent, they received $1.79 in benefits, a return of 179%.

Additional References:

Loomis, J.B., Hanemann, W.M., Kanninen, B., & Wegge, T. (1991). Willingness to pay to protect wetlands and reduce wildlife contamination from agricultural drainage. In A. Dinar & C. Zilberman (Eds.), *The Economics and Management of Water and Drainage in Agriculture.* Boston: Kluwer Academic Publishers.

Lakes and Reservoirs

Magat *et al.* (2000) introduced an iterative choice procedure for valuing the quality of inland waters, which breaks valuation into a series of component tasks. Respondents in Colorado and North Carolina assessed the value of water quality rated "good" by EPA standards, and it was found that the value of water increases with even a one-percent increase in water quality. Study results noted differences in the valuation of water quality improvements specific to swimming, fishing, and a healthy aquatic environment, and for water that is cloudy, smelly, or polluted by toxins.

Crowder (1987) estimated the annual economic costs of reservoir sedimentation, based on replacing lost capacity, at $819 million per year.

Table 6: Summary of Findings for Lakes and Reservoirs

Reference	Location	Subject	Findings
Magat, W.A., Huber, J., Viscusi, W. K., & Bell, J. (2000). An Iterative Choice Approach to	Colorado and North Carolina	Iterative choice procedure for valuing the	The value of water increases with even a 1 percent increase in water quality.

Valuing Clean Lakes, Rivers, and Streams. *Journal of Risk and Uncertainty*, 21(1), 7-43.		quality of inland waters	
Crowder, B.M. (1987). Economic costs of reservoir sedimentation: A regional approach to estimating cropland erosion damage, *Journal of Soil and Water Conservation*, 42(3), 194-197.		Annual economic costs of reservoir sedimentation	Annual economic costs, based on replacing lost capacity, were estimated to be $819 million per year.

Additional References:

Feather, T.D. 1992. Valuation of lake resources through hedonic pricing. U.S Army Corps of Engineers, Institute for Water Research, AD-A271900.

Hitzhusen, F., Macgregor, R., & Southgate, D. (1984). Private and social cost-benefit perspectives and a case application on reservoir sedimentation. *Water International*, 9(4), 181-184.

Hitzhusen, F.J. (1996). Economic analysis of reservoir sedimentation impacts. Proceedings of the International Conference on Reservoir Sedimentation, September 9-13, 1996: Ft. Collins, CO.

Habitat

Palone and Todd (1997) provided guidance for establishing and maintaining riparian forest buffers, and discussed the economic values associated with buffers. One example from Fairfax County, Va., showed a reduction of $47 million in costs related to storm water runoff by retaining riparian forest buffers and forested areas in the county.

Table 7: Summary of Findings for Habitat

Reference	Location	Subject	Findings
Palone, R.S. & Todd, A.H. (1997). Chesapeake Bay riparian handbook: A guide for establishing and maintaining riparian forest buffers. USDA Forest Service. NA-TP-02-97. Radner, PA.	NA	Guidance for riparian buffers. Discusses economic values associated with riparian forest buffers	One example from Fairfax County, Va., showed a reduction of $47 million in costs related to storm water runoff by retaining riparian forest buffers and forested areas in the county.

Additional References:

Qui, Z. & Prato, T. (2001). Physical determinants of economic value of riparian buffers in an agricultural watershed. *Journal of the American Water Resources Association*, 37(2), 295-303.

Fisheries

Connelly and Brown (1991) conducted a statewide angler survey in New York in 1988 to estimate the net economic value of the state's recreational fishery. Respondents were asked how much they would be willing to pay above current expenditures for a specific fishing trip. The net economic value estimated from the responses exceeded $284 million for the freshwater fisheries of New York in 1988. Although inland fisheries accounted for 76 percent of the statewide net economic value, $69 million was associated with the portion of the Great Lakes assigned to New York.

Dutta (1984) looked at the value of recreational boating and fishing in the Central Basin of Ohio's portion of Lake Erie using the individual travel cost model. The data for this study was provided by a sample of 443 recreational boaters and anglers who visited the Central Basin during 1982. Several different estimates were derived, using alternative models and inputs. Dutta approximated a "best estimate" for the economic value of recreational boating and fishing in the Central Basin of Lake Erie at $18.84 million (1984 dollars).

Gunderson and Kreag (1991) estimated the economic impact of recreational fishing on Minnesota waters of Lake Superior. The recreational fishing industry (including charter fishing) on the Minnesota waters of Lake Superior contributed approximately $9.74 million dollars in direct expenditures to the state in 1990, with the total state economic impact estimated at $12.67 million to $17.54 million. Estimates of the state economic impact can go as high as $34.43 million to $49.06 million, depending on the source of the information. Lake Superior's charter fishing businesses contributed $6.47 million and noncharter recreational fishing contributed $3.27 million of the total direct 1990 state expenditures of $9.74 million. Charter fishing businesses generated $8.41 million to $11.65 million in state economic impacts while noncharter recreational fishing generated $4.25 million to $5.89 million.

Hoen *et al.* (1996) investigated the economic value of recreational angling in Michigan. The overall goal of their research was to build an economic model which could be used to: 1) value recreational angling experiences in Michigan, and 2) determine how the values for recreational angling are affected by changes in water quality and other measures of fishing quality. No actual values were provided.

Lupi and Hoen (1997) presented a travel-cost model developed for recreational angling in Michigan. The paper focused on how Great Lakes trout and salmon catch rates were related to angler behavior. Fish population levels can be linked to a host of Great Lakes environmental quality issues, including fish stocking, fish habitat restoration/preservation, and control/prevention of nonindigenous species. Particular emphasis was placed on the environmental data needed in order to establish pathways for valuing environmental quality with the travel cost method.

Lupi (date unknown) provided an overview of efforts to estimate economic values for recreational fisheries of the Great Lakes. The discussion focuses on what the methods actually estimate and how these estimates can be used for fisheries management. The empirical values for Great Lakes recreational fishing are derived from a random utility travel cost model of the demand for fishing in Michigan.

Milliman *et al.* (1992) presented a bioeconomic fishery model that explores the dynamics of stochastic populations and the shifts in harvests obtained by sport and commercial user groups. The model was used to analyze a rehabilitation plan launched for a yellow perch fishery in Green Lake, Mich. The analysis revealed that the rehabilitation plan had produced positive economic gains, with sport user groups reaping substantial benefits and commercial groups experiencing a modest decline in harvests.

Talhelm (1988) summarized estimates of Great Lakes fisheries-related economic values and economic impacts, and described how to interpret this information in evaluating public sector fisheries management choices. Talhem estimated that anglers spent about $2 billion on angling for Great lakes fish in 1985 and that anglers would have paid a maximum of about $3.4 billion on angling for Great Lakes fish and associated goods and services in 1985. He placed the value of angling resources (gross value minus costs) at $1.4 billion (1985 dollars).

Loomis (1989) estimated changes in value of recreational and commercial fisheries due to timber harvesting and road building in two national forests. A travel-cost method was applied to bioeconomic models of the fisheries in order to examine incremental changes in economic value under different levels of watershed disturbance. Results for the Siuslaw National Forest indicated that the loss of salmon and trout due to clear-cutting on 87 acres of forestland resulted in a $2 million economic loss to recreational and commercial anglers over a 30-year period. Results indicated that timber harvesting in the Porcupine-Hyalite Wilderness study area in Montana resulted in a loss of $3.5 million in trout fishing over a 50-year period.

Loomis and White (1996) conducted a meta-analysis of the economic benefits of rare, threatened and endangered species in the United States. The annual WTP ranged from a low of $6 per household for fish such as the striped shiner to a high of $95 per household for the northern spotted owl and its old growth habitat. The values reported in this paper are most useful to assess whether the costs are likely to be disproportionate to the benefits. To date, for even the most expensive endangered species preservation effort (e.g., the northern spotted owl) the costs per household fall well below the benefits per household found in the literature.

Loomis and White (1996) discussed the types of economic benefits that rare and endangered fish provide to members of the general public, and a survey method increasingly used to measure those benefits. The paper also presented results from recent surveys that attempted to elicit the economic values for rare and endangered fish. These surveys indicated that citizens would pay $4–$9 per year to increase stream flows and restore habitat of species such as the Colorado squawfish, and $30–$60 per year for increasing populations of Pacific Northwest salmon. Validation of market simulations shows that Montana resident anglers donated on average $2 and nonresident anglers $12 to The Nature Conservancy to increase flows in one river for the Arctic grayling and Yellowstone cutthroat trout. A large portion of the dollar values reflect the benefits citizens derive from simply knowing the abundance of these species will be increased and available for future generations.

Table 8: Summary of Findings for Fisheries

Reference	Location	Subject	Findings
Connelly, N.A. & Brown, T.L. (1991). Net economic value of the freshwater recreational fisheries of New York. Transactions of the American Fisheries Society. 120(6), 770-775.	New York	Willingness to pay for state's recreational fishery	The net economic value exceeded $284 million for the freshwater fisheries of New York in 1988. Although inland fisheries accounted for 76 percent of the statewide net economic value, $69 million was associated with the portion of the Great Lakes assigned to New York.
Dutta, N. (1984). The value of recreational boating and fishing in the central basin portion of Ohio’s portion of Lake Erie. Ohio Sea Grant Technical Bulletin OHSU-TB-18, Ohio State University.	Central Basin of Ohio’s portion of Lake Erie	Economic value of recreational boating and fishing	Approximates a “best estimate” for the economic value of recreational boating and fishing in the Central Basin of Lake Erie at $18.84 million (1984 dollars).
Gunderson & Kreag. (1991). Estimated economic impact of recreational fishing on Minnesota waters of Lake Superior. Minnesota Sea Grant.	Minnesota waters of Lake Superior	Economic impact of recreational fishing on	The recreational fishing industry contributed approximately $9.74 million dollars in direct expenditures to the state in 1990, with the total state economic impact estimated at $12.67 million to $17.54 million.

Hoen, Tomasi, Lupi & Chen. (1996). An economic model for valuing recreational angling resources in Michigan. Department of Agricultural Economics, Michigan State University.	Michigan	Economic value of the recreational angling	Build an economic model to: (1) value recreational angling experiences in Michigan, and (2) determine how the values for recreational angling are affected by changes in water quality and other measures of fishing quality. No actual values are provided.
Lupi, F., & Hoehn, J.P. (1997). Recreational fishing use-values for Michigan's Great Lake trout and salmon fisheries. The Environmental Economics Program, Department of Agricultural Economics, Michigan State University.	Michigan	Travel cost model developed for recreational angling	Fish population levels can be linked to a host of Great Lakes environmental quality issues. Emphasis is placed on the environmental data needed to establish pathways for valuing environmental quality with the travel cost method.
Lupi, F. (2002). "Economic Values for Recreational Fishing in the Great Lakes." Invited presentation at Great Lakes Sea Grant Network Conference, Milwaukee, Wisconsin, April 17, 2000.	Great Lakes	Review of efforts to estimate economic values for recreational fisheries of the Great Lakes.	Review of efforts to estimate economic values for recreational fisheries of the Great Lakes, including what the methods actually estimate and how these estimates can be used for fisheries management.
Milliman, S.R., Johnson, B.L., Bishop, R.C. & Boyle, K.J. (1992). The bioeconomics of resource rehabilitation: A commercial-sport analysis for a Great Lakes fishery. *Land Economics*. 68(2), 191-210.	Green Lake, Michigan	Bioeconomic fishery model to analyze a rehabilitation plan for yellow perch	Analysis reveals that the rehabilitation plan has produced positive economic gains, with sport user groups reaping substantial benefits and commercial groups experiencing a modest decline in harvests.
Talhelm, D.R. (1988). Economics of Great Lakes fisheries: A 1985 assessment. Great Lakes Fishery Commission. Technical Report No. 54.	Great Lakes	Summary of estimates of Great Lakes fisheries-related economic values and impacts	Estimates the value of angling resources (gross value minus costs) at $1.4 billion (1985 dollars).
Loomis, J.B. (1989). A bioeconomic approach to estimating the economic effects of watershed disturbance on recreational and commercial fisheries. *Journal of Soil and Water Conservation*, 44(1), 83-87.	Siuslaw National Forest and Porcupine-Hyalite Wilderness	Changes in value of recreational and commercial fisheries due to timber harvesting and road building	Results from the study indicate that the loss of salmon and trout due to clear-cutting on 87 acres of forestland resulted in a $2 million economic loss to recreational and commercial anglers over a 30-year period. Results also indicate that timber harvesting in the Porcupine-Hyalite Wilderness study area in Montana resulted in a loss of $3.5 million in trout fishing over a 50-year period.
Loomis, J. B. & White, D.S. (1996). Economic benefits of rare and endangered species: Summary and meta-analysis. *Ecological Economics*, 18(3), 197-206.	United States	Meta-analysis of the economic benefits of rare, threatened and endangered species.	Annual willingness to pay range from a low of $6 per household for fish such as the striped shiner to a high of $95 per household for the northern spotted owl and its old growth habitat. The values reported in this paper are most useful to assess whether the costs are likely to be disproportionate to the benefits.

Loomis, J. B. & White, D.S. (1996). Economic values of increasingly rare and endangered fish. *Fisheries*, 21(11), 6-11.	United States	Surveys of economic benefits that rare and endangered fish provide public	Surveys indicate that citizens would pay $4–$9 per year to increase stream flows and restore habitat of species such as the Colorado squawfish and $30–$60 per year for increasing populations of Pacific Northwest salmon. Montana resident anglers donated on average $2 and nonresident anglers $12 to increase flows in one river for the Arctic grayling and Yellowstone cutthroat trout.

<u>Additional References:</u>

Lyke, A.J. (1993). Discrete choice models to value changes in environmental quality: A Great Lakes case study. Ph.D. Dissertation. University of Wisconsin-Madison, Department of Agriculture and Applied Economics.

Bishop, R.C., Milliman, S.R., Boyle, K.J., & Johnson, B.L. (1990). Benefit-cost analysis of fishery rehabilitation projects: A Great Lakes case study. *Ocean and Shoreline Management*, 13(3-4), 253-274.

Boyle, K.H. & Bishop, R.C. (1987). Toward total valuation of Great Lakes fishery resources. *Water Resources Research,* 5943-5950.

Connelly, N.A. & Brown, T.L. (1991). Net economic value of the freshwater recreational fisheries of New York. *Transactions of the American Fisheries Society*, 120(6), 770-775.

Hushak, L.J., Winslow, J.M., & Dutta, N. (1989). Economic value of Great Lakes sportfishing: The case of private-boat fishing in Ohio's Lake Erie. Ohio Sea Grant College Program, Ohio State University.

Hushak, L., Winslow, J. & Dutta, N. (1984). Economic value of Lake Erie sport fishing to private-boat anglers. Ohio State University.

Jaworski. (1978). Fish, wildlife and recreational values of Michigan's coastal wetlands. Northeast Midwest Institute.

Lyke, A.J. (1990). Travel cost values for sport fishing in Wisconsin waters of the Great Lakes. University of Wisconsin. Ph.D Dissertation.

Carson, R. & Mitchell, R. (1993). The value of clean water: The public's willingness to pay for boatable, fishable and swimmable quality water. *Water Resources Research*, 29(7), 2445-2454.

Whitehead, J.C. (1993). Total economic values for coastal and marine wildlife: Specification, validity, and valuation issues. *Marine Resource Economics*, 8(2), 119-132.

Recreation

Clark *et al.* (1985) conducted a national study of the off-site damages of erosion and sedimentation. They estimate that the total costs to recreation, including fishing, boating, swimming and hunting, total $2 billion per year (1980 dollars). Individual estimates are as follows: freshwater fishing - $450 million; marine fishing - $450 million; boating - $680 million; swimming - $450 million; and waterfowl hunting - $50 million (all values in 1980 dollars).

Alouze (1999) presented an economic analysis of eutrophication in two rivers in New South Wales, Australia. The eutrophication was a result of increased water use for irrigation, drought and nutrient pollution (mainly phosphorus). Results suggested that if the marginal costs of phosphorus removal were low, the equilibrium level of phosphorus was likely to be below that which would cause losses from reduced recreational value of the rivers.

Feather and Hellerstein (1997) examined the use of benefit transfer to determine the benefits of the CRP on water-based recreation. They looked at erosion reductions on private lands in the U.S. over the period 1982 to 1992 and estimated benefits to water-based recreation at $373 million, including fishing, boating and swimming.

Dutta (1984) conducted a study to determine the value of recreational boating and fishing in the Central Basin of Ohio's portion of Lake Erie. The data for this study was provided by a sample of 443 recreational boaters and anglers who visited the Central Basin during 1982. Several different estimates were derived, using alternative models and inputs. The researchers approximate a "best estimate" for the economic value of recreational boating and fishing in the Central Basin of Lake Erie as $18.84 million (1984 dollars).

Jones and Sung (1993) developed a random utility model of demand for recreational fishing in Michigan, covering all water bodies and all species types throughout all counties in the state. The purpose of developing the model was to improve fisheries resource management and to perform natural resource damage assessments. Since one out of two households in Michigan have fishing licenses, fishing-related benefits are expected to represent a substantial portion of the total benefits resulting from improvements in water and sediment quality in the state.

Parsons *et al.* (2003) estimated the economic benefits of water quality improvements for recreational users of lakes, rivers and coastlines in six northeastern states. The benefits were measured using separate travel cost random utility maximization models for fishing, boating, swimming and viewing. All models were utilized for day-trip recreation. Several scenarios for water quality improvements were considered and annual benefits in the region due the Clean Water Act were estimated to be near $100 million.

Sohngen *et al.* (1998) estimated the value of day trips to Lake Erie beaches. Individuals visiting Maumee Bay and Headlands State Park beaches were surveyed during the summer of 1997 and the results were used to estimate travel-cost demand functions for beach visits. The results suggested that single-day visitors take an average of six trips per year to Maumee Bay State Park beach, and seven trips per year to Headlands. The estimated value of a day at the beach is $25 for Maumee Bay and $15 for Headlands. When aggregated over potential users, these results suggested that beaches are highly valuable public resources along Lake Erie's shoreline State Park beach.

Carson and Mitchell (1993) investigated the national benefits of freshwater pollution control. They conducted a national contingent valuation survey to estimate the public's WTP for boatable, fishable and swimmable waters. The researchers found that respondents were willing to pay, on average, $106 annually for maintaining boatable quality water, $80 more to reach the fishable minimum water quality level, and an additional $89 to move from the fishable minimum quality to a national minimum of swimmable quality water, for an adjusted mean total of $275.

Clayton and Mendelsohn (1993) measured the value of watchable wildlife. This study estimated the user value of McNeil River, a bear-watching game sanctuary. Results suggested that users were willing to pay an average of between $228 and $277 per person to visit this unique site.

Loomis and Creel (1992) surveyed California households to estimate the monthly recreation benefits to anglers, wildlife viewers, and waterfowl hunters on the San Joaquin and Stanislaus rivers. Results showed that an increase in summer flows in California's San Joaquin River yielded estimated recreation benefits in excess of $70 per acre-foot (with peak values in August). The model structure allows for estimating monthly values of water flow and may be useful in aiding in-stream flow decisions involving renewal of federal water delivery contracts and hydroelectric relicensing decisions.

Narayanan (1986) evaluated recreational benefits of in-stream flows in Utah. Using the travel cost approach, the demand for recreation and visiting habits based on stream flows were studied in order to propose a methodology for estimating in-stream flow benefits. The methodology was then applied to a case study area, the Blacksmith Fork of the Little Bear River, Utah. Total economic benefits of recreation in this area were estimated to be $8,064, with the marginal in-stream flow benefit estimated to be $0.42/acre-foot.

Table 9: Summary of Findings for Recreation

Reference	Location	Subject	Findings
Clark II, E.H., Haverkamp, J.A., & Chapman, W. (1985). Eroding soils: The off-farm impacts. Washington, DC: The Conservation Foundation.	United States	Off-site damages of erosion and sedimentation to recreation, fishing, boating, swimming, hunting, among others	Estimates of the total costs to recreation - including fishing, boating, swimming, and hunting - total $2 billion per year (1980 dollars).
Alaouze, C.M. (1999). An economic analysis of the eutrophication problem of the Barwon and Darling Rivers in New South Wales. *Australian Economic Papers*, 38(1), 51- 63.	New South Wales	Economic analysis of eutrophication in two rivers	Results suggest that if the marginal costs of phosphorus removal are low, the equilibrium level of phosphorus is likely to be below that which would cause losses from reduced recreational value of the rivers.
Feather, P., & Hellerstein, D. (1997). Calibrating benefit function transfer to assess the Conservation Reserve Program. *American Journal of Agricultural Economics*, 79(1), 151-162.	United States	Benefits of the Conservation Reserve Program on water-based recreation	Feather and Hellerstein looked at erosion reductions on private lands in the United States over the period 1982 to 1992 and estimated benefits to water-based recreation of $373 million, including fishing, boating and swimming.
Dutta, N. (1984). The value of recreational boating and fishing in the central basin portion of Ohio's portion of Lake Erie. Ohio Sea Grant Technical Bulletin OHSU-TB-18, Ohio State University.	Lake Erie	Economic value of recreational boating and fishing	The researchers approximate a "best estimate" for the economic value of recreational boating and fishing in the Central Basin of Lake Erie as $18.84 million (1984 dollars).
Jones, C.A., & Sung, Y.D. (1993). Valuation of environmental quality at Michigan recreational sites: Methodological issues and policy applications. EPA Contract No. CR-816247-01-2.	Michigan	Fishing related benefits	Developed a random utility model of demand for recreational fishing in Michigan. Fishing-related benefits are expected to represent a substantial portion of total benefits of improvements in water and sediment quality in Michigan.
Parsons, G.R., Helm, E.C., & Bondelid, T. (2003). Measuring the economic benefits of water quality improvements to recreational users in six northeastern states: An application of the random utility maximization model. U.S. Environmental Protection Agency.	Six Northeastern states	Economic benefits of water quality improvements for recreational users of lakes, rivers and coastlines	Several scenarios for water quality improvements are considered and annual benefits in the region due the Clean Water Act are estimated to be near $100 million per year.

Sohngen, B., Lichtkoppler F., & Bielen, M. (1998). The value of day trips to Lake Erie beaches. Department of Agricultural, Environmental and Development Economics, and The Ohio Sea Grant College Program, Ohio State University, Draft: November 18, 1998.	Lake Erie	Value of day trips to Lake Erie beaches	The estimated value of a day at the beach is $25 for Maumee Bay and $15 for Headlands (1997 dollars). These results suggest that beaches are highly valuable public resources along Lake Erie's shoreline State Park beach.
Carson, R., & Mitchell, R. (1993). The value of clean water: The public's willingness to pay for boatable, fishable and swimmable quality water, *Water Resources Research*, 29(7), 2445-2454.	United States	Willingness to pay for boatable, fishable, and swimmable waters	Survey respondents were willing to pay, on average, $106 annually for boatable quality water, $80 more for fishable water quality level, and an additional $89 for swimmable quality water, for an adjusted mean total of $275 (1993 dollars).
Clayton, C. & Mendelsohn, R. (1993). The value of watchable wildlife: A case study of McNeil River. *Journal of Environmental Management*, 39(2), 101-106.	McNeil River, a bear-watching game sanctuary	Value of watchable wildlife	Results suggest that users are willing to pay an average of between $228 and $277 per person to visit this unique site.
Loomis, J.B., & Creel, M. (1992). Recreation benefits of increased flows in California's San Joaquin and Stanislaus Rivers. *Rivers*, 3(1), 1-13.	California	Recreation benefits to anglers, wildlife viewers, and waterfowl hunters	Results show that an increase in summer flows yields estimated recreation benefits in excess of $70 per acre-foot (with peak values in August).
Narayanan, R. (1986). Evaluation of recreational benefits in instream flows. *Journal of Leisure Research*, 18(2), 116-128.	Utah	Economic benefits of in-stream flows	Total economic benefits of recreation in the study area were estimated to be $8,064 with the marginal in-stream flow benefits estimated to be $0.42/acre-foot.

Additional References:

Patrick, R., Fletcher, J., Lovejoy, S., Van Beek, W., Holloway, G., & Binkley, J. (1991). Estimating regional benefits of reducing targeted pollutants: An application to agricultural effects on water quality and the value of recreational fishing. *Journal of Environmental Management*, 33(4): 301-310.

Bishop, R.C. & Boyle, K.J. (1985). The economic value of Illinois Beach State Nature Preserve: Final Report to Illinois Department of Conservation.

Lee, S.T. (1996). The economics of recreational fishing. University of Wisconsin. Ph.D. Dissertation.

Navigation and Dredging

Sohngen and Rausch (1998) described how to estimate the benefits of reduced soil erosion in the Maumee River basin. This case study also describes how to estimate the benefits of reduced dredging costs arising from lower soil erosion upstream, using an example of the defensive expenditure approach. The objective of this analysis was to measure the decrease in dredging and confining expenditures associated with a 15 percent reduction in sediments entering the harbor. The benefits per ton of soil erosion in the basin were calculated to be $0.87 per ton of soil.

Clark *et al.* (1985) conducted a national study of the off-site damages of erosion and sedimentation, including navigation impacts. The major cost to navigation was from maintenance dredging of harbors and waterways, and was estimated to cost approximately $520 million per year (1980 dollars). Other costs included delays to commercial shipping (no estimate provided), accidents ($40 million in 1980 dollars), damage to engines (no estimate provided) and disposal of dredged material (no estimate provided). Total annual costs of navigation impacts related to soil erosion were estimated to be approximately $560 million dollars (1980 dollars).

Hansen *et al.* (2002) estimated how changes in soil conservation affect costs to downstream navigation. Models were developed to account for the hydrology and the subsequent flow of sediment within the conterminous states. The hydrologic models, along with detailed data on the location and costs of dredged harbors and shipping channels, provided an avenue for approximating erosion's impact on navigation costs. Results indicated that a ton of eroded soil in some areas imposes no costs to navigation, while costs reach $5 per ton in other areas. Costs vary significantly across relatively small geographic areas because some watersheds affect no downstream shipping channels or harbors, while others affect major shipping areas and can have high sediment disposal costs. Costs to downstream navigation are estimated at $257 million/year.

Table 10: Summary of Findings for Navigation and Dredging

Reference	Location	Subject	Findings
Sohngen, B. & Rausch, J. (1998). Soil erosion in the Maumee River Basin: A case study using market methods to value environmental externalities.	Maumee River Basin, Ohio	Case study on how to estimate the benefits of reduced soil erosion	The benefits per ton of soil erosion in the basin are calculated to be $0.87 per ton of soil.
Clark II, E.H., Haverkamp, J.A. & Chapman, W. (1985). Eroding soils: The off-farm impacts. Washington, DC: The Conservation Foundation.	United States	Cost to navigation from erosion and sedimentation	Total annual costs of navigation impacts related to soil erosion are estimated to be approximately $560 million dollars (1980 dollars).
Hansen, L.T., Breneman; V.E., Davison, C.W., & Dicken, C.W. (2002). The cost of soil erosion to downstream navigation. *Journal of Soil and Water Conservation,* 57(4), 205.	United States	How changes in soil conservation affect costs to downstream navigation	Results indicated that a ton of eroded soil in some areas imposes no costs to navigation, while costs reach $5 per ton in other areas. Costs to downstream navigation were estimated at $257 million/year.
Hitzhusen. (1991). The economics of sustainable agriculture: A downstream perspective. *Journal of Sustainable Agriculture,* 2(2), 75-89.	United States	Downstream costs from soil erosion	Summarizes a number of studies that estimate downstream costs from soil erosion.

Additional References:

Lehman, T., Hitzhusen, F. & Batte, M. (1995). The political economy of dredging to offset sediment impacts on water quality in Ohio's State Park Lakes. *Journal of Soil and Water Conservation*, 50(6), 659-662.

Drinking Water, Water Treatment and Water Supply

Clark *et al.* (1985) conducted a national study of the off-site damages of erosion and sedimentation, impacts to water treatment and water storage facilities. Estimated annual costs of eroded soil to water treatment and water supply totaled $690 million (1980 dollars). These costs included the construction of sediment pools - $350 million; dredging and excavating - $50 million; replacement capacity - $300 million; increased evapotranspiration - $50 million; and water quality treatment - $40 million.

Holmes (1988) used a cost-function approach to obtain economic estimates of water treatment costs caused by suspended sediment mitigation measures. Source water turbidity level was found to be significant factor in explaining operating and maintenance costs. Results indicated that a 1 percent increase in turbidity was associated with a 0.07 percent increase in operating and maintenance expenditures. Based on this, turbidity mitigation measures cost the water treatment industry between $4.40 and $83.34 per million gallons. These estimates were then applied to total surface water withdrawals, resulting in estimates of sediment-induced damages between $35.33 million and $661.19 million annually nationwide. In considering the intersection of the two methods, a conservative nationwide estimate of water treatment costs due to suspended sediment was found to be $353.32 millon per year.

Dearmont *et al.* (1998) estimated the cost of municipal water treatment due to diminished water quality. In this study, the chemical costs of municipal water treatment were expressed as a function of raw surface water quality. Data were used for a three-year period for 12 water treatment plants in Texas. Results showed that when regional raw water contamination was present, the chemical cost of water treatment increased by $95 per million gallons from a base of $75. A 1 percent increase in turbidity was shown to increase chemical costs by 0.25 percent.

Brox *et al.* (1996) conducted a large contingent valuation survey to estimate the social benefits of water quality improvements in the Grand River watershed, which is located in southern Ontario and drains into Lake Erie. Early results indicated a WTP for residential water quality improvements of up to $4.50 per household per month (19 percent of the average water bill), with a somewhat lower value for preserving the environmental quality of parkland in the watershed. The narrowness of the estimated range of WTP values, and their similarity to values found in other studies, suggests that the estimates are a reliable measure of the monetary value of social benefits from water quality improvements in the region. The main socioeconomic determinants of WTP appear to be household income, number of children, perception of existing water quality, and awareness of environmental issues on the part of survey respondents.

Howe and Smith (1994) measured the demand for water supply reliability using contingent valuation methods and hydrologic simulation. A framework for optimizing reliability was presented and the contingent valuation survey was described. Results from three Colorado towns were presented.

Rollins *et al.* (1997) examined consumers' WTP for improving water service infrastructure. In many Canadian municipalities the infrastructure that helps to deliver quality water to households, and transports the wastewater produced is in need of major capital reinvestment. Estimates made by Environment Canada showed that some $4.59 billion per year, over the next 10 years, will be required in order to maintain existing levels of water supply and quality, and to meet future needs. This paper reported on the results of a study to probe this question, carried out jointly by Environment Canada and the University of Guelph. The study, which employed a contingent valuation methodology, found that the average willingness-to-pay to ensure adequate water servicing was just over $26 per month above current water servicing prices. At this level, the municipal water industry would generate an additional $3.5 billion annually, a large portion of the extra revenue required. The public policy implications of this finding were discussed in the paper.

Table 11: Summary of Findings for Drinking Water, Water Treatment and Water Supply

Reference	Location	Subject	Findings
Clark II, E.H., Haverkamp, J.A. & Chapman, W. (1985). Eroding soils: The off-farm impacts. Washington, DC: The Conservation Foundation.	United States	Erosion and sedimentation impacts to water treatment and water storage facilities.	Estimated annual costs of eroded soil to water treatment and water supply total $690 million (1980 dollars). These costs include the construction of sediment pools - $350 million; dredging and excavating - $50 million; replacement capacity - $300 million; increased evapotranspiration - $50 million; and water quality treatment - $40 million.
Holmes, T. (1988). The offsite impact of soil erosion on the water treatment industry. *Land Economics*, 64(4), 356-366.	United States	Water treatment costs caused by suspended sediment mitigation measures.	Results indicate that a 1 percent increase in turbidity is associated with a 0.07 percent increase in operating and maintenance expenditure. These estimates are then applied to total surface water withdrawals, and nationwide damages induced by sediment is estimated to be between $35.33 million and $661.19 million annually, with a conservative estimate of $353.32 million.
Dearmont, D. McCarl, B. & Tolman, D.A. (1998). Costs of water treatment due to diminished water quality: A case study in Texas. *Water Resources Research*, 34(4), 849-854.	Texas	Cost of municipal water treatment due to diminished water quality	Results show that when regional raw water contamination is present, the chemical cost of water treatment is increased by $95 per million gallons from a base of $75. A 1 percent increase in turbidity is shown to increase chemical costs by 0.25 percent.
Brox, J.A., Kumar, R.C. & Stollery, K.R. (1996). Willingness to pay for water quality and supply enhancements in the Grand River Watershed. *Canadian Water Resources Journal*, 21(3).	Ontario	Social benefits of water quality improvements	Results indicate a willingness to pay (WTP) for residential water quality improvements of up to $4.50 per household per month (19 percent of the average water bill), with a somewhat lower value for preserving the environmental quality of parkland in the watershed.
Howe, C.W., & Smith, M.G. (1994). The value of water supply reliability in urban water systems. *Journal of Environmental Economics and Management*, 26(1), 19-30.	Colorado	Demand for water supply reliability	A framework for optimizing reliability is presented and the contingent valuation survey is described. Results from three Colorado towns are presented.
Rollins, K., Frehs, J., Tate, D. and Zachariah, O. (1997). Resource valuation and public policy: Consumers' willingness to pay for improving water service infrastructure. *Canadian Water Resources Journal*, 22(2).	Canada	Willingness to pay for improving water service infrastructure.	Results show that the average willingness to pay to ensure adequate water servicing was just over $26 per month above current water servicing prices.

Additional References:

Coelli, T., Lloyd-Smith, J., Morrison, D. & Thomas, J. (1991). Hedonic pricing for a cost-benefit analysis of a public water supply scheme. *Australian Journal of Agricultural Economics*, 35(1), 1-20.

Aesthetics and Property Values

Kim (1992) examined how property values along Lake Erie's shoreline are affected by erosion control systems. The overall objective of this doctoral dissertation was to estimate the WTP for erosion protection of residential property along the Lake Erie shoreline. Kim then used the hedonic price method to measure the benefits of erosion protection. The results indicated that buyers of lakeshore property had a positive WTP for erosion protection. The benefits of erosion protection were found to be greatest when the property was endangered. Results also suggested that erosion control practices are generally capitalized into the value of property.

Leefers and Jones (1996) assessed property values and selling prices along areas with the "Natural River" designation in Michigan. The results revealed that property values and selling prices are indeed higher along areas with a "Natural River" designation. The study detailed the procedures used as well as the methods for data evaluation.

Herzog *et al.* (2000) tested whether an economic advantage exists for developers who use vegetative cover for erosion control, independent of advantages gained in addressing environmental or regulatory concerns. Improving residential lot appearance from muddy brown to green grass may increase the appeal of the lot to buyers. A market survey in Ohio and Indiana showed that homebuyers and realtors perceived vegetated lots to be worth more than unvegetated lots, and this increased value exceeds the cost of seeding. Thus, developers can now be encouraged to invest in vegetative cover because of the potentially high return on the investment.

David (1968) examined lakeshore property values and their relationship to water quality. In a study of water quality in 60 artificial Wisconsin lakes, David tested four equations with dependent variables measuring per acre value of land, per acre value of improvements, per acre number of improvements and land value calculated as a weighted sum that relates per acre land value to per acre value of improvements and per acre number of improvements. The author designated the water quality in each lake as poor, moderate or good based on the opinions of a member of the Department of Conservation and a member of the Committee on Water Pollution. David did not include any housing characteristics but included variables describing the property, such as road access, topography and size of adjacent lake. David concluded that most variation in land value was attributable to the value and number of improvements and that, while property on more polluted lakes was less valuable than property adjacent to cleaner lakes, the influence of pollution on land values was not more significant than most other variables.

Epp and Al-Ani (1979) used real estate prices to put a value on improvements in the water quality of small rivers and streams in Pennsylvania. Specific goals were: 1) to estimate the relationship between water quality and value of residential properties adjacent to small rivers and streams, and 2) to estimate the effect of various components of water quality, such as acidity, dissolved oxygen, biochemical demand, and nitrate/phosphate levels on the value of properties adjacent to small streams. Results indicated that water quality has a positive correlation with economic value of adjacent properties. For example, a one-point increase in pH was found to result in a 5.9 percent or $653.96 (1972 dollars) increase in the mean sales value of residential properties.

Leggett and Bockstael (2000) used hedonic techniques to show that water quality has a significant effect on property values along the Chesapeake Bay. A pollution variable measured median fecal coliform concentration at the site of the nearest monitoring stations to properties sold between July 1993 and August 1997. In addition, variables that measured distance from the various sources of pollution were included in the regressions in an attempt to reduce potential omitted variable bias. The authors commented that no previous study had taken into account the fact that these types of pollution sources may be undesirable neighbors because they are unattractive or emit unpleasant odors or noise. The distance variables were included to prevent the pollution variable from capturing these effects. The authors included a few housing variables, such as assessed value of the structure and lot size, to control for other "unobservables," and also a number of neighborhood characteristics such as distance to two major cities, percent of residences in the census block that were owner-occupied and level of development of surrounding land. They concluded that fecal coliform counts had a significant, negative effect on property values. Results showed that a change of 100 fecal coliform count per 100 milliliters resulted in a change in property prices of around 1.5 percent.

Michael, Boyle and Bouchard (1996) looked at secchi disk readings of minimum clarity (chosen because these are most observable by the public) in a study of 34 Maine lakes. The study examined property records for sales occurring between January 1, 1990 and June 1, 1994. The authors included variables for a variety of housing and neighborhood characteristics, such as number of stories in the house, square feet of living area, road maintenance and distance to the nearest city. For the various areas of the state, the authors found that a one-meter improvement in lake clarity would result in changes in average property prices ranging anywhere from $11 to $200 per foot of frontage.

Young (1984) studied the effect of perceived water quality on homes in the vicinity of St. Albans Bay on Lake Champlain in Vermont. The author concluded that the value of seasonal recreational properties located adjacent to St. Albans Bay, where a malfunctioning municipal waste treatment plant had caused pollution problems, were depressed relative to the value of similar properties located on the shoreline of the main lake near the bay. It was estimated that a location within the bay reduced property values by an average of 20 percent. The estimated value of properties adjacent to the bay was an average of $4,700 less than equivalent properties on the main lake.

Table 12: Summary of Findings for Aesthetics and Property Values

Reference	Location	Subject	Findings
Kim, K.T. (1992). An assessment of the economic effects of shoreline erosion control in the Lake Erie zone's residential housing market. Department of Agricultural Economics and Rural Sociology, The Ohio State University. Ohio Sea Grant College Program.	Lake Erie	Willingness to pay for erosion protection of residential property along the Lake Erie shoreline	Results indicate that buyers of lakeshore property have a positive willingness to pay for erosion protection. The benefits of erosion protection were found to be greatest when the property was endangered. Results also suggest that erosion control practices are generally capitalized into the value of property.
Leefers, L, & Jones, D.M. (1996). Assessing changes in private property values along designated natural rivers in Michigan. Lansing, MI: Michigan State University, Department of Forestry.	Michigan	Property values and selling prices along areas with a "Natural River" designation	The results reveal that property values and selling prices are indeed higher along areas with a "Natural River" designation. The study details the procedures used as well as the methods for data evaluation.
Herzog, M , Harbor, J., McClintock, K., Law, J., Bennett, K. (2000). Are green lots worth more than brown lots? An economic incentive for erosion control on residential developments. *Journal of Soil and Water Conservation*, 55(1), 43-50.	Ohio and Indiana	Appeal of vegetative lots versus nonvegetated lots	Results show that homebuyers and realtors perceive vegetated lots to be worth more than unvegetated lots, and this increased value exceeds the cost of seeding. Thus, developers can now be encouraged to invest in vegetative cover because of the potentially high return on the investment.

David, E.L. (1968). Lakeshore property values: A guide to public investment in recreation. *Water Resources Research,* 4(4), 697-707.	Wisconsin	Lakeshore property values and its relationship to water quality	Results suggest that most variation in land value was attributable to the value and number of improvements and that, while property on more polluted lakes was less valuable than property adjacent to cleaner lakes, the influence of pollution on land values was not more significant than most other variables.
Epp, D.J., & Al-Ani, K.S. (1979). The effect of water quality on rural non-farm residential property values. *American Journal of Agriculture and Economics*, 61(3), 529-534.	Pennsylvania	Using real estate prices to put a value on improvements in the water quality of small rivers and streams	Results indicate that water quality has a positive correlation with economic value of adjacent properties. For example, a one-point increase in pH was found to result in a 5.9 percent or $653.96 (1972 dollars) increase in the mean sales value of residential properties.
Leggett, C.G. & Bockstael, N.E. (2000). Evidence of the effects of water quality on residential land prices. *Journal of Environmental Economics and Management,* 39(2), 121-144.	Chesapeake Bay	Water quality's impact on property values	Results indicate that fecal coliform counts have a significant, negative effect on property values. Results showed that a change of 100 fecal coliform count/100 mL resulted in a change in property prices of around 1.5 percent.
Michael, H.J., Boyle, K.J., & Bouchard, R. (1986). Water quality affects property prices: A case study of selected Maine lakes. Maine Agricultural and Forest Experiment Station, University of Maine. Miscellaneous Report 398.	Maine	Relationship between lake clarity and property values	Results show that a one-meter improvement in lake clarity would result in changes in average property prices ranging anywhere from $11 to $200 per foot of frontage.
Young, C.E. (1984). Perceived water quality and the value of seasonal homes. American Water Association. *Water Resources Bulletin,* 20(2), 163-168.	Vermont	Relationship between perceived water quality and the value of seasonal recreational homes	Results show that location within the bay reduced property values by an average of 20 percent. The estimated value of properties adjacent to the bay was an average of $4,700 less than equivalent properties on the main lake (1981 dollars).

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Hitzhusen, F.J. (1997). Off-site costs of soil erosion, property rights and conservation policy: Some Ohio evidence and implications. In T. Robertson et al. (Eds.), *Evaluating Natural Resource Use in Agriculture* (pp. 225-239). Iowa: State University Press.

De Zoysa, D., Randall, A., & Hitzhusen, F. (1995). An assessment of soil erosion impacts on lakeside property values in Ohio: A hedonic method application. ESO 2275, Department of Agricultural Economics, The Ohio State University.

Kriesel, W. (1989). An economic analysis of the role of shoreline erosion in Ohio's residential housing market. The Ohio State University.

Steinnes, D.N. (1992). Measuring the economic value of water quality: The case of lakeshore land. *The Annals of Regional Science,* 26(2), 171-176.

Ecosystem

Colgan (1997) discussed the issues involved in preparing estimates for the economic value of the ocean and presented some preliminary findings based on 1997 figures. The key component was Gross Product Originating (GPO) of each industry that uses the ocean and its resources. GPO is the statistic that permits the most consistent way of measuring the output of industries, and so allows comparisons among industries based on their actual size. Preliminary estimates of GPO for 1997 totaled over $80 billion.

Costanza *et al.* (1997) estimated the value of ecosystem services for the entire planet. They estimated the economic value of 17 ecosystem services for 16 biomes, based on published studies and a few original calculations. For the entire biosphere, the value (most of which is outside the market) was estimated to be in the range of $16 trillion to $54 trillion ($10^{12}$) per year, with an average of $33 trillion per year. Because of the nature of the uncertainties, this was considered a minimum estimate. Global gross national product total was around $18 trillion per year.

Filion, Frehs and Sprecher (2002) conducted a case study that describes how the construction of a reservoir affected biodiversity in several ecosystems. A reservoir was constructed after an original study determined that the economic costs and benefits of the project were valued to be $76.5 million (Canadian dollars). The original study also identified some nonquantifiable environmental benefits and costs from the project, which an assessment panel concluded would tend to result in an overall net benefit, thus improving the relative economic effects of the project. This study focused on the importance of including biodiversity values into this type of assessment. The Environmental Valuation Reference Inventory was used to find valuation studies conducted in similar situations from which estimates of the values of the effects in this project could be drawn (benefits transfer). Once the benefits transfer exercise was conducted – and drawing on studies that utilized contingent valuation and travel cost methods for determining the environmental values – it was found that the revised benefit-cost analysis for the project would result in a net loss of approximately $10 million (Canadian dollars).

Gottfried (1991) views ecosystems as long-lived multiproduct factories. Increased use of one ecosystem good or service (function) often affects the supplies of other ecosystem functions. The relationships between these functions can be modeled in terms of key variables related to ecosystem management. Thus, the analyst can determine the different mixes of functions an ecosystem can perform. Watersheds can be viewed as a series of ecosystems linked spatially and temporally by the downward flow of water. Changes in the mix of upstream ecosystem functions change the mix of downstream ecosystem functions. Gottfried presents an approach to valuing one ecosystem as a multiproduct factory using consumer surplus. The author then proceeds to apply the same methodology to a watershed viewed as a series of linked multiproduct assets. Because the flow of water closely links upstream and downstream ecosystems, a watershed can be treated as one unit and valued accordingly. However, this approach obscures a question of particular interest. If erosion in an upstream ecosystem causes it to lose value, but in turn causes the wetland downstream to gain value, does the value of the watershed rise or not? The paper examines this issue in terms of boundaries, redundancy and defensive expenditures, sustainability, and other factors which must be considered in the economic valuation of the watershed.

Gowdy (1997) discussed the value of biodiversity at different levels, including market value, nonmarket values to humans and the value of biodiversity to ecosystems. The main conclusion was that, although market exchange values of environmental services may be used to justify biodiversity protection measures, it must be stressed that exchange value constitutes a small portion of total biodiversity value. The total value of existing biodiversity is largely unknown but indications are that it is essential to human existence. The various levels of biodiversity value point to the need for a hierarchical and pluralistic methodology to determine appropriate policies for its preservation.

Guo *et al.* (2001) studied the value of forest ecosystem services. In this case study, annual economic values were estimated at the county-level for the following ecosystem services: water conservation, soil conservation and gas regulation. Water conservation included hydrological flow regulation, and water retention and storage. Soil conservation related to the reduction of land disuse, prevention of silt accretion, decrease of soil deposit and protection of soil fertility. Gas regulation was by both carbon fixation and oxygen supply. These services provided an indirect economic value of 528.73 million Renminbi (Chinese currency) or $63.7 million in 1997 U.S. dollars.

Loomis *et al.* (2000) measured the total economic value of restoring ecosystem services in an impaired river basin. This paper quantified WTP for the restoration of five ecosystem services: dilution of wastewater, natural water purification, erosion control, habitat for fish and wildlife, and recreation along a 45-mile stretch of the South Platte River near Denver, Colo. Household surveys were used to determine WTP by giving individuals the hypothetical option to pay for protection of ecosystem services through higher water bill costs. Results indicated that those surveyed would pay an average increase of $21 per month ($252 annually) for the five ecosystem services. Generalizing this to the households living along the river yielded a value of $19 million to $70 million, depending on whether those refusing to be interviewed had a zero value or not. Even the lower benefit estimates exceeded the high estimate of water leasing costs ($1.13 million) and CRP farmland easements costs ($12.3 million) necessary to produce the increase in ecosystem services.

Wilson and Carpenter (1999) provided a comprehensive synthesis of peer-reviewed economic data on surface freshwater ecosystems in the United States and examined major accomplishments and gaps in the literature. Economic value has been assigned to nonmarket goods and services provided by surface freshwater systems in the United States by 30 published, refereed articles in the scientific literature from 1971 to 1997. These studies used variations of three approaches for a quantitative assessment of economic value: travel cost methods, hedonic pricing methods and contingent valuation methods. To determine the economic value of nonmarket ecosystem goods and services, each method focuses on a different aspect of social benefit associated with lakes, streams, rivers and wetlands. Valuation methodologies work from different underlying assumptions while possessing unique limitations and uncertainties. Dollar benefit estimates derived for nonmarket freshwater ecosystem goods and services from these studies tend to be specific to a particular method, ecosystem and socioeconomic circumstance. Creative interdisciplinary research is needed on the quantitative measurement of surface freshwater ecosystem goods and service values, the relation of these values to key limnological variates, and the communication of limnological insights to the public and social scientists in ways that facilitate and improve future management and research.

Table 13: Summary of Findings for Ecosystem

Reference	Location	Subject	Findings
Colgan, C.S. (2000). Estimating the economic value of the ocean in a national income accounting framework: Preliminary estimates of gross product originating for 1997. National Ocean Economics Project, Wrigley Institute for Environmental Studies, University of Southern California Working Paper 1.	United States	Economic value of the ocean	Uses Gross Product Originating (GPO) of each industry that uses the ocean and its resources to estimate value. Preliminary estimates of GPO for 1997 total over $80 billion.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grassot, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387(6630), 253-280.	World	Value of ecosystem services for the entire planet.	Estimates the economic value of 17 ecosystem services for 16 biomes. For the entire biosphere, the value is estimated to be in the range of $16 trillion - $54 trillion ($10^{12}$) per year, with an average of $33 trillion per year (minimum estimate). Global gross national product total is around $18 trillion per year.
Filion, F., Frehs, J., Sprecher, D. (2002). Revealing the economic value of biodiversity: A new incentive measure to conserve and protect it. Canadian Case Study on Biodiversity Incentive Measures. Environment Canada.	Canada	The effect of a reservoir construction on ecosystem biodiversity	A reservoir was constructed after an original study determined that the economic costs and benefits of the project were valued to be $76.5 million (Canadian dollars). This study reassesses this value by including biodiversity values and found that the revised benefit-cost analysis for the project would result in a net loss of approximately $10 million (Canadian dollars).
Gottfried, R.R. (1991). The value of a watershed as a series of linked multiproduct assets. *Ecological Economics*, 5(2), 145-161.	NA	Develops methodology for valuing the functions of a watershed	Develops methodology for valuing watershed functions, and includes factors such as boundaries, redundancy and defensive expenditures, sustainability, and other factors which must be considered in the economic valuation of the watershed.
Gowdy, J. (1997). The value of biodiversity. *Land Economics,* 73(1), 25-71.	NA	The value of biodiversity at different levels	Discusses the value of biodiversity at different levels including market value, nonmarket values to humans, and the value of biodiversity to ecosystems.
Guo, Z., Xiao, X., Gan, Y., Zheng, Y. (2001). Ecosystem functions, services and their values – a case study in Xingshan County of China. *Ecological Economics*, 38(1), 141–154.	China	Value of water conservation, soil conservation and gas regulation.	Water conservation, soil conservation and gas regulation services provide an indirect economic value of 528.73 million Renminbi (Chinese currency) or $63.7 million in 1997 U.S. dollars.
Loomis, J., et al. (2000). Measuring the total economic value of restoring ecosystem services in an impaired river basin: Results from a contingent valuation survey. *Ecological Economics*, 33(1), 103-117.	Colorado	Willingness to pay for restoration of five ecosystem services - dilution of wastewater, natural water purification, erosion control, habitat for fish and wildlife, and recreation	Results indicate that those surveyed would pay an average increase of $21 a month ($252 annually) for the five ecosystem services.

Wilson, M.A., & Carpenter, S.R. (1999). Economic valuation of freshwater ecosystem services in the United States: 1971-1997. *Ecological Applications* 9, 772-783.	United States	Comprehensive synthesis of peer-reviewed economic data on surface freshwater ecosystems in the United States	Provides a comprehensive synthesis of peer-reviewed economic data on surface freshwater ecosystems in the United States and examines major accomplishments and gaps in the literature. Creative interdisciplinary research is needed to facilitate and improve future management and research.

<u>Additional References:</u>

Hitzhusen, F. (2000). Economic analysis of sedimentation impacts for watershed management. In R. Lal (Ed.), *Integrated Watershed Management in the Global Ecosystem.* CRC Press.

Hitzhusen, F.J. (n.d.) A resource economic perspective on erosions control for Non-Economist: Erosion Control – Investing in the Protection of Our Environment. Proceedings of International Erosion Control.

Filion, F., Frehs, J. & Sprecher, D. (2002). Revealing the economic value of biodiversity: A new incentive measure to conserve and protect it. Canadian Case Study on Biodiversity Incentive Measures. Environment Canada.

Evaluating the Cost of Erosion Control Programs and Practices

Preventative measures such as BMPs help keep soil on the land and reduce the amount of sediment that accumulates in rivers and lakes. But preventative measures are costly and time-intensive to implement. Are the costs required to implement prevention measures worth the investment? In other words, how much money would be saved if the sediment load into the rivers and lakes was reduced? Understanding the economic benefits of intervention strategies can help answer these types of policy questions.

To help make costs and benefits more comparable, economists have developed methods by which to quantify the economic benefits of environmental programs. The three most common methods for assessing economic benefits are cost-benefit analysis[2], cost-effective analysis[3], and natural resource damage assessments[4].

A key environmental policy goal is to encourage producers to factor in the costs they impose on others through their pollution-generating activities. Ideally, the producers would choose those activities that are the most economically efficient in terms of the cost impacts to society. "Designing policies to achieve efficiency, however, is often impossible because the relationship between economic damages and nonpoint source pollution is seldom known" (Ribauldo, 1999, p. iv). Thus, policies are often designed to target environmental goals at the least cost.

There are serious limitations to choosing the most "cost-effective" strategies, however, due to the complex nature of erosion and sedimentation. First, erosion is difficult to measure at a reasonable cost because it is diffuse (soil erodes off of a farm field in many different places) and is impacted by random weather events (i.e., storms or droughts). Also, the process by which sediment is transported to and through rivers and lakes (where it causes economic damage) is influenced by a number of different factors, some of which are unpredictable. The random and unpredictable nature of the erosion and sedimentation process imposes serious limitations to crafting programs and policies that are cost-effective.

Another issue to consider is the scale of application. Erosion and sedimentation depends on many site-specific factors. The more site-specific that policies and programs can be, the more efficient they will be. However, designing and implementing site-specific programs can be very costly as it requires the collection of site-specific data and information, which can be expensive to acquire.

The following section provides an introduction to the current state of knowledge on the cost-effectiveness of sediment reduction programs, policies and practices.

Evaluating the Cost of Sediment Reduction Programs, Policies and Practices

Berrens *et al.* (1998) investigated the presence of nonmarket values for maintaining the status quo land use and avoiding social impacts from an environmental policy change. The test case, grazing reform on federal lands in New Mexico, was chosen because of the complexity of the public debate. The researchers were exploring the case of a proposed policy change aimed at environmental restoration, but that also involved social impacts. The authors looked at whether there were nonmarket values associated with maintaining the status quo. Their results

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[2] **Cost-benefit analysis (CBA):** a tool for policy analysis that attempts to monetize all the costs and benefits of a proposed action to determine the net benefit.

[3] **Cost-effective analysis:** a policy tool that determines the least-cost approach for achieving a given goal.

[4] **Natural resource damage assessment:** the process of collecting, compiling and analyzing information to assess the extent of injury to a natural resource and determine appropriate ways of restoring and compensating for that injury. Damages to natural resources are evaluated by identifying the function or 'services' provided by the resource(s), determining the baseline level of the services provided by the injured resource(s) and quantifying the reduction in service levels as a result of the damage.

indicated the presence of such a nonmarket value for maintaining federal lands for grazing in New Mexico. Approximately 40 percent of the sample population provided a positive contribution value. Over the entire sample, the mean value was approximately $21 per household annually, with a corresponding mean value of $52 for the portion of the sample willing to contribute a positive amount (1998 values).

Caswell *et al.* (2001) examined the extent of adoption of nutrient, pest, soil and water management practices and assessed the factors that affect adoption for a wide range of management strategies across different natural resource regions. The USDA Area Studies Project entailed the administration of a detailed field-level survey to farmers in 12 watersheds in the United States to gather data on agricultural practices, input use and natural resource characteristics associated with farming activities. The richness of the data set allowed a wide range of analyses. The lack of data on costs and prices, however, greatly handicapped the study. The authors assumed that a farmer’s choice of inputs and outputs reflected an economic decision (i.e., profit maximization), but the lack of explicit cost data meant that the influence of technology costs, input costs, taxes and cost-sharing policies could not be directly tested.

Colombo, Calatrava-Requena, and Hanley (2003) applied the contingent valuation method to estimate the benefits to the general public resulting from a soil erosion control program in the Alto Genil area of southern Spain. Soil erosion results in many off-site negative effects, such as the eutrophication of waterways and impacts on landscape quality. Because these off-site effects are rarely “captured” in markets, they are often given too little weight in policy decisions. The authors’ survey design attempted to reduce part-whole bias by getting respondents to also value other, substitute environmental programs. The main finding was that a majority of the catchment's population was willing to pay to reduce off-site damages and that current off-site damages imposed costs of around 4 million-7 million euros/year, or around 42-72 euros/hectare/year (17-29 euros/acre/year). Reminding respondents about substitute environmental projects was found to have a significant impact on the value placed on soil erosion control.

Countryman and Murrow (2002) performed an economic analysis to compare contour tree buffer strips with rowcropping, terracing, conventional tillage, contour strip-cropping and the CRP. Four tree species were analyzed: black walnut, red oak, white oak and ash. Sensitivity analyses were carried out on land values, real interest rates and the projected costs and revenues associated with different scenarios. Without subsidies, contour tree buffer strips were economically competitive with all practices evaluated except tree plantations (at $1,183/hectare land value), rowcropping (at $2,223/hectare land value) and combined rowcropping and strip-cropping (at $3,263/hectare land value). With equal subsidies, contour tree buffer strips were economically competitive with all conservation practices and land values evaluated. These results supported the hypothesis that contour tree strips are an economically feasible conservation practice for soil erosion control.

Feather and Hellerstien (1997) suggested a method of calibrating benefit transfer to reduce bias. Benefit transfer offers an inexpensive alternative to conducting an original study to determine economic value, but can also result in biased welfare estimates. An empirical example to determine the benefits of the CRP on water-based recreation illustrates the potentially large biases that can result if the transfer is not calibrated.

Feather, Hellerstein and Hansen (1999) demonstrated how nonmarket valuation models could be used in targeting conservation programs such as the CRP. The range of environmental problems confronting agriculture has expanded in recent years. As the largest program designed to mitigate the negative environmental effects of agriculture, the CRP has broadened its initial focus on reductions in soil erosion to consider other landscape factors that may also be beneficial. For example, preserving habitats can help protect wildlife, thus leading to more nature-viewing opportunities.

Feather and Cooper (1995) presented research findings on the success of incentive programs to control agricultural nonpoint source pollution. Agricultural chemicals and sediment from cropland may reduce the quality of America's surface and ground water resources. The Clean Water Act stipulates that individual states are responsible for controlling agricultural nonpoint source pollution. Most state plans rely chiefly on education and technical assistance to promote the adoption of less polluting practices. Because profitability drives production decisions, these programs tend to be most successful when they promote inexpensive changes in existing practices.

Hansen and Ribaudo (2008) conducted a national study of the per-ton values of 14 types of soil conservation benefits. The values are derived from models that capture the cause-and-effect relationships between agricultural erosion and environmental benefits. Values and methodology are described so that analysts can apply the data to calculate regional and national benefits of specific soil conservation projects. Analysts can also use the per-ton benefit estimates to determine where a 1-ton reduction in soil erosion might be most beneficial.

Henglun, Houston, and Bergstrom (1996) provided evidence that the control of nonpoint source pollution through crop production and water management practices, alone, appears to be expensive and very limited.

Herzog *et al.* (2000) tested whether an economic advantage exists for developers who use vegetative cover for erosion control, independent of advantages gained in addressing environmental or regulatory concerns. Improving residential lot appearance from muddy brown to green grass may increase the appeal of the lot to buyers. A market survey showed that homebuyers and realtors perceive vegetated lots to be worth more than unvegetated lots, and this increased value exceeded the cost of seeding. Thus, developers can now be encouraged to invest in vegetative cover because of the potentially high return on the investment.

Johnson (2003) discussed how to use stream bank stabilization to reduce flooding, improve water quality and prevent sedimentation. Stream bank stabilization reduces flooding to farmland and stream banks, improves water quality and helps prevent sedimentation.

Lakshminarayan and Babcock (1996) presented estimates of the benefits and costs of alternative soil conservation policies in a spatially and temporally consistent framework. The policies considered were: 1) implementation of soil conservation practices with an objective of reducing erosion to a site's tolerance level, and 2) a policy with an objective of a voluntary 50 percent reduction in conventional tillage. Costs and erosion benefits of these two policies were compared with that obtained from CRP. The changes in erosion and cost were estimated relative to 1992 levels. The analysis was conducted on every NRI point in a 12-state region in the northcentral United States. Erosion metamodels developed using site-specific resource, production, topography and weather data make such an endeavor tractable. The results indicated that having farmers adopt conservation plans on highly erodible fields was a sensible, cost-effective policy. The public benefits of controlling erosion more than offset the small increased cost from adoption of conservation practices and conservation tillage. A significant amount of current CRP land was not susceptible to high erosion rates, which drove down the average benefit-to-cost ratio across the study region. A more targeted CRP would increase this ratio to the point where it could approach unity.

Lipton *et al.* (1995) presented the outcomes of NOAA Coastal Ocean Program (COP)-sponsored environmental valuation workshops in this handbook. As the text to support the teaching in these workshops was developed and as the need to transfer this information to a wider audience of coastal managers than workshop attendees became apparent, it was decided to present the handbook as a stand-alone document. The handbook includes information on the following: history and legislative mandates for environmental valuation; concepts in environmental valuation; economic tools for use in coastal management decisionmaking; measuring the value of goods and services traded in markets; measuring the value of nonmarket goods and services; benefit transfer; reconciling differences between theory and application; and case studies.

Nakao and Sohnge (2000) estimated the cost of reducing soil erosion with riparian buffers. This paper explored how the cost of a ton of soil erosion reduction varied across site characteristics in a watershed, including field shape and size, tillage method and soil type. The methods were used to show how watershed managers may target funds to high- and low-cost sites and regions within a watershed. The results suggest that the costs of reducing soil erosion with riparian buffers are lower when buffers are applied to conventionally tilled fields, and that the costs of buffers are comparable to the costs of no-till. The relationship between buffer size, drainage area size and effectiveness was also explored. The authors show how riparian buffers with low effectiveness can be cheaper to install than riparian buffers with high effectiveness.

Napier and Bridges (2002) collected data from land owner-operators who were managing farms within the Darby Creek watershed and within selected areas in the upper Scioto River watershed in central Ohio during the late winter of 1998 and the summer of 1999. The study found that massive human and economic resources employed to motivate land owner-operators to adopt and use conservation production systems within the Darby Creek watershed were not successful in accomplishing that objective.

Napier (2001) focused on the use of conservation production systems and suggests that existing intervention approaches employed to motivate land owner-operators to adopt and to use conservation production systems will be marginal at best and will probably lead to failures in the long-term. The findings suggest that other approaches will probably be required to achieve national soil and water quality goals.

The National Research Council (1986) presented the first independent analysis of an important national data base, the National Resources Inventory (NRI). It cites potential uses of the NRI in controlling soil erosion, determining land use, deciding conservation treatment, classifying soils and protecting groundwater quality. Methods for soil conservation activities, ranging from the ranking of the lands most susceptible to erosion to the measurement and prediction of both wind and water erosion, are recommended throughout the volume.

The National Research Council (1986) brought together the technical papers from which Volume 1 was drawn. The 10 papers and discussion from a National Research Council symposium cover such topics as soil erosion classification, evaluating how soil erosion damages productivity, calculating soil erosion, understanding ephemeral gully erosion, wind erosion and the impact of range erosion on land use.

The National Research Council (1993) offered four specific strategies that could serve as the basis for a national policy to protect soil and water quality while maintaining U.S. agricultural productivity and competitiveness. Timely and comprehensive, the volume had important implications for the Clean Air Act and the 1995 farm bill. Advocating a systems approach, the committee recommended specific farm practices and new approaches to the prevention of soil degradation and water pollution for environmental agencies. The volume details methods of evaluating soil management systems and offers a wealth of information on improved management of nitrogen, phosphorus, manure, pesticides, sediments, salt and trace elements. Landscape analysis of nonpoint source pollution is also detailed, drawing together research findings, survey results and case examples.

Palone and Todd (1997) addressed economic values of forested streams. Discussions include nutrient removal, stream temperature, erosion control, flood protection, property value, pollution prevention, recreational greenways and wildlife habitat. Included were site-specific examples of economic impacts of riparian forest buffers. One example from Fairfax County, Va., showed a reduction of $47 million in costs related to storm water run-off by retaining riparian forest buffers and forested areas in the county.

Parsons and Wu (1991) presented a study focusing on one negative economic efficiency effect of land-use control. The cost of displaced residential development, arising from the imposition of land-use controls in Anne Arundel County, Md., was analyzed by conducting hedonic price regression analysis for housing. A prediction was then made for the value of lost coastal access amenities due to land-use controls. The results provided useful information that may be used in rational policymaking in the area of environmental control.

Pattanayak and Mercer (1996) aimed to reduce the gap between the benefits of agroforesty and the empirical estimates of those benefits by designing and testing a three stage farm-level productivity methodology for the economic evaluation of the soil conservation benefits of agroforestry. Stage 1 quantified the relationship between soil conservation, agroforestry and soil quality. In Stage 2, the effects of changes in soil quality on individual household agricultural production were estimated. Finally, in Stage 3, these changes in production were valued at net market prices. The data to test this framework were drawn from two USAID/Government of

Philippines projects that introduced contour hedgerow agroforestry in the Eastern Visayas, Philippines. Multiple regression analysis was used in each stage to establish the relationship between the agroforestry practice, soil quality and changes in farm-household income. The value of soil conservation was measured in terms of the change in net household income which was the true measure of change in the economic welfare of the household. The results indicated that agroforestry-related soil conservation does benefit the farmer, with the average farmer gaining 114 pesos (approximately $10) annually. This in itself provided insufficient incentive for the farmer to invest in agroforestry, in this case because the direct opportunity costs of agroforestry adoption and maintenance resulted in a negative overall contribution to individual household income. However, the specific soil conservation benefit calculations did not account for several significant off-site and on-site benefits external to the individual households. In addition, all long-run soil conservation benefits (and particularly improvements in the agro-ecological profile) may not have been realized in the short 10-year period since the initiation of the agroforestry project. Thus, even though net benefits of agroforestry was negative, there may be good reason for society to encourage the farmers to practice agroforestry to conserve the soil and enhance overall societal welfare.

Ribaudo, Horan and Smith (1999) outline the economic characteristics of five instruments that can be used to reduce agricultural nonpoint source pollution (economic incentives, standards, education, liability, and research) and discuss empirical research related to the use of these instruments. Agricultural nonpoint pollution reduction policies can be designed to induce producers to change their production practices in ways that improve the environmental and related economic consequences of production. The information necessary to design economically efficient pollution control policies is almost always lacking. Instead, policies can be designed to achieve specific environmental or other related goals at the least cost, taking into account transaction costs and any other political, legal, or informational constraints that may exist.

Ribaudi (1989) estimated the water quality benefits from the CRP. The CRP, a land retirement program designed to remove from production 40 million to 45 million acres of highly erodible cropland, may generate an estimated $3.5 billion to $4 billion in water quality benefits. Reducing erosion via retirement of 40 million to 45 million acres of highly erodible cropland would generate $3.5 billion to $4.5 billion in surface-water quality benefits over the life of the program.

Ribaudo and Hellerstein (1992) reviewed practical approaches and theoretical foundations for estimating the economic value of changes in water quality in regard to recreation, navigation, reservoirs, municipal water treatment and use, and roadside drainage ditches. Knowledge of the benefits and costs to water users was required for a complete assessment of policies to create incentives for water quality improving changes in agricultural production. A number of benefit estimation methods were required to handle the varying nature of water quality effects.

Tomer, James and Isenhart (2003) developed maps to help plan the placement of BMPs in a watershed for water quality benefits. Tipton Creek, a 49,000-acre Iowa watershed, provided a case study. Buffer-placement maps, developed from analysis of 30 m (100 ft.) elevation data, identified riparian locations with large wetness indices, where buffer vegetation could intercept sheet/rill flows from significant upslope areas. These sites were numerous, typically small (<200 m in length) and well-distributed spatially. However, results showed that 57 percent of riparian grid cells would receive runoff from less than 0.4 hectare (1 acre). Candidate wetland sites were also mapped by applying interpretive and automated techniques to terrain analysis results. A team of conservation professionals evaluated the planning utility of these maps in the field through consensus-seeking discussions. Buffer maps highlighted areas where, team members agreed, perennial vegetation could effectively intercept runoff and/or manage seasonal wetness. The review team also located three feasible wetland sites, which were all identified by an automated technique showing 12 candidate sites. The methods required only public data and should be applicable to other watersheds.

The U.S. General Accounting Office (1999) developed the report entitled *Federal Role in Addressing and Contributing to Nonpoint Source Pollution* as a response to congressional concerns about the impact of nonpoint source pollution and the potential cost of dealing with the problem. This report provides background information and funding levels for federal programs that primarily address nonpoint source pollution; examines the way in which EPA assesses the overall potential costs of reducing nonpoint pollution nationwide and alternative methods for doing so; and describes nonpoint source pollution from federal facilities, lands and activities. The federal agencies contacted by the Government Accountability Office (GAO) spent about $3 billion annually for fiscal years 1994 through 1998 on 35 programs that addressed nonpoint source pollution. EPA has pegged the cost to control three major sources of nonpoint source pollution at $9.4 billion annually. To arrive at that amount, EPA analyzed agriculture, silviculture and animal feeding operations and estimated pollution control costs for these sources. However, EPA acknowledged that the methodology has several limitations. The federal government manages or authorizes, or issues permits or licenses for, various activities that produce nonpoint source pollution and in some cases affect water quality.

Uri (2000) assessed farmers' perception of their actual use of no-till. An analysis of the Agricultural Resource Management Study survey data for 1996 shows that for soybeans (*Glycine max* L. Merr.), winter wheat (*Triticum aestivum* L.), spring wheat and durum wheat, farmers' perceptions are consistent with reality. In the case of corn (*Zea mays* L.), however, nearly 18 percent of corn farmers believe they are using no-till, while in reality, only slightly more than 12 percent are using this system. In order to properly associate the benefits of no-till with its use, it is important that farmers' perception of what constitutes no-till and their actual use of no-till be consistent.

Watzin and McIntosh (1999) discussed 1) the role of natural processes in agricultural watersheds; 2) the use of biological indicators in aquatic systems; 3) assessments of the effects of agriculturally derived pollutants, both in-stream and at the landscape scale; 4) achievable ecological outcomes; and 5) recommendations for developing ecological indicators and identifying appropriate restoration goals for agricultural systems. If ecological indicators are to be used effectively, it is necessary to identify those taxa and responses that are most closely associated with agricultural stressors. Once such tools are developed, an overall framework for designing holistic management plans will help identify realistic and achievable restoration goals that maximize the environmental benefits in a watershed.

Wossink and Osmond (2002) showed how farm economics information that is widely available can be used to help guide local resource managers and watershed groups in their efforts to design cost-effective programs to improve water quality. The focus was on the economic elements driving farmer and landowner decisions and how those compare with incentive payments to alter these decisions. The approach was illustrated for the case of BMPs mandated for nitrogen control in the Neuse River Basin in North Carolina. The empirical research showed that the economics of the BMPs were very different for the three regions in the basin as distinguished by physiographic conditions. Economic differences in implementing BMPs should be taken into account by state and federal authorities when they are determining cost-share programs. The research also showed that the cost-share payments offered for grass buffers might not be in line with the relative reduction in nitrogen emission offered by this BMP.

Yang *et al.* (date unknown) developed an integrated framework of economic, environmental and GIS modeling to study cost-effective retirement of cropland within and across multiple watersheds to achieve environmental goals. This framework was applied to 12 contiguous agricultural watersheds in the Illinois Conservation Reserve Enhancement Program (CREP) region of the United States. This program seeks to reduce sediment loadings in the Illinois River by 20 percent by retiring land from crop production. The characteristics of land parcels to be targeted for retirement within each watershed and the criteria for cost-effective allocation of abatement responsibility across watersheds were analyzed. The costs of abatement with a uniform allocation of abatement responsibility across watersheds and the ensuing pattern of land retirement were compared to those with the least-cost approach.

Yuan, Dabney, and Bingner (2002) applied the Annualized Agricultural Nonpoint Source pollutant loading model (AnnAGNPS 2.1) to a 12 hectare (30 acre) MDMSEA subwatershed to extend results and better evaluate the effectiveness of alternative BMP combinations on sediment reduction. BMPs considered included cover crops, filter strips, grade control pipes and impoundments. Each BMP was considered in combination with three tillage systems: conventional tillage, reduced tillage, and no-till. Costs of BMPs were estimated using 2001 state average prices for Mississippi. Amortized fixed costs, using a 25-year planning horizon and interest rates of both 5 and 10 percent, were combined with direct annual costs into total annual cost estimates. AnnAGNPS predicted that no-till alone, reduced tillage with winter cover and an edge-of-field pipe, or conventional tillage with a small permanent impoundment (covering less than 3 percent of the watershed) would all reduce sediment yield by at least 50 percent. The most cost-effective BMPs were management of volunteer winter weeds as cover crops and various types of edge-of-field grade-control pipes. The average marginal cost using BMPs for sediment yield reduction was about $8 million per metric ton ($7.3 per ton) for conventional and reduced tillage. The cost was higher, about $10.7 million per metric ton, ($9.7 per ton) for no-till because the practice of no-till alone reduced sediment yield by half, and further marginal reductions were more expensive.

Table 14: Summary of Findings for Cost Effectiveness of Sediment Reduction Programs, Policies and Practices

Reference	Location	Subject	Findings
Berrens, R.P., Brookshire, D., Ganderton, P., McKee, M. (1998). Exploring nonmarket values for the social impacts of environmental policy change. *Resource and Energy Economics*, 20(2).	New Mexico	Nonmarket values	The researchers explored the case of a proposed policy change aimed at environmental restoration, but that also involved social impacts. They looked at whether there were nonmarket values associated with maintaining the status quo. Their results indicate the presence of such a nonmarket value for maintaining federal lands grazing in New Mexico.
Caswell, M., Fuglie, K., Ingram, C., Jans, S., & Kascak, C. (2001). Adoption of agricultural production practices: Lessons learned from the U.S. Department of Agriculture Area Studies Project. Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Agricultural Economic Report No. 792.	United States	Adoption of best management practices	Examined the extent of adoption of nutrient, pest, soil, and water management practices and assessed the factors that affect adoption for a wide range of management strategies across different natural resource regions.
Colombo, S., Calatrava-Requena, J., & Hanley, N. (2003). The economic benefits of soil erosion control: An application of the contingent valuation method in the Alto Genil basin of southern Spain. *Journal of Soil and Water Conservation*, 58(6), 367.	Spain	Contingent valuation method used to estimate benefits of soil erosion control program	The researchers' main finding is that a majority of the watershed's population was willing to pay to reduce off-site damages. Reminding respondents about substitute environmental projects was found to have a significant impact on the value placed on soil erosion control.
Countryman, D.W., & Murrow, J.C. (2000). Economic analysis of contour tree buffer strips using present net value. *Journal of Soil and Water Conservation.* 55(2), 152-161.	United States	Economic analysis of different best management practices	Researchers perform an economic analysis to compare contour tree buffer strips with rowcropping; terracing, conventional tillage, contour strip-cropping, and the Conservation Reserve Program. Results support the hypothesis that contour tree strips are an economically feasible conservation practice for soil erosion control.

Feather, P., & Hellerstein, D. (1997). Calibrating benefit function transfer to assess the Conservation Reserve Program. *American Journal of Agricultural Economics,* 79(1), 151-162.	United States	Calibrating benefit transfer to reduce bias	Benefit transfer offers an inexpensive alternative to conducting an original study to determine economic value, but can also result in biased welfare estimates. A method of calibrating benefit transfer to reduce bias is suggested.
Feather, P., Hellerstein, D., & Hansen, L. (1999). Economic valuation of environmental benefits and the targeting of conservation programs: The case of the CRP. Agricultural Economics Report 778. U.S. Department of Agriculture. Economic Research Service.	United States	Using nonmarket valuation models to target conservation programs	Demonstrates how nonmarket valuation models can be used in targeting conservation programs such as the Conservation Reserve Program.
Feather, P. & Cooper, J. (1995). Voluntary incentives for reducing agricultural nonpoint source pollution. Economic Research Service, U.S. Department of Agriculture. Agricultural Information Bulletin Number 716.	Various regions within the United States	Success of incentive programs to control agricultural nonpoint source pollution	Research findings on the success of incentive programs to control agricultural nonpoint source pollution are presented.
Hansen, L., & Ribaudo, M. O. (2008). Economic measures of soil conservation benefits: Regional values for policy assessment. Resource and Rural Economics Division, Economic Research Service, U.S. Department of Agriculture, Technical Bulletin TB-1922.	United States	Benefits of soil saved in $/ton by county, by 8 Digit HUC and by region	Benefits in $/ton of soil saved in the Great Lakes States ranged from $2.77 to $4.68 (not counting the benefit to marine fisheries.)
Henglun, S., Houston, J., & Bergstrom, J. (1996). Economic analysis of best management practices in the Gum Creek Watershed water quality program. *Journal of Soil and Water Conservation,* 51(2), 176-181.	Gum Creek Watershed, Georgia	Cost-effectiveness of best management practices to control nonpoint source pollution	Researchers provide evidence that the control of nonpoint source pollution through crop production and water management practices alone appears to be expensive and very limited.
Herzog, M., Harbor, J., McClintock, K., Law, J., & Bennett, K. (2000). Are green lots worth more than brown lots? An economic incentive for erosion control on residential developments. *Journal of Soil and Water Conservation*, 55(1), 43-50.	Ohio and Indiana	Economic analysis of vegetated lots versus nonvegetated lots	A market survey shows that homebuyers and realtors perceive vegetated lots to be worth more than unvegetated lots, and this increased value exceeds the cost of seeding. Thus, developers can now be encouraged to invest in vegetative cover because of the potentially high return on the investment.
Johnson, C. (2003). 5 low-cost methods for slowing streambank erosion. *Journal of Soil and Water Conservation,* 58(1), 12A.	NA	Low cost methods to control stream bank erosion	Discusses how to use stream bank stabilization to reduce flooding, improve water quality, and prevent sedimentation.

Lakshminarayan, P.G. & Babcock, B.A. (1996). Temporal and spatial evaluation of soil conservation policies. Center for Agricultural and Rural Development, Iowa State University, Working Paper 96-WP 149.	Michigan, Wisconsin, Minnesota, Ohio, Indiana, Illinois, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas	Benefits and costs of alternative soil conservation policies	Results indicate that having farmers adopt conservation plans on highly erodible fields is a sensible, cost-effective policy. The public benefits of controlling erosion more than offset the small increased cost from adoption of conservation practices and conservation tillage.
Lipton, D., Wellman, K., Sheifer, I.C., & Weiher, R. (1995). Economic valuation of natural resources: A handbook for coastal resource policymakers. NOAA Coastal Ocean Program Decision Analysis Series No. 5. NOAA Coastal Ocean Office, Silver Spring, MD.	NA	Handbook on economic valuation of natural resources.	The handbook includes information on the following: History and Legislative Mandates for Environmental Valuation; Concepts in Environmental Valuation; Economic Tools for Use in Coastal Management Decisionmaking; Measuring the Value of Goods and Services Traded in Markets; Measuring the Value of Nonmarket Goods and Services; Benefit Transfer; Theory and Application - Reconciling Differences; and Case Studies.
Nakao, M. & Sohngen, B. (2000). The effect of site quality on the costs of reducing soil erosion with riparian buffers. *Journal of Soil and Water Conservation*, 55(2), 231.	Maumee River Basin, Ohio	Variability of cost-effectiveness of best management practices across site characteristics	Results suggest that the costs of reducing soil erosion with riparian buffers are lower when buffers are applied to conventionally tilled fields, and that the costs of buffers are comparable to the costs of no-till. The paper shows how riparian buffers with low effectiveness can be cheaper to install than riparian buffers with high effectiveness.
Napier, T.L., & Bridges, T. (2002). Adoption of conservation production systems in two Ohio watersheds: A comparative study. *Journal of Soil and Water Conservation*, 57(4), 229-236.	Ohio	Cost-effectiveness of adoption of conservation practices	Study found that massive human and economic resources employed to motivate land owner-operators to adopt and use conservation production systems within the Darby Creek watershed were not successful in accomplishing that objective.
Napier, T.L. (2001). Soil and water conservation behaviors within the upper Mississippi River Basin. *Journal of Soil and Water Conservation*, 56(4), 279-286.	Upper Mississippi River Basin	Cost-effectiveness of adoption of conservation practices	Findings strongly suggest that existing intervention approaches employed to motivate land owner-operators to adopt and use conservation production systems will be marginal at best and will probably lead to failures in the long term. The findings suggest that other approaches will likely be required to achieve national soil and water quality goals.
National Research Council. (1986). Soil conservation: Assessing the national resources inventory. Volume 1. Committee on Conservation Needs and	NA	Uses of the National Resources Inventory in controlling	Presents the first independent analysis of an important national data base, the National Resources Inventory (NRI). It cites potential uses of the NRI in controlling soil erosion, determining land

Opportunities, Board On Agriculture.		erosion	use, deciding conservation treatment, classifying soils and protecting groundwater quality. Methods for soil conservation activities, ranging from the ranking of the lands most susceptible to erosion to the measurement and prediction of both wind and water erosion, are recommended throughout the volume.
National Research Council. (1986). Soil conservation: Assessing the National Resources Inventory, Volume 2. Committee on Conservation Needs and Opportunities, Board On Agriculture.	United States	Uses of the National Resources Inventory in controlling erosion	Ten papers and discussions from a National Research Council symposium cover such topics as soil erosion classification, evaluating how soil erosion damages productivity, calculating soil erosion, understanding ephemeral gully erosion, wind erosion and the impact of range erosion on land use.
National Research Council. (1993). Soil and water quality: An agenda for agriculture. Committee on Long-Range Soil and Water Conservation Policy.	United States	National Research Council Agenda for soil conservation	Offers four specific strategies that can serve as the basis for a national policy to protect soil and water quality while maintaining U.S. agricultural productivity and competitiveness.
Palone, R.S. & Todd, A.H. (Eds). (1997). Section XII - Economics of riparian forest buffers. In R.S. Palone & A.H. Todd (Eds.), *Chesapeake Bay riparian handbook: A guide for establishing and maintaining riparian forest buffers.* USDA Forest Service. NA-TP-02-97. Radner, PA.	NA	Economic values of forested streams	Addresses economic values of forested streams. Discussions include nutrient removal, stream temperature, erosion control, flood protection, property value, pollution prevention, recreational greenways and wildlife habitat.
Parsons, G.R. & Wu, Y. (1991). The opportunity cost of coastal land-use controls: An empirical analysis. *Land Economics*, 67(3), 308-316.	Maryland	Economic efficiency of coastal land-use controls	Presents a study focusing on one negative economic efficiency effect of land-use control. The results provide useful information that may be used in rational policymaking in the area of environmental control.
Pattanayak, S. & Mercer, D.E. (1996). Valuing soil conservation benefits of agroforestry practices. Southeastern Center for Forest Economics Research, Research Triangle Park, NC. FPEI Working Paper No. 59.	Philippines	Valuing soil conservation benefits of agroforestry practices	Design and test methodology for economic evaluation of soil conservation benefits of agroforestry. Results indicate that agroforestry related soil conservation does benefit the farmer. However, the specific soil conservation benefit calculations do not account for several significant off-site and on-site benefits external to the individual households. Thus, even though net benefits of agroforestry is negative, there may be good reason for society to encourage the farmers to practice agroforestry to conserve the soil and enhance overall societal welfare.

Ribaudo, M.O., Horan, R.D., & Smith, M.E. (1999). Economics of water quality protection from nonpoint sources: Theory and practice. Resource Economics Division, Economic Research Service, U.S. Department of Agriculture. Agricultural Economic Report No. 782.	United States	Economics of instruments used to reduce nonpoint source pollution	Outlines the economic characteristics of five instruments that can be used to reduce agricultural nonpoint source pollution (economic incentives, standards, education, liability and research) and discusses empirical research related to the use of these instruments.
Ribaudo, M.O. (1989). Water quality benefits from the Conservation Reserve Program. U.S. Department of Agriculture. Economic Research Service, AER-606.	United States	Cost-effectiveness of the Conservation Reserve Program	Estimates the water quality benefits from the Conservation Reserve Program. The CRP, may generate an estimated $3.5 billion to $4 billion in water quality benefits.
Ribaudo, M.O., & Hellerstein, D. (1992). Estimating water quality benefits: Theoretical and methodological issues. U.S. Department of Agriculture. Economic Research Service, TB 1808.	NA	Estimating economic values of water quality benefits	Reviews practical approaches and theoretical foundations for estimating the economic value of changes in water quality regarding recreation, navigation, reservoirs, municipal water treatment and use and roadside drainage ditches.
Tomer, M.D., James, D.E., & Isenhart, T.M. (2003). Optimizing the placement of riparian practices in a watershed using terrain analysis. *Journal of Soil and Water Conservation*, 58(4), 198.	Tipton Creek, Iowa	Placement of BMPs	Uses maps to help plan the placement of BMPs in a watershed for water quality benefits. A team of conservation professionals evaluated the planning utility of these maps in the field through consensus-seeking discussion. The methods required only public data and should be applicable to other watersheds.
U.S. General Accounting Office. (1999). Federal Role in Addressing-and Contributing-to Nonpoint Source Pollution. GAO/RCED-99-45.	United States	Federal role in addressing and contributing to nonpoint source pollution	This report provides background information and funding levels for federal programs that address nonpoint source pollution; examines the way in which the Environmental Protection Agency assesses the overall potential costs to reduce nonpoint pollution nationwide and alternative methods for doing so; and describes nonpoint source pollution from federal facilities, lands, and activities.
Uri, N.D. (2000). Perceptions on the use of no-till farming in production agriculture in the United States: An analysis of survey results. *Agriculture, Ecosystems & Environment*, 77(3), 263-266.	United States	Perceptions on the use of no-till farming	Assesses farmers' perception of their actual use of no-till. For some crops, farmers' perceptions are consistent with reality. In the case of corn (*Zea mays* L.), however, nearly 18 percent of corn farmers believe they are using no-till, while in actuality, only slightly more than 12 percent are using this system. In order to properly associate the benefits of no-till with its use, it is important that farmers' perception of what constitutes no-till and their actual use of no-till be consistent.

Watzin, M.C, & McIntosh, A. W. (1999). Aquatic ecosystems in agricultural landscapes: A review of ecological indicators and achievable ecological outcomes. *Journal of Soil and Water Conservation*, 54(4), 636-645.	Various locations	Ecological indicators and ecological outcomes	Discusses (1) the role of natural processes in agricultural watersheds; (2) the use of biological indicators in aquatic systems; (3) assessments of the effects of agriculturally derived pollutants both in-stream and at the landscape scale; (4) achievable ecological outcomes; and (5) recommendations for developing ecological indicators and identifying appropriate restoration goals for agricultural systems.
Wossink, G.A. & Osmond, D.L. (2002). Farm economics to support the design of cost-effective best management practice (BMP) programs to improve water quality: Nitrogen control in the Neuse Basin, North Carolina. *Journal of Soil and Water Conservation,* 57(4), 213.	North Carolina	Cost-effective placement of BMPs	Shows how farm economics information that is widely available can be used to help guide local resource managers and watershed groups in their efforts to design cost-effective programs to improve water quality.
Yang, W., Khanna, M., Farnsworth, R., & Onal, H. (2003). Integrating economic, environmental and GIS modeling to target cost effective land retirement in multiple watersheds. *Ecological Economics*, 46(2), 249-267.	Illinois	Targeting cost-effective land retirement	Presents an integrated framework of economic, environmental and GIS modeling to study cost-effective retirement of cropland within and across multiple watersheds to achieve environmental goals. The costs of abatement with a uniform allocation of abatement responsibility across watersheds and the ensuing pattern of land retirement are compared to those with the least-cost approach.
Yuan, Y., Dabney, S.M., & Bingner, R.L. (2002). Cost effectiveness of agricultural BMPs for sediment reduction in the Mississippi Delta. *Journal of Soil and Water Conservation,* 57(5), 259.	Mississippi	Cost-effectiveness of agricultural BMPs for sediment reduction	Applies the Annualized Agricultural Nonpoint Source pollutant loading model (AnnAGNPS 2.1) to extend results and better evaluate the effectiveness of alternative BMP combinations on sediment reduction.

Conclusion

Estimating the off-site costs of erosion and sedimentation and the benefits from reduced soil erosion is difficult for several reasons. It involves understanding the linkages between soil erosion and its impacts, which are not always clear or well-documented (Waddell, 1985). It also involves assigning an economic value to these impacts. This is challenging because this often requires placing a value on "nonmarket" environmental resources. Nonmarket resources are goods and services that are not traded in markets and have no clear monetary value, such as clear streams or healthy fish habitat. These uses have value, but no prices to help estimate economic benefits. Thus, estimating the costs associated with impacts to these resources can be challenging. In contrast, understanding costs associated with market resources can be fairly straightforward. Market resources are commercially traded goods with clear monetary value. Dredging is considered a market impact because the USACE must spend money to dredge and store sediment. Other market impacts include increased water treatment costs and ditch maintenance costs.

A recent study by the Ohio State University (OSU) in the Maumee River Basin illustrates how cost savings from reduced sediment loads can be estimated for a market resource - dredging. The Maumee River basin is the largest watershed in the Great Lakes basin and contributes the most sediment to the lakes. It is estimated that, on average, the USACE removes 850,000 cubic yards of sediment a year, at an average cost of $2.2 million per year. The OSU study concluded that a program to reduce the sediment load in the basin by 15 percent would result in a savings to the USACE of $1.3 million per year in dredging and confining costs (Sohngen, 2001).

While market benefits can be fairly straightforward to estimate, many of the benefits of reduced sediment load relate to nonmarket goods, such as improved water quality and fish and wildlife habitat. In order to understand the full value of reduced soil erosion and sedimentation, incorporation of both market and nonmarket benefits into economic analyses is needed (Cangelosi, et. al., 2001). There is a lack of research in this area, but economists are expanding the techniques and models available to capture the values that humans place on environmental goods.

In recent years, there has been pressure to expand the scope of estimating costs and benefits in national policymaking, including proposals to require federal regulatory agencies to address costs and benefits of legislation (Cangelosi, et. al., 2001). Furthermore, there also appears to be growing pressure to incorporate nonmarket values in economic analysis and decisionmaking. This trend will likely spur research into new methods and interest in applying economic valuation to policy and decisionmaking which, in turn, will help to determine the economic costs of soil erosion and sedimentation in the Great Lakes basin. In addition, an accurate measurement of the total amount of soil loss in the basin is sorely needed, as is an accurate measurement of sediment delivery ratios and sediment loads to the Great Lakes and a better understanding of how sediment is transported through the basin.

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