2.3 Water Quality Impacts of Agriculture

Agricultural production releases residuals that may degrade the quality of the Nation's water resources and impose costs on water users. The extent and magnitude of this degradation is difficult to assess because of its nonpoint nature. However, agriculture is the leading source of remaining impairments in the Nation's rivers and lakes and a major source of impairments to estuaries.

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Producing food and fiber involves many activities and practices that can affect the quality of water resources under and near the field. For example, tilling the soil and leaving it without plant cover for extended periods of time can accelerate soil erosion. Residues of chemical fertilizers and pesticides may wash off the field into streams or leach through the soil into ground water. Irrigation can move salt and other dissolved minerals to surface water. Livestock operations produce large amounts of waste, which if not properly disposed, can threaten human health as well as contribute to excess nutrient problems in streams, rivers, lakes, and estuaries. When pollutants degrade water quality, they impose costs on water users. These costs are in the form of degraded ecosystems that people wish to remain healthy, reduced recreational opportunities, reduced commercial fishing catches and shellfish bed closings, increased water treatment costs, threats to human health, and damage to reservoirs and water conveyance systems. These costs provide the impetus for policies to reduce water pollution.

Quality of the Nation's Water

The Clean Water Act (33 U.S.C. §§ 1288, 1329, passed in 1972 as the Federal Water Pollution Control Act Amendments) defines water quality in terms of designated beneficial uses with numeric and narrative criteria that support each use. Designated beneficial uses are the desirable uses that water should support, and vary by waterway. Examples are drinking water supply, primary contact recreation, and aquatic life support. Numeric water quality criteria establish the minimum physical, chemical, and biological parameters required for water to support a beneficial use. Physical and chemical criteria may set maximum concentrations of pollutants, acceptable ranges of physical parameters, and minimum concentrations of desirable parameters, such as dissolved oxygen. Biological criteria describe the expected attainable community attributes and establish values based on measures such as species richness, presence or absence of indicator organisms, and distribution of classes of organisms (USEPA, 1998). Narrative water quality criteria define, in general terms, conditions and attainable goals that must be maintained to support a designated use. Narrative biological criteria describe aquatic community characteristics expected to occur within a water body.

The Clean Water Act allows States and tribes to set their own water quality standards but requires that all beneficial uses and their criteria comply with the goals of the Act. At a minimum, beneficial uses must provide for the "protection and propagation of fish, shellfish, and wildlife" and provide for "recreation in and on the water" (fishable and swimmable) (U.S. Congress, PL 92-500, 1972, p. 31). The Act prohibits waste assimilation as a beneficial use. EPA reviews and approves standards every 3 years.

Since passage of the Clean Water Act, surface water quality has improved largely through reductions in toxic and organic chemical loadings from point sources (see chapter 6.4 for a discussion of the Point Source Program). Discharges of toxic pollutants have been reduced by an estimated billion pounds per year (Adler, 1994). Rivers affected by sewage treatment plants show a consistent reduction in ammonia between 1970 and 1992 (Mueller and Helsel, 1996). The percentage of the U.S. population served by wastewater treatment plants increased from 42 percent in 1970 to 74 percent in 1998 (USEPA-USDA, 1998). A widely scattered surface-water-monitoring network has shown national reductions in fecal bacterial and phosphorus concentrations (Knopman and Smith, 1993; Smith, Alexander, and Lanfear, 1993; Lettenmaier, Hooper, Wagoner, and Faris, 1991; Mueller and Helsel, 1996; Litke, 1999). Case studies, opinion surveys, and anecdotal information suggest that these reductions in pollutants have improved the health of aquatic ecosystems in many basins, particularly near urban areas (Knopman and Smith, 1993).

However, challenges to water quality improvement remain. Some of these are due to continuing discharges of pollutants from point sources. A growing share of remaining problems is due to nonpoint source pollution, which is pollution associated with runoff from urban and agricultural lands (USEPA, 2000). Nonpoint source pollution is not regulated under the Clean Water Act and is left largely to voluntary controls implemented by States. As point source pollution is brought under control, pollution from agriculture and other nonpoint sources assumes a greater significance. For example, in the 1980's the largest human sources of phosphorus to the environment were fertilizer application (1.8 million metric tons), manure application (1.8 million metric tons), other nonpoint sources (1.1 million metric tons), and wastewater-treatment plant discharges (260,000 metric tons) (Litke, 1999). While the decline in point source loadings of phosphorus is having a detectable effect on water quality, only a small proportion of stream sites have a large enough point-source component for water quality improvements to be appreciable (Litke, 1999).

While farmers do not intend for pollutants such as sediment, nutrients, and pesticides to move from the field or enterprise, they often do. For example, as much as 15 percent of the nitrogen fertilizer and up to 3 percent of pesticides applied to cropland in the Mississippi River Basin make their way to the Gulf of Mexico (Goolsby and Battaglin, 1993).

A number of national assessments give some indication of the nature and magnitude of water quality impairments. The Water Quality Inventory is prepared with information contained in semi-annual reports from the States, required by the Clean Water Act, on the status of their surface-water resources (known as Section 305(b) reports). Of the waters surveyed in 1996, 36 percent of river miles, 39 percent of lake acres (excluding the Great Lakes), and 38 percent of estuary square miles were unable to fully support the uses for which they were designated by States under the Clean Water Act (table 2.3.1) (USEPA, 1998). The leading cause of impairments in rivers is siltation and nutrients. For lakes and estuaries, nutrients are the leading pollutants. Agriculture is identified as the single largest source of impairments for rivers and lakes.

Another source of information is the 1998 Section 303(d) list of impaired waters, submitted to the Environmental Protection Agency (EPA) by States, tribes, and territories. These are waters that do not support water quality standards, and cannot meet those standards through point source controls alone. For the 1998 listing cycle, 21,845 waters with 41,318 associated impairments were listed, covering over 300,000 miles of rivers and streams and more than 5 million acres of lakes (USEPA, 2000). Over 218 million people live within 10 miles of a polluted waterbody (figure 2.3.1). The top three categories of impairment identified in the 303(d) lists are sediments (6133 waters), pathogens (5281 waters), and nutrients (4773 waters). Pesticides ranked tenth, affecting 1432 waters. Reductions in nonpoint source loadings will be required for these waters to achieve water quality standards.

The National Oceanographic and Atmospheric Administration conducted the National Estuarine Eutrophication Survey from 1992 to 1997 to assess the quality of the 138 major estuaries in the U.S. The survey found that 44 estuaries (40 percent) exhibited high expressions of eutrophic conditions, caused by nutrient enrichment (Bricker et al., 1999). These conditions occurred in estuaries along all coasts, but are most prevalent in estuaries along the Gulf of Mexico and Middle Atlantic coasts. Human influences (point and nonpoint source nutrient pollution) are associated with 36 of the 44 estuaries.

Another problem becoming common to estuaries and coastal water is harmful algal blooms (HAB's). The nature of HAB's in estuaries and coastal waters has changed over the past two decades (Boesch et al., 1997). The number of blooms, the economic losses from them, the types of resources affected, and the number of toxins and toxic species have increased dramatically (Boesch et al., 1997). HAB's describe a diverse array of blooms of both microscopic and macroscopic marine algae that produce: toxic effects on humans and other organisms; physical impairment of fish and shellfish; nuisance conditions from odors and discoloration of waters; or severe oxygen depletion of bottom habitats. The reasons for this increase are not entirely clear, but nutrients from human activities that are enriching coastal waters are believed to play an important role.

Many States report on the general quality of their groundwater resources in their section 305(b) reports, although this is optional. Of 38 States that reported overall groundwater quality in 1992, 29 judged their groundwater quality to be good or excellent (USEPA, 1994). Generally, States report that contamination of groundwater is localized. In 1994, 45 States reported that pesticide and fertilizer applications were sources of groundwater contamination (USEPA, 1995). However, out of 37 States reporting sources of contamination in 1996, only 18 reported pesticides as a source, and only 17 fertilizer (USEPA, 1998). This difference raises questions about the usefulness of 305(b) reports for information on ground water quality. An important difference between ground water and surface water is that once polluted, ground water remains contaminated for a much longer period of time. This makes pollution of ground water a more serious problem when the resource is utilized for economic purposes, such as drinking water.

The most comprehensive assessment of ground water quality is EPA's National Survey of Pesticides in Drinking Water Wells, conducted over 1988-90. EPA found nitrate in more than half of the 94,600 community water system wells (CWS) and almost 60 percent of the 10.5 million rural domestic drinking water wells, making nitrate the most frequently detected chemical in well water (USEPA, 1992a). The survey also found that 10 percent of the CWSs and 4 percent of rural domestic wells contained at least one pesticide (1992a).

An evaluation of data from over 300 studies of pesticide occurrence in ground water found that pesticides or their transformation products have been detected in ground waters of more than 43 States (Barbash and Resek, 1996). At least 143 different pesticides have been detected.

Agriculture’s Share and Implications for Policy

National-scale water quality assessments strongly suggest that agriculture is a leading source of remaining water quality problems. Additional studies have taken a closer look at the sources of water quality impairments and shed some light on agriculture’s role.

The U.S. Geological Survey’s (USGS) National Water Quality Assessment (NAWQA) Program was started in 1991 to assess the quality of the Nation’s water quality, to study how water quality changes with time, and to study how human activities and natural factors affect water quality (Gilliom, Alley, and Gurtz, 1995). This program is scheduled to continue for many years, and should provide valuable information on the linkages between land use and water quality in most parts of the U.S. Monitoring in 20 NAWQA projects, representing large river basins has found that streams in basins with significant agricultural or urban development, or with a mix of these land uses, almost always contain mixtures of nutrients and pesticides originating from human activities (USGS, 1999). About 57 percent of sampled streams were enriched with phosphorus, and 61 percent were enriched with nitrogen. In some cases, concentrations were high enough to be of concern for human or ecosystem health. High concentrations of nitrogen in agricultural streams were correlated with nitrogen inputs from fertilizers and manure used for crops and from livestock wastes (USGS, 1999). Pesticides were found to be widespread in streams. More than 90-percent of water and fish tissue samples from all streams sampled contained one, or more often, several pesticides. Pesticides found in water were primarily those that are currently used, while those found in sediment and tissue were primarily organochlorine insecticides, such as DDT, that were heavily used years ago but that have been banned since the 1970's and 1980's.

A USGS study of agricultural land in watersheds with poor water quality estimated that 71 percent of U.S. cropland (nearly 300 million acres) is located in watersheds where the concentration of at least one of four common surface-water contaminants (dissolved nitrate, total phosphorus, fecal coliform bacteria, and suspended sediment) exceeds criteria for supporting water-based recreation (Smith, Schwarz, and Alexander, 1994). While not conclusive evidence that agriculture is the cause of the water quality problems, it is suggestive that agriculture is an important source of pollution in many areas.

Nutrient concentrations in the Mississippi River have increased dramatically in this century (Goolsby and Battaglin 1995). There are a number of sources of nitrogen in the Mississippi basin, including municipal and industrial point sources, commercial fertilizer and animal manure used on cropland, septic systems, and atmospheric deposition. Agricultural sources (fertilizer, soil inorganic N pool, and manure) are estimated to contribute about 65 percent of the nitrogen loads entering the Gulf from the Mississippi Basin (Goolsby et al., 1999). (See box “Hypoxia in the Gulf of Mexico").

Groundwater monitoring in 20 NAWQA study units found that high concentrations of nitrate in shallow groundwater were widespread and strongly related to agricultural land use (USGS, 1999). In the four shallow aquifers that were monitored, nitrate concentrations exceeded the MCL in more than 15 percent of samples. All four aquifers are in agricultural areas overlain by sand or gravel. On the other hand, nitrate was detected much less frequently in deeper aquifers.

A 1991 USGS study of nitrate in near-surface aquifers in the mid-continental U.S. detected nitrate in 59 percent of the samples taken (Kolpin, Burkart, and Thurman, 1994). Concentrations greater than the MCL were found in 6 percent of the samples. Statistical analyses indicated that the frequency of samples having concentrations greater than 3 mg/l (believed to be the maximum level from natural sources) was positively related to the proximity of agricultural land, to the use of irrigation, and to fertilizer application rates.

A study of the presence in groundwater of 7 important herbicides (atrazine, cyanazine, simazine, alachlor, metolachlor, prometon, and acetochlor) using data collected by NAWQA and the USGS Midwest Pesticide Study sought to find statistical correlations between land use and herbicide use detections (Barbash, Thelin, Kolpin, and Gillion, 1999). All herbicides but acetochlor were widely found in both agricultural and non-agricultural settings. More than 98 percent of detections were at concentrations less than 1 part per billion, well below drinking water standards. In agricultural settings, frequencies of detection in shallow ground water were generally higher in areas of more intensive use. Limits on current information regarding the spatial distribution of pesticide use may have contributed to a relatively poor geographic correspondence between detections and use.

Agricultural Pollutants and Their Economic Impacts

Agriculture is an important source of sediment, nutrients, pesticides, salts, and pathogens. The presence of these materials in water resources can impose costs on water users. Some estimates of the cost to water uses have been made, but overall, an accounting of the economic damages caused by poor water quality is lacking, due to a lack of physical monitoring and the difficulties in estimating economic costs and benefits for environmental goods and services.

Sediment Damage

Disturbing the soil through tillage and cultivation and leaving it without vegetative cover may increase the rate of soil erosion. Dislocated soil particles can be carried in runoff water and eventually reach surface water resources, including streams, rivers, lakes, reservoirs, and wetlands. Sediment is the largest contaminant of surface water by weight and volume (Koltun et al. 1997), and is identified by States as the leading pollution problem in rivers and streams (USEPA, 1998)

Sediment causes various damage to water resources and to water users. Accelerated reservoir siltation reduces the useful life of reservoirs. Sediment can clog roadside ditches and irrigation canals, block navigation channels, and increase dredging costs. By raising streambeds and burying streamside wetlands, sediment increases the probability and severity of floods. Suspended sediment can increase the cost of water treatment for municipal and industrial water uses. Sediment can also destroy or degrade aquatic wildlife habitat, reducing diversity and damaging commercial and recreational fisheries. Many toxic materials can be bound to silt and clay particles that are carried into water bodies, including nutrients, pesticides, industrial wastes, and metals (Osterkamp, Heilman, and Lane, 1998). When sediment is stored, the sorbed pollutants are also stored and become available for assimilation. Regions where large amounts of sediment from cropland reach streams include the Corn Belt and Delta farm production regions (figure 2.3.2).

Annual costs to the water treatment industry from sediment were estimated to be between $458 and $661 million in 1984 (Holmes, 1988). Reservoir sedimentation is one of the consequences of soil erosion. Survey data collected by USDA and USDI indicated that in the 1970s and early 1980s sedimentation eliminated slightly more than 0.2% of the Nation's reservoir capacity each year (Crowder, 1987). Annual economic costs, based on replacing lost capacity, were estimated to be $819 million per year (Crowder, 1987). Sedimentation in navigation channels increases the costs to shipping by increasing transit time and decreasing the amount of cargo that can be carried. The Army Corps of Engineers incurred dredging costs of over $500 million per year for maintaining navigation channels over the period 1992-1998 (Davison, 2000). Sediment damages from agricultural erosion have been estimated 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.

Trends in erosion losses and instream sediment concentration seem to show improvements in recent years. The National Resources Inventory reports that the average rate of sheet and rill erosion on cropland declined by about 38 percent between 1982 and 1997 (USDA, NRCS, 2000). In most regions, the USGS found that suspended sediment concentrations trended slightly downward over the 1980's, particularly in the Ohio-Tennessee, and Upper and Lower Mississippi regions (table 2.3.2) (Smith, Alexander, and Lanfear, 1993). Areas characterized by corn and soybean production and mixed crops had the greatest downward trends. Soil conservation efforts over the past 10 years, particularly the Conservation Reserve Program and Conservation Compliance, likely played a role (USDA, ERS, 1997). Feather and Hellerstein (1997) looked at erosion reductions on private lands in the U.S. over the period 1982 to 1992, and estimated benefits to water-based recreation of $373 million, including fishing, boating, and swimming. They also found that almost 88 percent of the benefits accrued to recreation on lakes. Ribaudo (1989) estimated that the Conservation Reserve Program could result in $21.4 million per year in benefits to freshwater recreational fishing from reduced sedimentation.

Nutrient Damage

Nutrients, chiefly nitrogen, potassium, and phosphorus, promote plant growth. About 11 million tons of nitrogen, 5 million tons of potash (the primary chemical form of potassium fertilizer), and 4 million tons of phosphate (the primary chemical form of phosphorus fertilizer) are applied each year to U.S. cropland (USDA, ERS, 1997). An unknown amount is also deposited through atmospheric fallout. Nutrients can enter water resources three ways. *Runoff* transports pollutants over the soil surface by rainwater, melting snow, or irrigation water that does not soak into the soil. Nutrients move from fields to surface water while dissolved in runoff water or adsorbed to eroded soil particles. *Run-in* transports chemicals directly to groundwater through sinkholes, porous or fractured bedrock, or poorly constructed wells. *Leaching* is the movement of pollutants through the soil by percolating rain, melting snow, or irrigation water.

Nitrogen and phosphorus can cause quality problems when they enter water systems. Nitrogen, in the form of nitrate, is easily soluble and is transported in runoff, in tile drainage, and with leachate. Phosphate is only moderately soluble, and relative to nitrate, is not very mobile in soils. Erosion can transport considerable amounts of sediment-adsorbed phosphate to surface waters. If soils have been over-fertilized they become saturated with phosphorus, and rates of dissolved phosphorus losses in runoff will increase.

Nitrogen and phosphorus from agriculture accelerate algal production in receiving surface water, resulting in a variety of problems including clogged pipelines, fish kills, and reduced recreational opportunities (USEPA, 1998). Increased biological activity can also result in lowered oxygen levels, leading to anoxic or hypoxic zones that cannot support life. Nitrogen is primarily a problem in brackish or salt water, while phosphorus is primarily a problem in freshwater (USGS, 1999).

Besides harming aquatic ecosystems, nitrate is also a potential human health threat. The EPA has established a maximum contaminant level (MCL, a legal maximum exposure) in drinking water of 10 mg/l. Nitrate can be converted to nitrite in the gastrointestinal tract. In infants, nitrite may cause methemoglobinemia, otherwise known as "blue-baby syndrome," which prevents the transport of sufficient oxygen in the bloodstream. Public water systems that violate the MCL must use additional treatment to bring the water they provide into compliance, though exemptions are specified (42 U.S.C. §300g). Data from the Safe Drinking Water Information System indicates that 188 systems, serving 748 thousand people, reported violations of the nitrate MCL in 1998 (USEPA, 1999). This is down from 234 systems in violation in 1995 and 241 in violation in 1990.

Exposure to nitrate in drinking water is chiefly a concern to those whose source water is groundwater, which generally has higher nitrate concentrations than surface water (Mueller and others, 1995). From its 1988-90 national survey of drinking water wells, the EPA found nitrate in more than half of the 94,600 community water system wells (CWS) and almost 60 percent of the 10.5 million rural domestic drinking water wells, making nitrate the most frequently detected chemical in well water (USEPA, 1992a). However, only 1.2 percent of the CWSs and 2.4 percent of the rural domestic wells were estimated to contain levels above the MCL. About 3 million people (including 43,500 infants) using water from CWSs and about 1.5 million people (including 22,500 infants) using rural wells were exposed to nitrate at levels above the MCL (USEPA, 1992a).

In a study of well water samples in 18 NAWQA study units, USGS found that the MCL was exceeded in about 1 percent of CWSs and 9 percent of rural domestic wells (Mueller and others, 1995). About 16 percent of domestic wells under agricultural land exceeded the MCL in selected watersheds, with particularly high proportions exceeding the MCL in the Northern Plains (35 percent) and the Pacific (27 percent) regions.

Data developed by the USDA were used to identify regions most vulnerable to nitrogen and phosphorus problems (figures 2.3.3, 2.3.4, 2.3.5). The Corn Belt has a high potential for nitrate contamination of both groundwater and surface water from commercially applied fertilizer, and for phosphorus contamination of surface water from commercially applied fertilizer. Surface water and groundwater in the Delta States are at risk from nitrogen contamination from commercially applied fertilizer. Watersheds in the Southeast appear to be vulnerable to runoff of both nitrogen and phosphorus fertilizer. Watersheds in the Lake States and Northern Plains are also at risk from phosphorus runoff of commercially applied fertilizer.

Nitrogen and phosphorus from animal waste is an important source of total nutrient loads in some parts of the country. A USGS study of nitrogen loadings in 16 watersheds found that manure was the largest source in 6, primarily in the Southeast and Mid-Atlantic States (Puckett, 1994). Nitrogen and phosphorus (and other contaminants) from manure are an increasing concern given the recent trend towards larger, more specialized beef, dairy, swine, and poultry operations (see box "Concentration in Animal Feeding"). Approximately 213,000 operations nationwide confine or concentrate animals (Gollehon and Caswell, 2000). Of these, about 11,200 can be defined under the Clean Water Act as Concentrated Animal Feeding Operations, or CAFOs. Such operations must handle large amounts of animal waste, and can be the source of water quality problems at several stages of handling. First, CAFOs require large and sophisticated manure handling and storage systems for collecting and storing waste prior to disposal, which have at times failed with serious local consequences.

Second, CAFOs tend to lack sufficient cropland on which manure can be spread without exceeding crops' nutrient needs (Gollehon and Caswell, 2000). The greatest threats to water quality degradation from manure that is applied to land are shown in figures 2.3.6 and 2.3.7. Parts of the Appalachian, Delta, Southeast and Pacific States are at risk from water quality degradation from both nitrogen and phosphorus in manure. Watersheds potentially vulnerable to phosphorus in manure are more widespread, additionally located in parts of the Northeast, Lake States, Corn Belt, Southern Plains, and Northern Plains.

Data from USGS on nutrients in surface waters over the 1980's show different trends for nitrate and phosphorus (Smith, Alexander, and Lanfear, 1993). Nitrate, in general, showed no statistically significant trend, which differs from the rise noted during 1974-81 (Smith, Alexander, and Wolman, 1987). This follows the pattern of agricultural nitrogen use, which rose sharply during the 1970's, peaked in 1981, and then stabilized. Phosphorus in water during the 1980's continued a decline noted in the 1970's, likely due to improved wastewater treatment, decreased phosphorus content of detergents, reduced phosphorus fertilizer use, and reduced soil erosion. The rate of phosphorus decline in water in cropland areas was more than twice that in urban areas (Smith, Alexander, and Lanfear, 1993).

There are very few estimates of the damages caused by nutrients in water resources. Since the impacts on quality are felt through complex biological relationships, it has been difficult to determine nutrients' effects. There are some economic estimates related to drinking water that give an indication of the damages from nitrate contamination of drinking water sources. The EPA (1997a) estimated that a total investment of $200 million is needed for additional drinking water treatment facilities to meet Federal nitrate standards. Crutchfield, Cooper, and Hellerstein (1997) estimated total consumer willingness to pay for reduced nitrate in drinking water in four watersheds of the United States to be about $314 million per year (White River, IN, Central Nebraska, Lower Susquehanna, Mid-Columbia Basin). The benefits of nitrate-free drinking water were estimated to be $351 million.

Pesticide Damage

A wide variety of pesticides are applied to agricultural crops to control insect pests, fungus, and disease. Well over 500 million pounds (active ingredient) of pesticides are applied annually on farmland, and certain chemicals can travel far from where they are applied (Smith, Alexander, and Lanfear, 1993; Goolsby and others, 1993). Pesticides move to water resources much as nutrients do, in runoff, run-in, and leachate. In addition, pesticides can be carried into the air attached to soil particles or as an aerosol, and deposited into water bodies with rainfall. The route a pesticide takes to a water body depends on its physical properties and the properties of the soil.

Pesticide residues reaching surface-water systems may harm freshwater and marine organisms, damaging recreational and commercial fisheries (Pait, DeSouza, and Farrow, 1992).

Pesticides in drinking water supplies may also pose risks to human health. Some commonly used pesticides are probable or possible human carcinogens (Engler, 1993). Regulation requires additional treatment by public water systems when certain pesticides exceed health-safety levels in drinking water supplies, though exemptions are specified (42 U.S.C. §300).

Pesticides are commonly detected in water quality studies, though usually at low levels. USGS detected at least one pesticide in every one of the 58 rivers and streams sampled in 20 NAWQA regions, representing both agricultural and urban basins (Larson, Gilliom, and Capel, 1999). The herbicides atrazine, metolachlor, prometon, and simazine, and the pesticides carbaryl, chlorpyrifos, and diazinon, were detected most frequently. Concentrations of pesticides rarely exceeded the standards and criteria for drinking water, but some frequently exceeded criteria established to protect aquatic life (Larson, Gilliom, and Capel, 1999). Herbicides generally were detected more frequently than insecticides, particularly in streams draining agricultural basins. Herbicide concentrations were higher than insecticide concentrations at most agricultural sites. In areas where a large variety of crops are grown, especially vegetables and fruits, insecticide concentrations were often higher than herbicide concentrations.

Pesticides in water supplies have been scrutinized in the Midwest, where large amounts of pesticides are used. Goolsby and others (1993) found that herbicides are detected throughout the year in the rivers of the Midwest, including the Mississippi River. Concentrations are highest during the spring when most pesticides are applied and when spring rains occur. The amounts transported by streams and rivers in the Midwest are generally less than 3 percent of the amount applied, but can still result in concentrations above the MCL. Atrazine (and its metabolites), alachlor, cyanazine, and metolachlor, used principally for weed control in corn and soybeans, were the principal contaminants detected, and are also the most widely used pesticides in the region. Such chemicals, once in drinking water supplies, are not removed by conventional treatment technologies (Miltner and others, 1989).

Pesticides may pose a special problem for reservoirs. Results from a study of herbicides in 76 midwestern reservoirs showed that some herbicides are detected more frequently throughout the year in reservoirs than in streams, and except for the spring, at higher concentrations (Goolsby and others, 1993). Many of these reservoirs receive much of their storage during the spring and early summer rains, when runoff from cropland contains high concentrations of herbicides. Because the half-lives of many herbicides are longer in the water than in the soil, relatively high concentrations can persist in reservoirs long after the materials have been applied.

The EPA's survey of drinking water wells found that 10 percent of the CWSs and 4 percent of rural domestic wells contained at least one pesticide (1992a). However, the EPA estimated that less than 1 percent of the CWSs and rural domestic wells had concentrations above MCLs or Lifetime Health Advisory Levels (the maximum concentration of a water contaminant that may be consumed safely over an average lifetime). In a 1991 study of herbicides and some of their metabolites in near-surface aquifers in the midcontinental United States, USGS detected at least one herbicide in 28.7 percent of the wells sampled (Kolpin, Burkart, and Thurman, 1994). Similar to EPA's findings, no herbicides were found at concentrations greater than the MCL or Lifetime Health Advisory Level. Atrazine and its metabolite desethylatrazine were the most frequently detected compounds. A USGS study of seven herbicides in groundwater in 20 NAWQA study units found at least one herbicide in 37 percent of all sites sampled, with atrazine and one of its degradates again being the most frequently detected (Barbash, Thelin, Kolpin, and Gilliom, 1999). Most detections were at very low concentrations, with only 2 percent exceeding 1 part per billion. Frequency of detection and concentrations were higher in shallow groundwater than in deeper aquifers. Drinking-water standards were exceeded only for atrazine, and only at two of the 2,227 sites sampled. Both of these sites were shallow aquifers.

Ground- and surface-water vulnerability to pesticides varies geographically, depending on soil characteristics, pesticide application rates, and the persistence and toxicity of the pesticides used (figs. 2.3.8, 2.3.9). Areas with sandy, highly leachable soils and high application rates of toxic or persistent pesticides generally have high vulnerability ratings for pesticide leaching. These include parts of the Southeast, Corn Belt, Southern Plains, and California. Areas with heavy soils and high application rates of toxic or persistent pesticides generally have higher vulnerability ratings for pesticide runoff. These include almost all of the Corn Belt, parts of the Lake States, Southeast, and Southern Plains.

The cost to water suppliers of providing drinking water that meets Safe Drinking Water Act standards can increase substantially when pesticides are present in the water source. For example, the cost to 11 small water suppliers in the Midwest to install additional water treatment to remove the herbicide atrazine from drinking water was estimated to be $8.3 million in capital costs, and $180,000 per year in operating costs (Langemeier, 1992). EPA (1997a) estimates that total costs for additional treatment facilities needed to meet current regulations for pesticides and other specific chemicals would be about $400 million, with about another $100 million required over the next 20 years.

Mineral Damage

When irrigation water is applied to cropland, a portion of it runs off the field into ditches and flows back to a receiving body of water. These irrigation return flows may carry dissolved salts, as well as nutrients and pesticides, into surface- or groundwater. Increased concentrations of naturally occurring toxic minerals, such as selenium and boron, can harm aquatic wildlife and degrade recreational opportunities. Increased levels of dissolved solids in public drinking water can increase water treatment costs, force the development of alternative water supplies, and reduce the life spans of water-using household appliances. Increased salinity levels in irrigation water can reduce crop yields or damage soils so that some crops can no longer be grown.

Dissolved salts and other minerals are an important cause of pollution in the Southern Plains, and arid portions of the Pacific and Mountain regions. The mineral selenium is of particular concern because of its adverse biological effects. Selenium in irrigation return flows was identified as the cause of incidents of mortality, congenital deformities, and reproductive failures in aquatic birds in Kesterson Reservoir in western San Joaquin Valley, California (Seiler, Skorupa, and Peltz, 1999). A Department of Interior study of the possible extent of irrigation-induced selenium contamination in 26 areas of the western United States found that 4,100 square miles of land irrigated for agriculture is susceptible to selenium contamination, along with adjacent land that may receive return flows. Affected areas are primarily located in California, western Kansas, eastern Colorado, and western South Dakota.

Total damages from salinity in the Colorado River range from $310 million to $831 million annually, based on the 1976-85 average levels of river salinity. These include damages to agriculture ($113 - $122 million), households ($156 - $638 million), utilities ($32 million), and industry ($6 - $15 million) (Lohman, Milliken, and Dorn, 1988).

The USGS reports mixed trends of salinity in surface water over the 1980's (Smith, Alexander, and Lanfear, 1993). Measures of dissolved solids (mostly ions of calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride) indicate that water quality improved at more stations than it worsened. Salinity trends in water for domestic and industrial purposes generally improved during the 1980's, though salinity worsened for irrigation purposes. Among USGS cataloguing units (watersheds) with significant irrigation surface-water withdrawals, the share with annual average dissolved solids concentrations greater than 500 mg/L increased during 1980-89 from 30 percent in 1980 to 33 percent in 1989 (Smith, Alexander, and Lanfear, 1993).

Pathogen Damage

The possibility of pathogen-contaminated water supplies is attracting increased attention (NRAES, 1996; Olson, 1995). Bacteria are the third leading source of impairment of rivers and the second leading cause in estuaries (USEPA, 1998). Potential sources include inadequately treated human waste, wildlife, and animal operations. Animal waste contains pathogens that pose threats to human health (CAST, 1996). Microorganisms in livestock waste can cause several diseases through direct contact with contaminated water, consumption of contaminated drinking water, or consumption of contaminated shellfish. Bacterial, rickettsial, viral, fungal, and parasitic diseases are potentially transmissible from livestock to humans (CAST, 1996). Fortunately, proper animal management practices and water treatment minimize the risk to human health posed by most of these pathogens. However, protozoan parasites, especially *Cryptosporidium* and *Giardia,* are important agents of water-borne disease outbreaks (CDC, 1996). *Cryptosporidium* and *Giardia* may cause gastrointestinal illness, and *Cryptosporidium* may lead to death in persons with weak immune systems. These parasites have been commonly found in beef herds, and *Cryptosporidium* is estimated to be prevalent on dairy operations (USDA, APHIS, 1994; Juranek, 1995).

Outbreaks of waterborne diseases are a growing concern. The EPA (1997a) estimates the cost of facilities for improved microbial treatment to be about $20 billion over the next 20 years, with about half of that needed immediately. The health cost of *Giardia* alone is estimated to be between $1.2-$1.5 billion per year (USEPA, 1997b). *Cryptosporidium* is a more recently identified threat, with oocysts present in 65-97 percent of surface water sampled in the United States (CDC, 1996). The organism has been implicated in gastroenteritis outbreaks in Milwaukee, Wisconsin (400,000 cases and 100 deaths in 1993) and in Carrollton, Georgia (13,000 cases in 1987). The cost of the Milwaukee outbreak is estimated to have exceeded $54 million (*Health and Environment Digest*, 1994). While the source of the organism in these outbreaks was never determined, its occurrence in livestock herds has brought some attention to this sector, especially given the proximity of cattle and slaughterhouses to Milwaukee (MacKenzie and others, 1994).

Reducing Loadings from Agriculture

Farmers can take many steps to reduce loadings of agricultural pollutants to water resources. Both structural and management practices are available for managing water and chemical inputs more efficiently, or by controlling runoff. Practices include integrated pest management, comprehensive nutrient management planning, irrigation water management, animal waste management, conservation tillage, and vegetative buffers (for more on practices, see Section 4, Agricultural Production Management).

USDA has several programs that provide farmers the incentives and the means to adopt water quality practices, including the Environmental Quality Incentive Program, Conservation Technical Assistance, Wetland Reserve Program, and Conservation Reserve Program. Most current programs focus on providing education, technical, and financial assistance to farmers to get them to adopt alternative management systems that protect water quality. Education raises farmer awareness not only of the potential financial and environmental benefits of alternative practices, but also of the link between the practices they implement and local water quality. Technical and financial assistance provides information to a farmer so that he or she has the skills to apply a new practice effectively. If voluntary incentives are inadequate to achieve needed changes in farming practices, then regulatory approaches such as standards may be applied, as is being done in some States (see Chapter 6.4 “Water Quality Programs” for more on Federal and State programs).

Improvements in water quality from farmers' efforts to reduce pollutant loadings often take years to detect and document. The links between improved management and observed changes in water quality are complex. As many as 10 consecutive years of water quality data are needed before long-term changes can be distinguished from short-term fluctuations (Smith, Alexander, and Lanfear, 1993). For example, phosphorus accumulated in bottom sediments will affect water quality long after conservation practices have dramatically reduced phosphorus loadings in runoff. Similarly, fish and insects and other biological indicators of a healthy stream may only reach acceptable levels many years after water quality improves and riparian habitat is restored. Aquifers may take decades to show improvements in quality after chemical management is improved. This has implications for the design of monitoring necessary to assess the effectiveness of water quality policies and programs.

Value of Cleaner Water

The economic value of changes in water quality is an important component of economic assessment of policies to reduce pollution from agricultural production. Benefits and costs of water quality changes are measured in terms of changes in economic welfare, represented by consumer and producer surpluses. Estimating the economic effects of changes in water quality is complicated by the lack of organized markets for environmental quality. There are no observed prices with which to measure economic value. A number of methods exist for deriving these measures (Ribaudo and Hellerstein, 1992). One method for estimating consumer surplus is to study an individual's behavior in averting the consequences of poor environmental quality, such as expenditures made to prevent household damages from salinity. A second approach is to exploit the relationship between private goods and environmental quality (when it exists) to draw inferences about the demand for environmental quality. For example, people spend money and time traveling to a recreational lake. Data on costs of travel, frequency of visits over time, and changes in water quality over time can be used to estimate the demand for quality. A third approach is to use surveys to get individuals to reveal directly or indirectly their willingness to pay for changes in environmental quality.

When water quality is a factor in the production of a market good, the benefits of changes in quality can be inferred from changes in variables associated with the production of the good. There are two avenues through which benefits can be obtained. If the improvement in water quality reduces production costs in enough firms to reduce the market price of a good to consumers, then benefits are equal to the sum of changes to producer and consumer surpluses, which are estimated with data on demand and costs of production. An example could be a reduction in the price of vegetables because of lower salinity in irrigation water. If an improvement in water quality reduces production costs of a small number of firms without changing prices to consumers, then benefits are equal to the change in producer net return. An example could be a reduction in water filtration costs for a drinking water plant, where the price of the treated water is held constant by the utility.

Economists have conducted numerous studies of the value of water quality over the years. Most of these studies have focused on specific sites or "local" water quality issues (Crutchfield, Feather, and Hellerstein, 1995). Relatively few studies have looked at the costs of water pollution and the benefits of pollution reduction on a nationwide scale, and none have included costs to all classes of water users (table 2.3.3). However, the results of these studies indicate that the annual benefits from improving water quality could total tens of billions of dollars. Water quality benefits from erosion control on cropland alone could total over $4 billion per year (Hrubovcak, LeBlanc, and Eakin, 1995).

Federal expenditures to address nonpoint source pollution have grown substantially in recent years, reflecting its greater importance. Between 1994 and 1998, seven agencies obligated nearly $14 billion on 35 programs addressing nonpoint source pollution, averaging about $3 billion per year (USGAO, 1999). An increasing amount of financial and other resources are being directed to agricultural nonpoint source pollution. USDA spent $286 million on water quality research, education, technical assistance, financial assistance, and data activities in 1999. In addition, programs such as the Conservation Reserve Program and Wetland Reserve Program, while not specifically water quality protection programs, provide water quality benefits as well. Farmers themselves have spent a large amount on water quality practices. For example, over 50 percent of large swine operations changed their manure management systems due to concerns or regulations about environmental quality during the period 1990-1995 (USDA, APHIS, 1996). In addition, over 1992-1998 EPA awarded over $191 million in regional grants to States for agricultural nonpoint source programs (personal communication with Stuart Tuller, USEPA, 1999). These funds frequently are contracted to cooperating agencies such as local conservation districts to support project implementation. (For more information on water quality programs, see Chapter 6.4).

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Table 2.3.1 - Status of the Nation' s surface-water quality, 1990-96

	Rivers				Lakes[1]				Estuaries			
Item	1990	1992	1994	1996	1990	1992	1994	1996	1990	1992	1994	1996
					Percent of total water*							
Water systems assessed	36	18	17	19	47	46	42	40	75	74	78	72
					Percent of assessed waters							
Meeting designated uses[2]:												
Supporting	69	62	64	64	60	56	63	61	67	68	63	62
Partially supporting	21	25	22	36[3]	19	35	28	39[3]	25	23	27	38[3]
Not supporting	10	13	14		21	9	9		8	9	9	
Clean Water Act goals: Fishable												
Meeting	80	66	69	68	70	69	69	69	77	78	70	69
Not meeting	19	34	31	31	30	31	31	31	23	22	30	30
Not attainable	1	-	-	-	0	-	-	-	-	0	0	0
Clean Water Act goals: Swimmable												
Meeting	75	71	77	79	82	77	81	75	88	83	85	84
Not meeting	15	20	23	20	18	22	19	25	12	17	15	16
Not attainable	10	9	-	-	-	-	-	-	-	0	-	-

- = less than 1 percent of assessed waters.

[1] Excluding Great Lakes.

[2] Supporting - water quality meets designated use criteria; partially supporting - water quality fails to meet designated use criteria at times; not supporting - water quality frequently fails to meet designated use criteria.

[3] In 1996, the categories "Partially supporting" and "Not supporting" were combined.

Source: USDA, ERS, based on Environmental Protection Agency National Water Quality Inventories (1992b, 1994b, 1995, 1998).

*Miles of rivers, acres of lakes, square miles of estuaries.

Table 2.3.2 - Trends in concentrations of agricultural water pollutants in U.S. surface waters, 1980-90

Water resources region	Nitrate	Total phosphorus	Suspended sediment
	Average percentage change per year		
North Atlantic	*	-1.4	-0.4
South Atlantic-Gulf	*	0.1	0.2
Great Lakes	*	-3.3	0.5
Ohio-Tennessee	* -1.0	-1.3	
Upper Mississippi	-0.4	-1.2	-1.3
Lower Mississippi	-1.6	-3.8	-1.2
Souris-Red-Rainy	* -0.8	1.2	
Missouri	* -1.7	-0.2	
Arkansas-White-Red	*	-3.1	-0.7
Texas-Gulf-Rio Grande	* -0.9	-0.6	
Colorado	*	-2.4	-0.8
Great Basin	*	-2.7	-0.2
Pacific Northwest	* -1.7	-0.1	
California	*	-1.4	-0.6

* Between -0.1 and 0.1.
Source: Smith, Alexander, and Lanfear, 1993.

Table 2.3.3 - National estimates of the damages from water pollution or benefits of water pollution control

Estimate of:	Study/year	Description:
Selected estimates of damages		
Water quality damages from soil erosion	Clark and others (1985)	Damages to all uses: $3.2-$13 billion, “best guess” of $6.1 billion (1980 dollars). Cropland’s share of damages: $2.2 billion.
Water quality damages from soil erosion	Ribaudo (1989)	Damages to all uses: $5.1-$17.6 billion, “best guess” of $8.8 billion. Agriculture’s share of damages: $2-$8 billion.
Adjustments to net farm income considering effects of soil erosion	Hrubovcak, LeBlanc and Eakin (1995)	Reduction in net farm income account of about $4 billion due to soil erosion effects.
Infrastructure needs to protect drinking water from poor source water quality	Environmental Protection Agency (1997a)	$20 billion in current and future (20-year) need under Safe Drinking Water Act requirements for microbial treatment; $0.2 billion for nitrates; and $0.5 billion for other synthetic chemicals, including pesticides.
Health costs from water-borne disease outbreaks	Environmental Protection Agency (1997b)	Damages from *Giardia* outbreaks: $1.2-$1.5 billion in health costs.
Recreational damages of water pollution	Freeman (1982)	Total recreational damages from all forms of water pollution: $1.8-$8.7 billion; “best guess” of $4.6 billion (1978 dollars/year).
Selected estimates of benefits from water pollution control		
Water quality benefits of reduced soil erosion from conservation practices	Ribaudo (1986)	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.
Water quality benefits of reduced soil erosion from Conservation Reserve Prog.	Ribaudo (1989)	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 over program life.
Recreational fishing benefits from controlling water pollution	Russell and Vaughan (1982)	Total benefits of $300-$966 million, depending on the quality of fishery achieved.
Recreational benefits of surface-water pollution control	Carson and Mitchell (1993)	Annual household willingness to pay for improved recreational uses of $205-$279 per household per year, or about $29 billion.
Recreational benefits of soil erosion reductions	Feather and Hellerstein (1997)	Total of $611 million in benefits from erosion reductions on agricultural lands since 1982, based on recreation survey data.
Drinking water benefits in four regions from reduced nitrates	Crutchfield, Cooper, and Hellerstein (1997)	Monthly household willingness to pay for drinking water meeting EPA nitrate standards of $45 - $60 per month.
Freshwater-based recreation benefits from reduced soil erosion from the CRP	Feather, Hellerstein, and Hansen (1999)	Annual increase in consumer surplus $35.3 million from improved quality of recreation at rivers and lakes.

Concentration in Animal Feeding

There are growing concerns over the impact that concentrated animal feeding operations have on water quality and other rural amenities. As a result of domestic and export market forces, technological changes, and industry adaptations, animal production industries have seen substantial changes over the past decade. There has been an expansion in the number of large confined production units and geographic separation of animal production and feed production. In terms of production, the total number of animal units increased by about 4.5 million (about 3 percent) between 1987 and 1992 (EPA-USDA, 1999). (One animal unit equals 1 beef head, 0.7 dairy head, 2.5 hogs, 18 turkeys, or 100 chickens). During this same period, the number of feeding operations decreased. Between 1978 and 1992, the average number of animal units per operation increased 93 percent for dairy, 134 percent for hogs, 148 percent for broilers, and 176 percent for layers. Regions with large numbers of animal operations containing more than 1,000 animal units include the Northern Plains (for beef), Pacific (dairy), Corn Belt (swine), Appalachian (swine), and Southeast (broilers) (Gollehon et al., 1996). In 1997 there were approximately 213,000 animal feeding operations nationwide. Approximately 11,200 require Federal or State discharge permits because of their size or water quality impact (Gollehon and Caswell, 2000).

The geographic concentration of feeding operations can overwhelm the ability of a watershed to assimilate the nutrients contained in the waste and maintain water quality. In addition, the size and number of animal waste storage lagoons increases the chance for a leak or a catastrophic break. Over the past several years, major lagoon spills or leaks have been documented in Illinois, North Carolina, Iowa, Kentucky, Minnesota, Missouri, Montana, South Dakota, Utah, Virginia, Washington, and Wisconsin (NRDC, 1998).

Hypoxia in the Gulf of Mexico

A zone of hypoxic (<2.0 mg/l of dissolved oxygen) and anoxic (0.0 mg/l of dissolved oxygen) waters has become a dominant feature of the northern Gulf of Mexico. Hypoxia is defined as a deficiency in breathable oxygen sufficient to cause damage to living tissue. Anoxia is a deficiency in oxygen sufficient to cause death. Analyses of sediment cores from the Louisiana Shelf indicate that the increased eutrophication and hypoxia seen in the northern Gulf of Mexico are the result of increased nitrogen loadings from the Mississippi River (Rabalais et al. 1997).

The Northern Gulf of Mexico hypoxic zone represents one of the largest zones of oxygen-deficient bottom waters in the western Atlantic Ocean (Rabalais et al. 1997). At its peak, this zone stretches along the inner continental shelf from the Mississippi Delta westward to the upper Texas coast, covering about 8,000 square miles (NSTC, 2000). The hypoxic zone is caused by the interaction of several features of the northern Gulf. During the summer months, the waters in the Gulf are warm and relatively stable. Freshwater inflows from the Mississippi River are lighter than salt water and don’t mix with the salt water of the Gulf during stable periods. Large loads of inorganic nitrogen carried by the river, particularly during the spring, greatly increase the primary productivity (eutrophication) of the upper waters. Phytoplankton and organic carbon from zooplankton sink to the bottom and utilize oxygen, either through respiration or decay. Without adequate mixing with the upper waters, dissolved oxygen near the bottom decreases to hypoxic or anoxic levels.

A long-term sampling program by the Louisiana Department of Wildlife and Fisheries (LDWF) found changes to marine life in hypoxic waters (Hanifen, Perret, Allemand, and Romaire 1997). Mobile communities and assemblages will move away from areas with insufficient dissolved oxygen and congregate along the edges of the zone. Planktonic communities that are unable to leave the area, and benthic communities within the hypoxic zone suffer stress or mortality, depending on the severity and duration of the oxygen deficiency. LDWF sampling found that 35 percent of near shore trawl samples collected from hypoxic waters during the summer contained no live organisms.

Nutrient concentrations in the Mississippi River have increased dramatically in this century, particularly since 1950, coincident with increasing fertilizer use on cropland in the Midwest (Goolsby and Battaglin 1997). There are a number of sources of nitrogen in the Mississippi basin, including municipal and industrial point sources, commercial fertilizer and animal manure used on cropland, septic systems, and atmospheric deposition. Nonpoint source pollution from agricultural sources is estimated to contribute more than 80 percent of the nitrogen loadings in the Mississippi basin (Goolsby et al., 1999).

Recent ERS Reports Related to Water Quality

Economics of Water Quality Protection From Nonpoint Sources: Theory and Practice, AER-782, November 1999 (Marc O. Ribaudo, Richard D. Horan, and Mark Smith). Alternative policy approaches for reducing nonpoint source pollution are compared using a consistent economic framework. Policies analyzed include economic incentives, standards, education, liability, and research and development.

Economic Valuation of Environmental Benefits and the Targeting of Conservation Programs: The Case of the CRP, AER-778, April 1999 (Peter Feather, Daniel Hellerstein, and LeRoy Hansen). Non-market valuation models are used to estimate the increases in consumer welfare from reduced soil erosion and improved wildlife habitat. Reduced soil erosion from the CRP improved freshwater-based recreation.

Benefits of Safer Drinking Water: The Value of Nitrate Reduction, AER-752, June 1997 (Stephen R. Crutchfield, Joseph C. Cooper, and Daniel Hellerstein). Data from the Area Studies are used to evaluate the potential benefits of reducing human exposure to nitrates in drinking water supplies.

Accounting for the Environment in Agriculture, TB-1847, October 1995 (James Hrubovcak, Michael LeBlanc, and B. Kelly Eakin). Detailed information derived from the national income and product accounts provides the basis for economic interpretations of changes in the Nation's income and wealth. The effects of soil erosion on agricultural productivity and income, the economic effect of decreased water quality, and depletion of water stock are presented as examples of the potential scope of accounting adjustments needed in the agricultural sector.

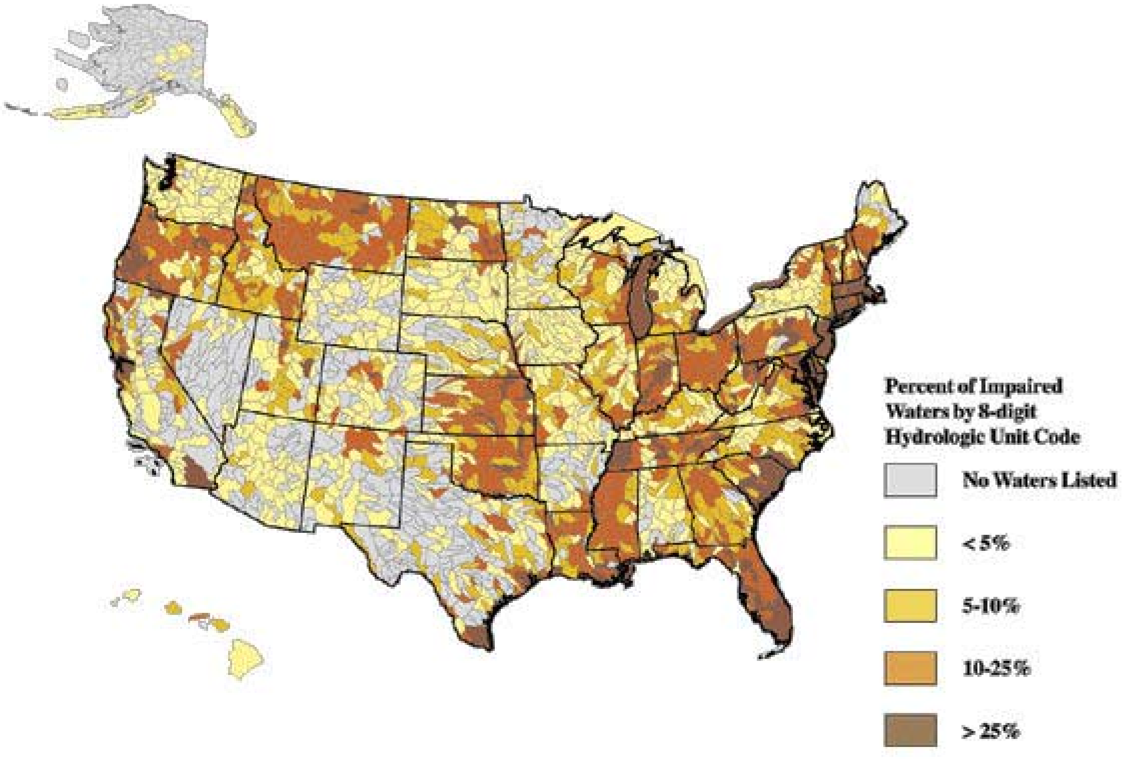
USDA's Water Quality Program Enters its 6th Year, AREI Update, 1995, No. 11 (Marc Ribaudo). Sixty-five water quality projects were started in 1995, and 6 projects were completed at the end of 1994. Over 400 water quality projects have been started since 1990.

Voluntary Incentives for Reducing Agricultural Nonpoint Source Water Pollution, AIB-716, May 1995 (Peter Feather and Joe Cooper). Data from the Area Studies are used to evaluate the success of existing incentive programs to control agricultural nonpoint source pollution. Because profitability drives production decisions, these programs tend to be most successful when they promote inexpensive changes in existing practices.

The Benefits of Protecting Rural Water Quality: An Empirical Analysis, AER-701, January 1995 (Stephen R. Crutchfield, Peter M. Feather, and Daniel R. Hellerstein). The use of nonmarket valuation methods to estimate the benefits of protecting or improving rural water quality from agricultural sources of pollution are explored. Two case studies show how these valuation methods can be used to include water-quality benefits estimates in economic analyses of specific policies to prevent or reduce water pollution.

Atrazine: Environmental Characteristics and Economics of Management, AER-699, September 1994 (Marc Ribaudo and Aziz Bouzaher). Atrazine is an important herbicide in the production of corn and other crops in the U.S. Recent findings indicate that elevated amounts of atrazine are running off fields and entering surface-water resources. The costs and benefits of an atrazine ban, a ban on pre-plant and pre-emergent applications, and a targeted ban to achieve a surface-water standard are examined.

Figure 2.3.1 – Waters listed under 303(d) of the Clean Water Act as threatened and impaired, 1998.



Source: EPA, *Atlas of America's Polluted Waters*, 2000

Figure 2.3.2 – Surface waters vulnerable to sedimentation from cropland

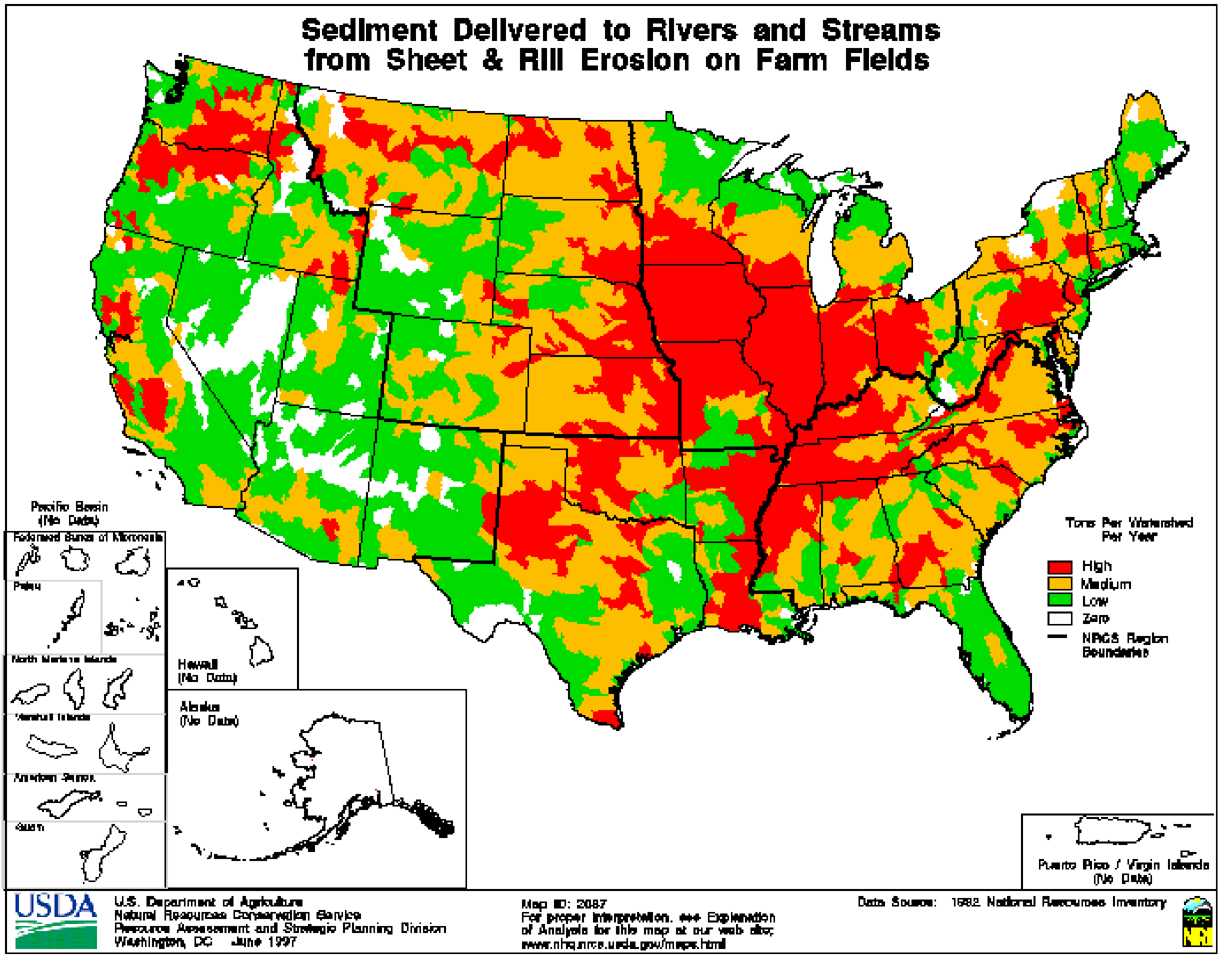
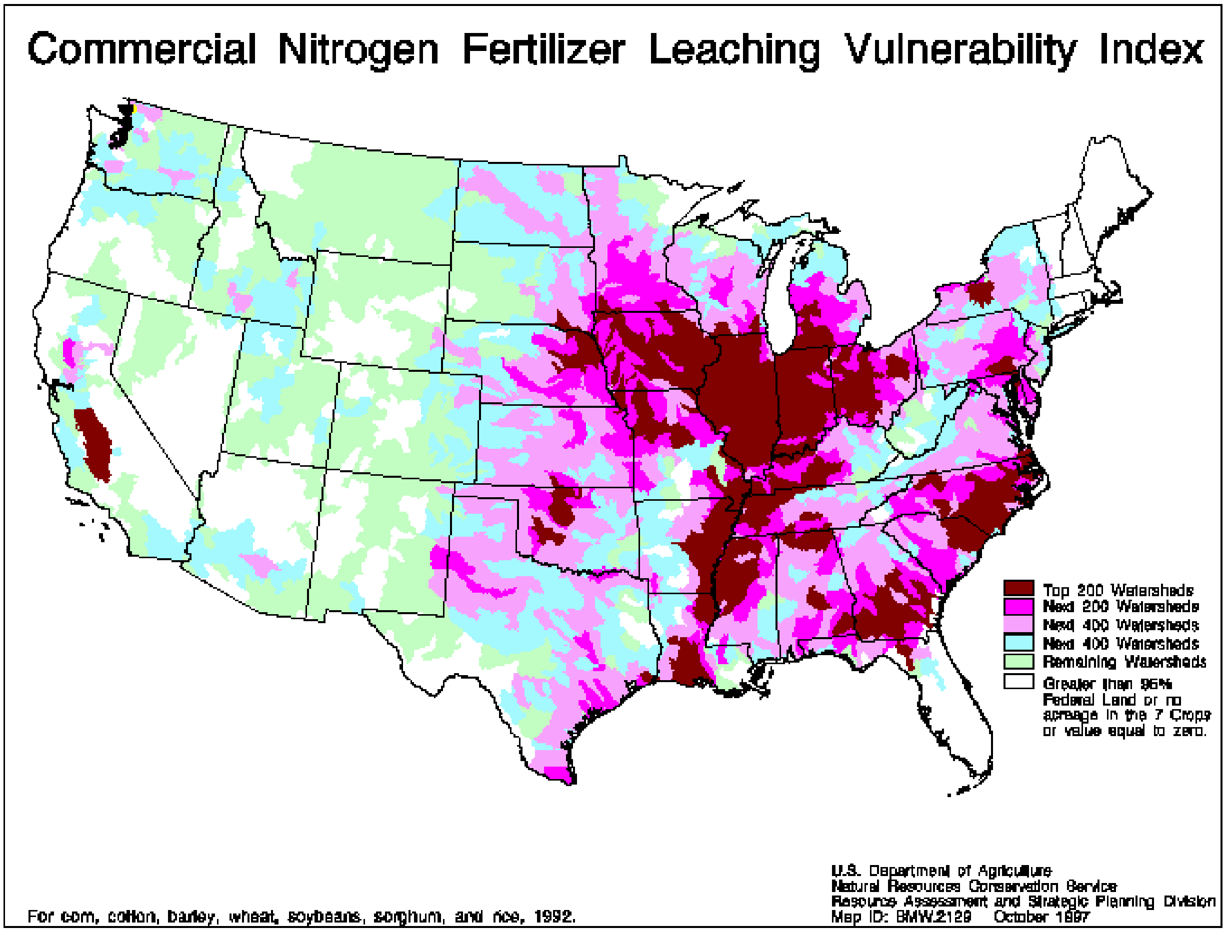


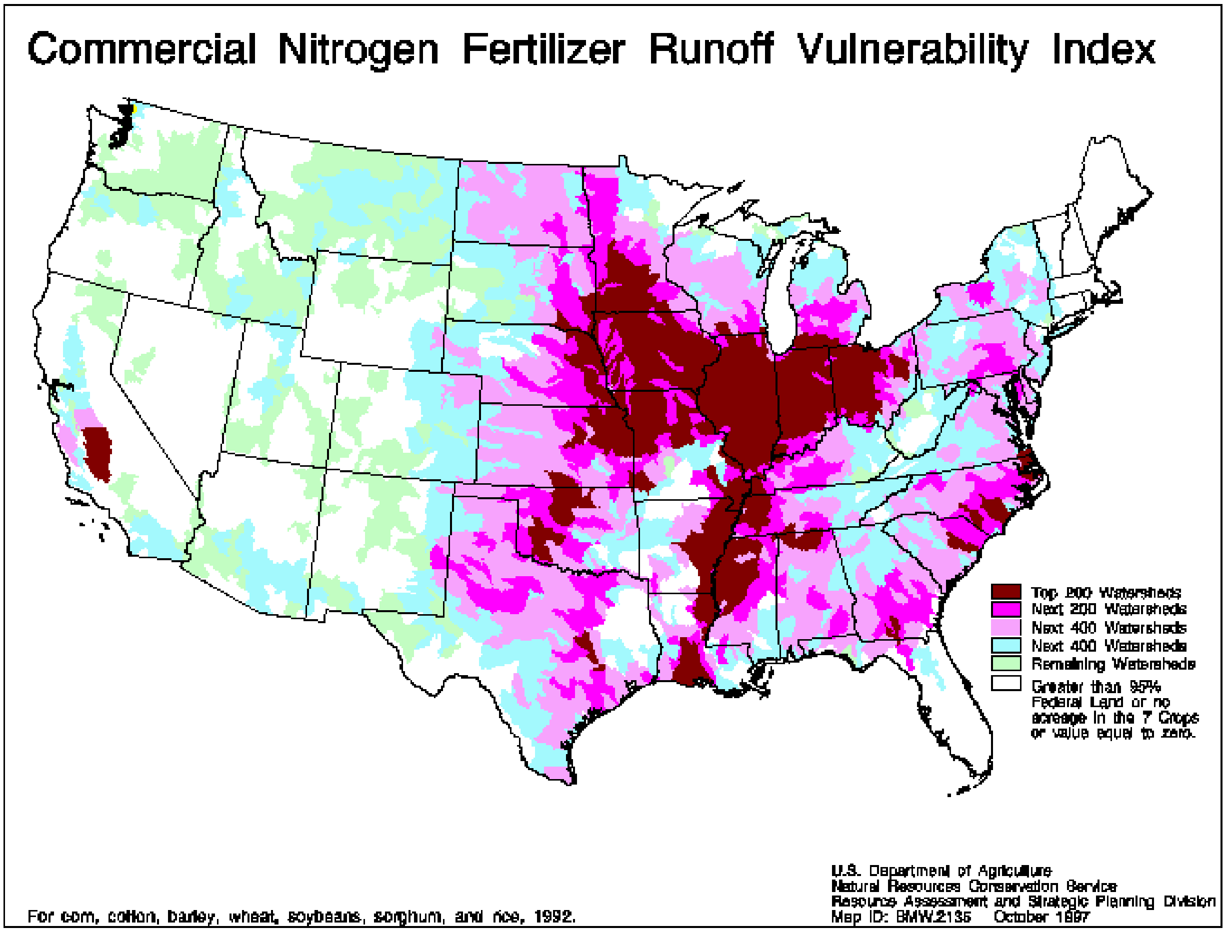
Figure 2.3.3 – Watersheds vulnerable to nitrate leaching from commercial fertilizer



For corn, cotton, barley, wheat, soybeans, sorghum, and rice, 1992.

U.S. Department of Agriculture
Natural Resources Conservation Service
Resource Assessment and Strategic Planning Division
Map ID: BMW2129 October 1997

Figure 2.3.4 – Watersheds vulnerable to runoff of nitrate from commercial fertilizer



Commercial Nitrogen Fertilizer Runoff Vulnerability Index

For corn, cotton, barley, wheat, soybeans, sorghum, and rice, 1992.

U.S. Department of Agriculture
Natural Resources Conservation Service
Resource Assessment and Strategic Planning Division
Map ID: BMW2135 October 1997

Figure 2.3.5 – Watersheds vulnerable to runoff from phosphorus from commercial fertilizer

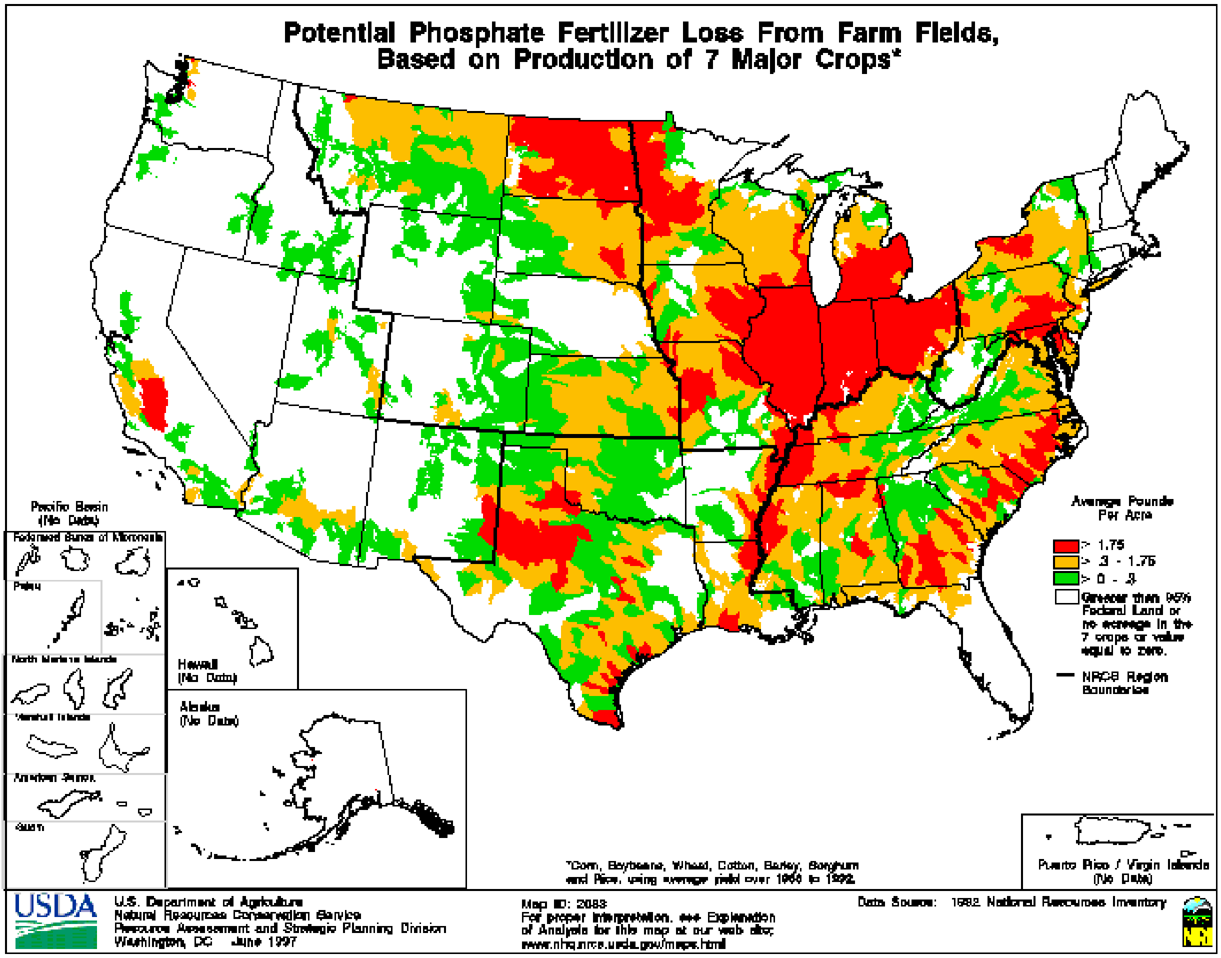
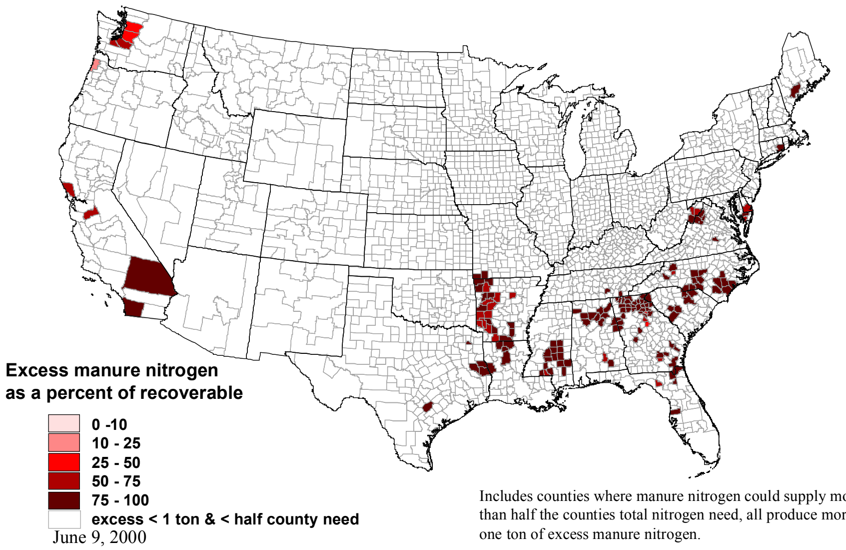


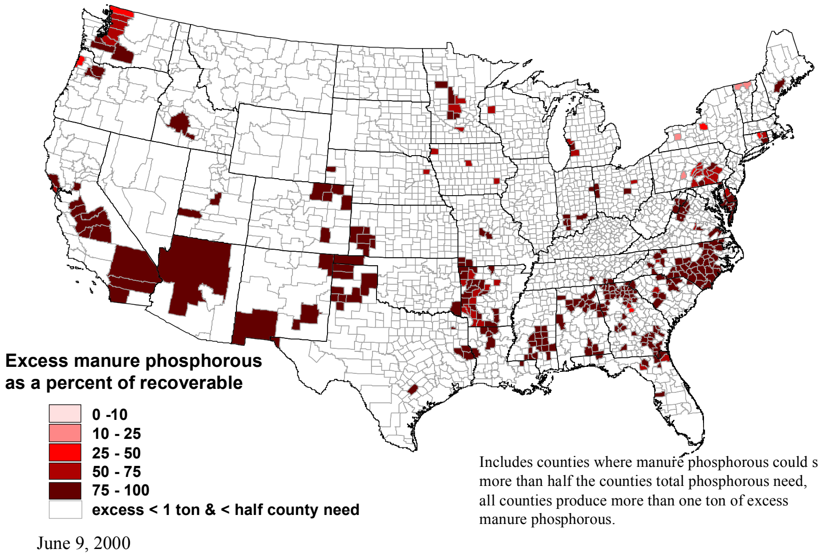
Figure 2.3.6 – Counties vulnerable to runoff or leaching from nitrate in animal waste


Excess manure nitrogen as a percent of recoverable nitrogen for counties where manure nitrogen is more than half the county uptake, 1997

June 9, 2000

Includes counties where manure nitrogen could supply more than half the counties total nitrogen need, all produce more than one ton of excess manure nitrogen.

Figure 2.3.7 – Counties vulnerable to runoff from phosphorus in animal waste


Excess manure phosphorous as a percent of recoverable phosphorous for counties where manure phosphorous is more than half the county uptake, 1997

Includes counties where manure phosphorous could supply more than half the counties total phosphorous need, all counties produce more than one ton of excess manure phosphorous.

June 9, 2000

Figure 2.3.8 – Watersheds vulnerable to pesticide leaching

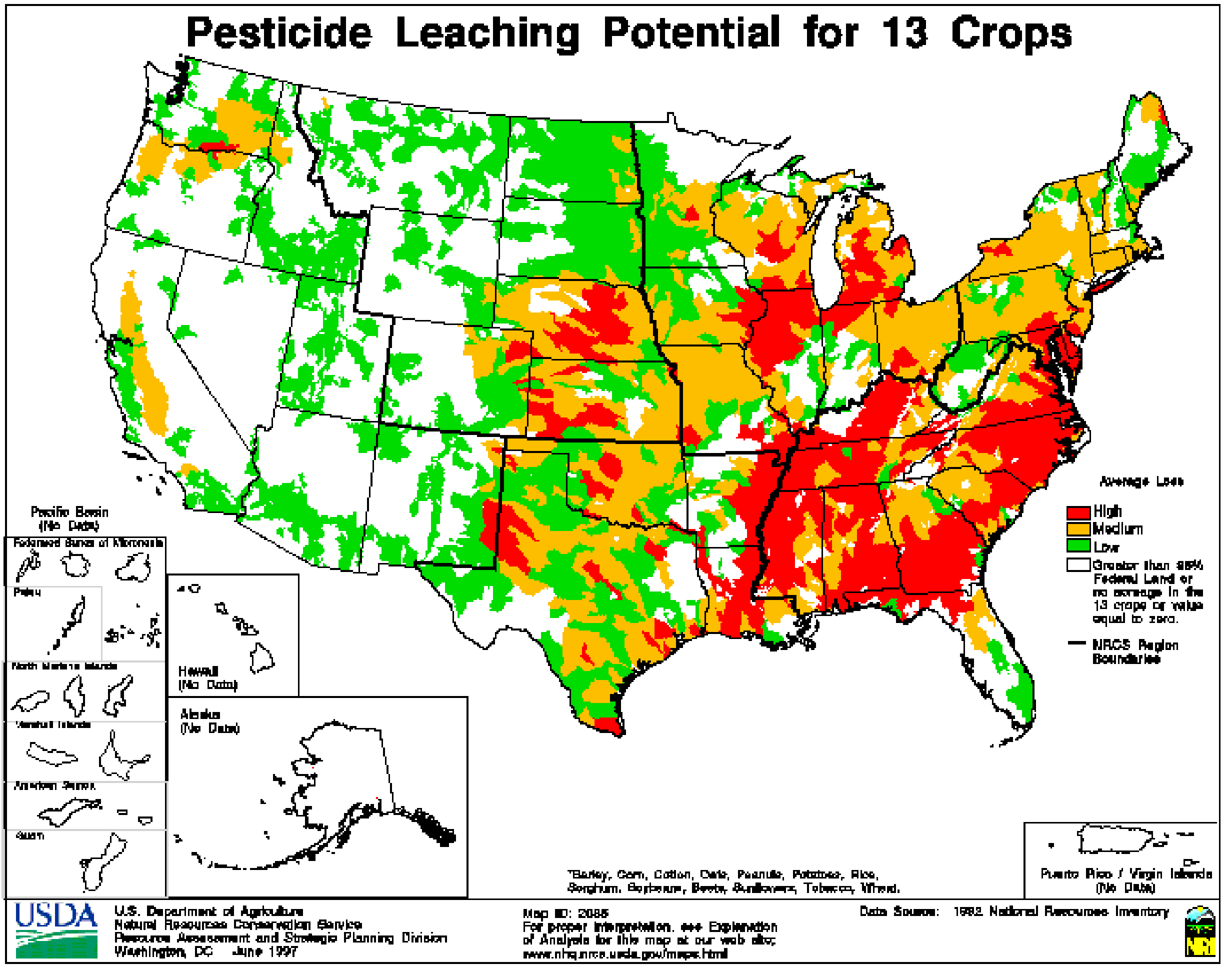


Figure 2.3.9 – Watersheds vulnerable to pesticide runoff