Overview

Agricultural Nonpoint Source Pollution

State water quality assessments continue to show that nonpoint source pollution is the leading cause of impairments in surface waters of the U.S. According to these assessments, agriculture is the most wide-spread source of pollution for assessed rivers and lakes. Agriculture impacts 18% of assessed river miles and 14% of assessed lake acres. The state reports also indicate that agriculture impacts 48% of impaired river miles and 41% of impaired lake acres (EPA, 2002).

The primary agricultural NPS pollutants are nutrients, sediment, animal wastes, salts, and pesticides. Agricultural activities also have the potential to directly impact the habitat of aquatic species through physical disturbances caused by livestock or equipment. Although agricultural NPS pollution is a serious problem nationally, a great deal has been accomplished over the past several decades in terms of sediment and nutrient reduction from privately-owned agricultural lands. Much has been learned in the recent past about more effective ways to prevent and reduce NPS pollution from agricultural activities.

The purpose of this chapter is to describe the general causes of agricultural NPS pollution, the specific pollutants and problems of concern, and the general approaches that have been found most effective in reducing the impact of such pollutants and problems on aquatic resources.

Nutrients

Nitrogen (N) and phosphorus (P) are the two major nutrients from agricultural land that degrade water quality. Nutrients are applied to agricultural land in several different forms and come from various sources, including:

❐ Commercial fertilizer in a dry or fluid form, containing nitrogen, phosphorus, potassium (K), secondary nutrients, and micronutrients;

❐ Manure from animal production facilities including bedding and other wastes added to the manure, containing N, P, K, secondary nutrients, micronutrients, salts, some metals, and organics;

❐ Municipal and industrial treatment plant sludge, containing N, P, K, secondary nutrients, micronutrients, salts, metals, and organic solids;

❐ Municipal and industrial treatment plant effluent, containing N, P, K, secondary nutrients, micronutrients, salts, metals, and organics;

❐ Legumes and crop residues containing N, P, K, secondary nutrients, and micronutrients;

❐ Irrigation water;

❐ Wildlife; and

❐ Atmospheric deposition of nutrients such as nitrogen, phosphorus, and sulphur.

Commercial fertilizers and manure are the primary sources of crop nutrients for agriculture.

In addition, decomposition of organic matter and crop residue may be a source of mobile forms of nitrogen, phosphorus, and other essential crop nutrients.

Surface water runoff from agricultural lands may transport the following pollutants:

❑ Particulate-bound nutrients, chemicals, and metals, such as phosphorus, organic nitrogen, and metals applied with some organic wastes;

❑ Soluble nutrients and chemicals, such as nitrogen, phosphorus, metals, and many other major and minor nutrients;

❑ Particulate organic solids, oxygen-demanding material, and bacteria, viruses, and other microorganisms applied with some organic waste; and

❑ Salts.

Ground water infiltration from agricultural lands to which nutrients have been applied may transport the following pollutants:

❑ Soluble nutrients and chemicals, such as nitrogen, phosphorus, metals;

❑ Other major and minor nutrients;

❑ Salts; and

❑ Bacteria and other pathogens applied with some organic waste.

> Overloading with nitrogen and phosphorus causes eutrophication which reduces the suitability of waterways for beneficial uses.

All plants require nutrients for growth. Nitrogen and phosphorus generally are present in aquatic environments at background or natural levels below 0.3 and 0.01 mg/L, respectively. When these nutrients are introduced into a stream, lake, or estuary at higher rates, aquatic plant productivity may increase dramatically. This process, referred to as cultural eutrophication, may adversely affect the suitability of the water for other uses.

Excessive aquatic plant productivity results in the addition to the system of more organic material, which eventually dies and decays. Bacteria decomposing this organic matter produce unpleasant odors and deplete the oxygen supply available to other aquatic organisms. Depleted oxygen levels, especially in colder bottom waters where dead organic matter tends to accumulate, can reduce the quality of fish habitat and encourage the propagation of fish that are adapted to less oxygen or to warmer surface waters. Anaerobic conditions can also cause the release of additional nutrients from bottom sediments.

Highly enriched waters will stimulate algae production, consequently increasing turbidity and color. In addition, certain algae can produce severe taste and odor problems that impair the quality of drinking water sources (EPA, 1999a). For example, the City of Tulsa, OK spends an additional $100,000 a year to correct taste and odor problems, resulting from extreme algae growth in the city's drinking water source (Lassek, 1997). Excess algae growth may also interfere with recreational activities such as swimming and boating. Algae growth is also believed to be harmful to coral reefs (e.g., Florida coast). Furthermore, the increased turbidity results in less sunlight penetration and availability to submerged aquatic vegetation (SAV). Since SAV provides habitat for small or juvenile fish, the loss of SAV has severe consequences for the food chain. Tampa Bay is an example in which nutrients are believed to have contributed to SAV loss.

Nitrogen

All forms of transported nitrogen are potential contributors to eutrophication in lakes, estuaries, and some coastal waters. In general, though not in all cases, nitrogen availability is the limiting factor for plant growth in marine ecosystems. Thus, the addition of nitrogen can have a significant effect on the natural functioning of marine ecosystems.

Eutrophication in coastal waters has been linked to increased nutrient loads from rivers, as evidenced by increasing incidence of noxious algal blooms and hypoxia in bottom waters (Justic et al., 1995.) The Gulf of Mexico has experienced midsummer hypoxia (low dissolved oxygen) since the early 1970s. From 1993 through 1999, the extent of bottom-water hypoxia ranged from about 6,200 to 7,700 square miles (16,000 to 20,000 km2), greater than twice the surface area of the Chesapeake Bay (Rabalais et al., 1999). The hypoxia is thought to be due to eutrophication resulting from high nutrient loading to the Gulf. Recent analysis has shown that about 89 percent of the annual total nitrogen flux to the Gulf (1.57 million metric tons) was from nonpoint sources, and the remaining 11 percent was from municipal and industrial point sources (Goolsby and Battaglin, 2000).

The toxic dinoflagellate *Pfiesteria piscicida*, implicated in causing about 50% of the major fish kills in North Carolina's estuaries and coastal waters from 1991 to 1993, has been linked to conditions of over-enrichment of nutrients such as nitrogen and phosphorus (Burkholder, 1996). More research is needed to determine the specific physical, chemical, and biological factors that promote outbreaks of *Pfiesteria piscicida.* Pfiesteria-like species have also been tracked to eutrophic sudden-death fish kill sites in estuaries, coastal waters, and aquaculture facilities from the mid-Atlantic through the Gulf Coast (Burkholder et al., 1995).

In addition to eutrophication, excessive nitrogen causes other water quality problems. Dissolved ammonia at concentrations above 0.2 mg/L may be toxic to fish, especially trout. Also, nitrates in drinking water are potentially dangerous to newborn infants. Nitrate is converted to nitrite in the digestive tract, which reduces the oxygen-carrying capacity of the blood (methemoglobinemia), resulting in brain damage or even death. The U.S. Environmental Protection Agency has set a limit of 10 mg/L nitrate-nitrogen in water used for human consumption (EPA, 1989a).

Nitrogen is naturally present in soils but must be added to meet crop production needs. Nitrogen is added to the soil primarily by applying commercial fertilizers and manure, but also by growing legumes (biological nitrogen fixation) and incorporating crop residues. Not all nitrogen that is present in or on the soil is available for plant use at any one time. Applied nitrogen may be stored in the soil as organic material, soil organic matter (humus), or adsorbed to soil particles. For example, in the eastern Corn Belt, it is normally assumed that about 50% of applied nitrogen is assimilated by crops during the year of application (Nelson, 1985). Organic nitrogen normally constitutes the majority of the soil nitrogen. It is slowly converted (2 to 3% per year) to the more readily plant-available inorganic ammonium or nitrate. Nitrogen conversions are governed by carbon to nitrogen rations of crop residue and environmental conditions (e.g., temperature, moisture).

> Excessive ammonia can be toxic to fish.

The chemical form of nitrogen affects its impact on water quality. The most biologically important inorganic forms of nitrogen are ammonium (NH4-N), nitrate (NO3-N), and nitrite (NO2-N). Organic nitrogen occurs as particulate matter, in living organisms, and as detritus. It occurs in dissolved form in compounds such as amino acids, amines, purines, and urea.

Nitrate-nitrogen is highly mobile and can move readily below the crop root zone, especially in sandy soils. It can also be transported in surface runoff. Ammonium, on the other hand, becomes adsorbed to the soil and is lost primarily with eroding sediment. Even if nitrogen is not in a readily available form as it leaves the field, it can be converted to an available form either during transport or after delivery to water bodies.

> Nitrate-nitrogen can readily leach below the root zone into shallow ground water and can threaten water supplies if it exceeds water quality standards.

Data collected in the U.S. Geological Survey NAWQA program sites showed that nitrate concentrations in ground water were highest in samples from wells in agricultural areas, with concentrations exceeding the drinking water standard of 10 mg/L in about 12% of domestic wells (Mueller and Helsel, 1996). Over the period 1986 – 1992, annual flow-weighted mean nitrate concentrations in ground water in the highly agricultural Big Spring basin of Iowa ranged from 5.7 mg/L in the very dry water year 1989 to 12.5 mg/L in the very wet water year 1991 (Rowden et al.,1995).

Across the U.S., nitrate levels in ground water are associated with source availability (i.e., population density, nitrogen inputs in fertilizer, manure, and atmospheric sources) and regional environmental factors (i.e., soil drainage characteristics, precipitation, cropland acres) (Spalding and Exner, 1993; Nolan et al., 1997). In Iowa's Big Spring basin, for example, the proportion of land in corn directly affected nitrogen concentrations and loads to surface and ground water because the greatest nitrogen inputs were fertilizers applied to corn (Rowden et al.,1995). In general, areas with high nitrogen input, well-drained soils, and high cropland areas have the highest potential for ground water contamination by nitrate (Nolan et al., 1997). Large areas of ground water where nitrate concentrations exceed the 10 mg/L limit occur in regions of irrigated cropland on well-drained soils; most of these areas are west of the Mississippi River where irrigation is necessary (Spalding and Exner, 1993). In the eastern U.S., localized nitrate-nitrogen contamination occurs beneath cropped, well-drained soils that receive excessive applications of fertilizer and manure, notably in the middle Atlantic states and the Delmarva Peninsula.

Soil drainage has reduced ground water nitrate problems in the Corn Belt states, because extensive tiling and ditching intercept soil water and carry it to surface water. High nitrogen inputs in such areas are more likely to affect surface water than ground water (Nolan et al., 1997). Studies in Walnut Creek, Iowa, showed that nitrate levels in the stream ranged from 10 to 20 mg/L (Hatfield et al., 1995). Walnut Creek, like many Midwestern streams, is fed by subsurface drainage, and high nitrate levels originated from the bottom of the root zone (1 – 1.2 m) in corn-soybean cropland in the watershed.

Phosphorus

Phosphorus can also contribute to the eutrophication of both freshwater and estuarine systems. Studies on the Cannonsville Reservoir, New York, showed that eutrophication was accelerated by phosphorus loading (Brown et al., 1986).

The low dissolved oxygen levels associated with eutrophication impacted fish populations, and use of the lake for recreational fishing was much less than at nearby Pepacton Reservoir. Moreover, the accelerated phosphorus loadings also contributed to the impairment of the drinking water supply for New York City because both reservoirs serve as major drinking water sources for the New York City water supply system. Also, nutrients are the major cause of use impairment in Lake Champlain, Vermont, with phosphorus the main culprit (Vermont Agency of Natural Resources, 1996). It is estimated that 55 – 66% of the NPS phosphorus load to Lake Champlain is derived from agricultural activities (Meals and Budd, 1998; Hegman et al., 1999).

While phosphorus typically plays the controlling role in freshwater systems, in some estuarine systems both nitrogen and phosphorus can limit plant growth. Algae consume dissolved inorganic phosphorus and convert it to the organic form. Phosphorus is rarely found in concentrations high enough to be toxic to higher-level organisms.

Phosphorus can be found in the soil in dissolved, colloidal, or particulate forms. Although the phosphorus content of most soils in their natural condition is low (between 0.01 and 0.2% by weight), soil test data indicate that decades of P application to agricultural land in excess of crop removal have resulted in widespread increases in soil P levels in the U.S. and elsewhere (Sims, 1993; Sharpley et al., 1993; Sims et al., 2000). Long-term trends in soil test values show that soil P in many areas of the world is excessive, relative to crop require-ments; the greatest concern occurs with animal-based agriculture, where farm and watershed-scale P surpluses and over-application of P to soils are common (Sims et al., 2000). Manures are normally applied at rates needed to meet crop nitrogen needs, yet the ratio of nitrogen to phosphorus in most manures results in over-application of phosphorus (Sharpley et al., 1996).

> Most often, phosphorus is sediment-attached. Phosphorus may also be dissolved. Either form can contribute to eutrophication.

The main forces controlling P movement from land to water are transport (runoff, infiltration, and erosion) and source factors (surface soil P and manage-ment of fertilizer/manure applications) (Sharpley et al., 1993; Daniel et al., 1998). Erosion processes control particulate P movement, while runoff processes drive dissolved P movement. Particulate P movement is a complex function of rainfall, irrigation, runoff, and soil management factors affecting erosion. Movement of dissolved P is a function of sorption/desorption, dissolution, and extraction of P from soil and plant material by water. Whereas surface runoff is typically the dominant pathway of P loss from agricultural land, there is increas-ing evidence that leaching of P from some soil types, especially on tile-drained fields, can present a threat to water quality (Beauchemin et al. 1998; Schoumans and Groenendijk, 2000; Simard et al., 2000).

Farm practices, such as manure or fertilizer applications and tillage, largely determine the quantity of P available in the soil to be moved by transport factors. Accumulation of P near the soil surface (0 – 2 inches) has been widely observed to influence the concentration and loss of P in runoff. Significant linear relation-ships have been demonstrated on a variety of soils and cropping systems be-tween the amount of soil test P in surface soil and dissolved P concentrations in surface runoff (Sharpley et al., 1993; Sharpley, 1995b; Pote et al., 1996; Pote et al., 1999; Sims et al., 2000; Sharpley et al., 2000; Sims, 2000). Soil P saturation status, rather than simply soil test P value, is thought to be a better predictor of runoff P loss, especially as the theoretical basis to establish environmental soil

test P limits, because it integrates the effect of soil type (Sharpley, 1995b; Sims et al., 2000).

While there is little doubt that increased P concentrations at the soil surface contribute to higher P concentrations in runoff, the value of using soil test P as the sole predictor of transportable P is questionable (Coale, 2000). Consideration of hydrology is critical to understanding P export from a watershed. (Daniel et al., 1998). Chemical soil tests quantify concentration of soluble, biologically available, and potentially desorbable P in soils, but they provide no information on transport processes and management practices that influence movement of P from soil to water. They also do not characterize direct release of P from fertilizers, animal manure, and biosolids applied to soils (Sims et al., 2000).

Although soil P content is clearly important in determining the concentration of P in agricultural runoff, surface runoff and erosion potential, as well as mismanagement of fresh P inputs will often override soil P levels in determining P export. Use of a single threshold value for soil test P is too limited in its prediction of surface runoff P to be the only criterion to guide P management (Sharpley, 2000). Data from soil P testing must be integrated with understanding of transport processes and information on P management to predict P loss to water.

Lemunyon and Gilbert (1993) described an index for identifying soils, landforms, and management practices that could cause phosphorus problems in water bodies. The index uses soil erosion rates, runoff, soil test values of available phosphorus, and fertilizer and organic phosphorus application rates to assess the potential for phosphorus movement from the site. Sharpley (1995a) applied the Lemunyon and Gilbert phosphorus index to 30 watersheds in the Southern Plains, and concluded that the index is a valuable tool for identifying sources where phosphorus management is most needed. Several recommendations were made for improving the accuracy and utility of the index.

Gburek et al. (2000a and 2000b) have stressed that management of watershed phosphorus export should focus not just on areas of high soil P or P saturation but on critical source areas (CSA) that represent the intersection of surface runoff source areas (i.e., areas of actual or potential transport mechanisms) with areas of high soil P and high fertilizer/manure application. It is suggested that management of phosphorus loss from agricultural watersheds must focus on identifying, targeting, and remediating these spatially variable areas.

Runoff and erosion can carry some phosphorus to nearby water bodies. Dissolved inorganic phosphorus (orthophosphate phosphorus) is probably the only form directly available to algae, but eutrophication can be stimulated by the bioavailable phosphorus derived from the upper 5 cm of agricultural soils (Sharpley, 1985). Bioavailable phosphorus consists of dissolved phosphorus and a portion of particulate phosphorus that varies from site to site. Sharpley (1993) developed a method using iron-oxide impregnated paper to estimate the amount of phosphorus in soil that is available for algal growth. This method covers both dissolved and adsorbed phosphorus. Particulate and organic phosphorus delivered to water bodies may later be released as dissolved phosphorus and made available to algae when the bottom sediment of a stream becomes anaerobic, causing water quality problems.

Sediment

Sediment is the result of erosion. It is the solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by wind, water, gravity, or ice. The types of erosion associated with agriculture that produce sediment are (1) sheet and rill erosion, (2) ephemeral and classic gully erosion, (3) wind erosion, and (4) streambank erosion. Soil erosion can be characterized as the transport of particles that are detached by rainfall, flowing water, or wind. Eroded soil is either redeposited on the same field or transported from the field in runoff or by wind.

Soil loss reduces nutrients and deteriorates soil structure, causing a decrease in the productive capacity of the land from which it is eroded. Wind erosion may cause abrasion of crops and structures by flying soil particles, air pollution by particles in suspension, transport of sediment-attached nutrients and pesticides, and burial of structures and crops by drifting soil.

> Sediment threatens water supplies and recreation, and causes harm to plant and fish communities.

Sediment affects the use of water in many ways. Suspended solids reduce the amount of sunlight available to aquatic plants, cover fish spawning areas and food supplies, smother coral reefs, clog the filtering capacity of filter feeders, and clog and harm the gills of fish. Turbidity interferes with the feeding habits of certain species of fish. These effects combine to reduce fish, shellfish, coral, and plant populations and decrease the overall productivity of lakes, streams, estuaries, and coastal waters. Recreation is limited because of the decreased fish population and the water's unappealing, turbid appearance. Turbidity also reduces visibility, making swimming less safe.

Deposited sediment reduces the transport capacity of roadside ditches, streams, rivers, and navigation channels. Decreases in capacity can result in more frequent flooding. Sediment can also reduce the storage capabilities of reservoirs and lakes and necessitate more frequent dredging.

The use of Highland Silver Lake, Illinois, as a public water supply was impaired by high turbidity levels and sedimentation (EPA, 1990b). Similarly, sediment surveys revealed that Lake Pittsfield, also in Illinois, was losing storage capacity at a rate of 1.08%, which would cause the lake to fill in with sediment in 92 years if no efforts had been made to control erosion (Davenport and Clarke, 1984). Due to erosion control efforts the rate of storage capacity loss has been reduced from 15% over 13 years to 10% over the subsequent 18 years (EPA, 1996). In addition, a water supply intake on Long Creek, North Carolina, was clogged due to erosion from surrounding lands, necessitating annual dredging of the water supply intake pool (EPA, 1996).

At current rates of sedimentation, Morro Bay, California, could be lost as an open water estuary within 300 years unless erosion control efforts are stepped up (EPA, 1996). Sedimentation has been associated with the lack of ocean-run trout in tributary streams, as well as significant economic losses to the oyster industry in the bay. Also, a trout fishery in Long Pine Creek, Nebraska, was impaired by high sediment loadings from streambank erosion and irrigation discharge (Hermsmeyer, 1991). Irrigation return flows with high sediment loads and streambank erosion caused negative impacts to salmonid spawning and recreational uses of Rock Creek, Idaho (Yankey et al., 1991).

Chemicals such as some pesticides, phosphorus, and ammonium are transported with sediment in an adsorbed state. Changes in the aquatic environment, such as decreased oxygen concentrations in the overlying waters or the development of anaerobic conditions in the bottom sediments, can cause these chemicals to be released from the sediment. Adsorbed phosphorus transported by the sediment may not be immediately available for aquatic plant growth but does serve as a long-term contributor to eutrophication.

Sediments from different sources vary in the kinds and amounts of pollutants that are adsorbed to the particles. For example, sheet, rill, ephemeral gully, and wind erosion mainly move soil particles from the surface or plow layer of the soil. Sediment that originates from surface soil has a higher pollution potential than that from subsurface soils. The topsoil of a field is usually richer in nutrients and other chemicals because of past fertilizer and pesticide applications, as well as nutrient cycling and biological activity. Topsoil is also more likely to have a greater percentage of organic matter. Sediment from gullies and streambanks usually carries less adsorbed pollutants than sediment from surface soils.

Soil eroded and delivered from cropland as sediment usually contains a higher percentage of finer and less dense particles than the parent soil on the cropland. This change in composition of eroded soil is due to the selective nature of the erosion process. For example, larger particles are more readily detached from the soil surface because they are less cohesive, but they also settle out of suspension more quickly because of their size. Organic matter is not easily detached because of its cohesive properties, but once detached it is easily transported because of its low density. Clay particles and organic residues will remain suspended for longer periods and at slower flow velocities than will larger or more dense particles. This selective erosion can increase overall pollutant delivery per ton of sediment delivered because small particles have a much greater adsorption capacity than larger particles. As a result, eroding sediments generally contain higher concentrations of phosphorus, nitrogen, and pesticides than the parent soil (i.e., they are enriched).

> Sediment from topsoil, often containing higher levels of nutrients and pesticides, can be a greater threat to water quality compared to subsoil sediment.

Animal Wastes

Animal waste (manure) includes the fecal and urinary wastes of livestock and poultry; process water (such as from a milking parlor); and the feed, bedding, litter, and soil with which they become intermixed. The following pollutants may be contained in manure and associated bedding materials and could be transported by runoff water and process wastewater from confined animal facilities:

❒ Oxygen-demanding substances;

❒ Nitrogen, phosphorus, and many other major and minor nutrients;

❒ Organic solids;

❒ Salts;

❒ Bacteria, viruses, and other microorganisms;

❒ Metals; and

❒ Sediments.

> Runoff containing animal waste that reaches surface water can result in oxygen depletion and fish kills.

When such runoff, process wastewater or manure enters surface waters, excess nutrients and organic materials are added. Increased nutrient levels can cause excessive growth of aquatic plants and algae. The decomposition of aquatic plants depletes the oxygen supply in the water, creating anoxic or anaerobic conditions which can lead to fish kills. Amines and sulfides are produced in anaerobic waters, causing the water to acquire an unpleasant odor, taste, and appearance. Methane, a greenhouse gas, can also be produced in anaerobic waters. Such waters can be unsuitable for drinking, fishing, and other recreational uses. Investigations in Illinois have demonstrated the impacts of animal waste on water quality, including fish kills associated with a hog facility, a cattle feeding operation, and surface application of liquid waste on frozen or snow-covered ground (Ackerman and Taylor, 1995). In addition, North Carolina experienced six spills from animal waste lagoons in the summer of 1995, totaling almost 30 million gallons. This total included a spill of 22 million gallons of swine waste into the New River, which killed fish along a 19-mile downstream area (EPA Office of Inspector General, 1997).

A study of Herrings Marsh Run in the coastal plain of North Carolina showed that nitrate levels in stream and ground water were highest in areas with the greatest concentration of swine and poultry production (Hunt et al., 1995). Orthophosphate levels were affected only slightly by animal waste applications since most of the phosphorus was bound by the soil. In addition, runoff from feedlots has long been associated with severe stream pollution. Feedlots, which are devoid of vegetation and subjected to severe hoof action, generate runoff containing large amounts of bacteria, which may cause violations of water quality standards (Baxter-Potter and Gilliland, 1988).

Diseases can be transmitted to humans through contact with animal or human feces. Runoff from fields receiving manure will contain extremely high numbers of microorganisms if the manure has not been incorporated or the microorganisms have not been subject to stress. Shellfishing and beach closures can result from high fecal coliform counts. Although not the only source of pathogens, animal waste has been responsible for shellfish contamination in some coastal waters.

The pathogen *Cryptosporidium*, a protozoan parasite, is common in surface waters, especially those containing high amounts of sewage contamination or animal waste. Without advanced filtration technology, *Cryptosporidium* may pass through water treatment filtration and disinfection processes in sufficient numbers to cause health problems, such as the gastrointestinal disease cryptosporidiosis. The most serious consequences of cryptosporidiosis tend to be focused on people with severely weakened immune systems. In 1993, Milwaukee, Wisconsin, which draws its water from Lake Michigan, experienced an outbreak of cryptosporidiosis, affecting 400,000 people, with more than 4,000 hospitalized and over 50 deaths attributed to the disease (EPA, 1997c). While the source of contamination is uncertain, the problem was linked to suboptimal performance of the water treatment plant, together with unusually heavy rainfall and runoff. The watersheds of two rivers which discharge into Lake Michigan contain slaughterhouses, human sewage discharges, and cattle grazing ranges (Lisle and Rose, 1995).

Giardia is another commonly identified pathogen in surface waters. *Giardia* is the intestinal parasite that causes the disease giardiasis. Giardiasis is sometimes

referred to as "backpacker's disease" since the disease frequently occurs in hikers and nature lovers who unwittingly drink water from contaminated springs or streams. However, several community-wide outbreaks of giardiasis have been linked to contaminated municipal drinking water (CDC, n.d.). The commonly associated symptoms of giardiasis are persistent diarrhea, weight loss, abdominal cramps, nausea, and dehydration. With proper treatment and a healthy immune system, giardiasis is not deadly, but it can be life threatening to AIDS patients, small children, the elderly, or someone recovering from major surgery. The best strategy to protect a drinking water supply from *Giardia* contamination is the physical removal of the organism. This can be accomplished by controlling land use within a watershed to prevent degradation of the source water and by utilizing a properly designed and operated water filtration plant.

Viruses in animal waste also pose a potential health threat to humans. Enteric viruses are the most significant virus group affecting water quality and human health (EPA, 2001). There are over 100 different types of enteric viruses, all considered pathogenic to man (EPA, 1984). When ingested, enteric viruses may attack the gastrointestinal track or the respiratory system, sometimes, fatally. More typically, infection causes sore throat, diarrhea, fever and nausea. Enteric viruses may be found in livestock excrement from barnyards, pastures, rangelands, feedlots, and uncontrolled manure storage areas; and areas of land application of manure and sewage sludge (NCSU, 2001). When animal waste is applied to agricultural land for irrigation or fertilization purposes, enteric viruses can survive in soil for periods of weeks or even months (EPA, 1984). Enteric viruses in land applied manure or sewage sludge can leach into ground water and/or eventually be transported by overland flow into surface water bodies, thus creating a potential for the contamination of water resources. Management measures should be instituted in all situations in which sludge is used for irrigation or fertilization, to prevent the contamination of vegetables and drinking water sources by enteric viruses (EPA, 1984).

Since pathogenic organisms present in polluted waters are generally difficult to identify and isolate, scientists typically choose to monitor indicator organisms. Indicator organisms are usually nonpathogenic bacteria assumed to be associated with pathogens transmitted by fecal contamination but are more easily sampled and measured. Fecal indicators are used to develop water quality criteria to support designated uses, such as primary contact recreation and drinking water supply. For example, studies conducted by USEPA have demonstrated that the risk to swimmers of contracting gastrointestinal illness seems to be predicted better by enterococci than by fecal coliform bacteria since the die off rate of fecal coliform bacteria is much greater than the enterococci die off rate (EPA, 2001). Moreover, a comparison of various fecal indicators of potential pathogens with disease incidence revealed that elevated levels of enterococci bacteria were most strongly correlated with gastroenteritis in both fresh and marine recreational waters (EPA, 1986). The USEPA believes that enterococci is best suited as an indicator organism for predicting the presence of gastrointestinal illness-causing pathogens in fresh water and marine waters and recommends that people do not swim in fresh waters that contain 33 or more enterococci per 100 milliliters (mL) or marine waters with 35 or more enterococci per 100 mL (EPA, 2000b).

Animal wastes contain large numbers of bacteria and other microorganisms. Although many of these organisms tend to die rapidly outside the animal, some can survive under favorable conditions. Microorganisms can survive for extended periods in fecal deposits on pasture, in soils, and in aquatic sediments (Thelin and Gifford, 1983; Kress and Gifford, 1984; Sherer et al., 1992). Conditions that promote die-off of microorganisms after land application include low soil moisture, low pH, high temperatures, direct solar radiation, and predation by protozoa. Manure storage generally promotes die-off, although pathogens can remain dormant at certain temperatures. Composting the wastes can be quite effective in decreasing the number of pathogens.

In a review of literature regarding the impacts of long-term animal waste applications on soil characteristics, it was concluded that positive impacts include buildup of soil organic matter, increased soil fertility, and improvement of soil physical properties (Wood and Hattey, 1995). Negative impacts include nitrate pollution of ground water, phosphorus contamination of surface water, and potential toxicity to crops from elevated concentrations of metals or other trace elements. For example, copper and zinc concentrations can build up where poultry litter and hog manure are applied.

The method, timing, and rate of manure application are significant factors in determining the likelihood that water quality contamination will result. Manure is generally more likely to be transported in runoff when applied to the soil surface than when incorporated into the soil. Spreading manure on frozen ground or snow can result in high concentrations of nutrients being transported from the field during rainfall or snowmelt, especially when the snowmelt or rainfall events occur soon after spreading (Robillard and Walter, 1986). Binding of phophorus with soil particles also increases as soil temperature increases. Winter spreading of manure onto corn fields in Vermont increased phosphorus export by up to 1500%, with up to 15% of the applied phosphorus lost in runoff (Meals, 1996). Soil type, crops, anticipated yields, and crop nutrient uptake are other factors that should be considered when determining the likelihood of manure contaminated runoff.

When application rates of manure for crop production are based on N, the P and K rates applied normally exceed plant requirements (Westerman et al., 1985). The soil generally has the capacity to adsorb much of the phosphorus from manure applied on land, but this capacity is not unlimited. As previously mentioned, however, nitrates are easily leached through soil into ground water or to return flows, and phosphorus can be transported by eroded soil.

Salts

Salts are a product of the natural weathering process of soil and geologic material. They are present in varying degrees in all soils and in fresh water, coastal waters, estuarine waters, and ground waters.

In soils that have poor subsurface drainage, high salt concentrations are created within the root zone where most water extraction occurs. The accumulation of soluble and exchangeable sodium leads to soil dispersion, structure breakdown, decreased infiltration, and possible toxicity; thus, salts often become a serious problem on irrigated land, both for continued agricultural production and for water quality considerations. High salt concentrations in streams can harm

Accumulation of excess sodium reduces agricultural production, and runoff of saline water harms aquatic ecosystems.

freshwater aquatic plants just as excess soil salinity damages agricultural crops. While salts are generally a more significant pollutant for freshwater ecosystems than for saline ecosystems, they may also adversely affect anadromous fish. Although they live in coastal and estuarine waters most of their lives, anadromous fish depend on freshwater systems near the coast for crucial portions of their life cycles.

The movement and deposition of salts depend on the amount and distribution of rainfall and irrigation, the soil and underlying strata, evapotranspiration rates, and other environmental factors. In humid areas, dissolved mineral salts have been naturally leached from the soil and substrata by rainfall. In arid and semi-arid regions, salts have not been removed by natural leaching and are concentrated in the soil. Soluble salts in saline and sodic soils consist of calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, and chloride ions. They are fairly easily leached from the soil. Sparingly soluble gypsum and lime also occur in amounts ranging from traces to more than 50% of the soil mass.

Irrigation water, whether from ground or surface water sources, has a natural base load of dissolved mineral salts. As the water is consumed by plants or lost to the atmosphere by evaporation, the salts remain and become concentrated in the soil. This is referred to as the "concentrating effect."

The total salt load carried by irrigation return flow is the sum of the salt remaining in the applied water plus any salt picked up from the irrigated land. Irrigation return flows provide the means for conveying the salts to the receiving streams or ground water reservoirs. If the amount of salt in the return flow is low in comparison to the total stream flow, water quality may not be degraded to the extent that use is impaired. However, if the process of water diversion for irrigation and the return of saline drainage water is repeated many times along a stream or river, water quality will be progressively degraded for downstream irrigation use as well as for other uses.

Another related issue is selenium toxicity. Selenium is a natural element in soil, found in a variety of geologic formations, including Cretaceous sediments in the western U.S. Selenium is essential to human and animal health in very small amounts, but is toxic to some organisms when ingested in excessive quantities (Letey et al., 1986). The major threat posed by selenium is the leaching of its soluble, oxidized form (selenate) from seleniferous soils and movement of leachate to shallow ground water and ultimately surface waters. It is in the aquatic environment where selenium enters the food chain through plants, which then become the food base for higher organisms such as insects, fish or birds. Accumulation and concentration of selenium as it moves up the food chain can become toxic (Letey et al., 1986).

In the western U.S., irrigation of soils from seleniferous parent materials can accelerate the natural leaching process. In the early 1980's, irrigation drainage water laden with high concentrations of selenium caused congenital deformities and mortality of waterfowl at Kesterson Reservoir, a National Wildlife Refuge in central California (Long et al., 1990). Concern over this incident prompted the U.S. Department of Interior to establish the National Irrigation Water Quality Program in 1985, to evaluate the potential for toxic effects of selenium in other irrigated areas of the west (Nolan and Clark, 1997).

Pesticides

The term *pesticide* includes any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest or intended for use as a plant regulator, defoliant, or desiccant. The principal pesticidal pollutants that may be detected in surface water and in ground water are the active and inert ingredients and any persistent degradation products. Pesticides and their degradation products may enter ground and surface water in solution, in emulsion, or bound to soil colloids. A study of 303 wells from across the Midwest showed that pesticide metabolites were found more frequently than the parent compounds (Kolpin et al., 1996). For example, the metabolite alachlor ethanesulfonic acid was detected nearly 10 times more frequently than alachlor in the 153 wells where both chemicals were analyzed. For simplicity, the term *pesticides* will be used to represent "pesticides and their degradation products" in the following sections.

Despite the documented benefits of using pesticides (insecticides, herbicides, fungicides, miticides, nematicides, etc.) to control plant pests and enhance production, these chemicals may, in some instances, cause impairments to the uses of surface water and ground water. Some types of pesticides are resistant to degradation and may persist and accumulate in aquatic ecosystems.

Many studies have evaluated pesticides in runoff and in streams, generally finding that the concentration can be relatively high near the application site soon after application with significant reductions further downstream and with time. Seasonal pulses of some of the most widely used pesticides can exceed lifetime maximum contaminant levels (MCL) established by the U.S. EPA, however the annual means on which those regulations are based are rarely exceeded (Larson et al., 1997).

Monitoring of seven Lake Erie tributaries from 1983 to 1993 detected maximum atrazine concentrations of 6.80 to 68.40 ug/L, and maximum concentrations of alachlor, metolachlor, metribuzin, cyanazine, and linuron ranging of 1.16 to 64.94, 5.39 to 96.92, 1.49 to 25.15, 1.36 to 24.77, and 1.92 to 15.5 ug/L, respectively (Baker, 1993). The long-term time-weighted mean concentrations in these cases, however, were all below EPA's maximum contaminant levels and lifetime health advisory levels for drinking water. In a related study, it was determined that alachlor and atrazine were the most frequently detected pesticides in drinking water supplies in Ohio (Baker and Richards, 1991). Although chronic health standards were not exceeded, public water supplies derived from rivers or reservoirs draining agricultural watersheds were more likely to have detectable residues of pesticides than other water supplies.

Pesticides have a wide range for potential harm to the environment due to the large variations in both chemical makeup and application schedule. Generally speaking, pesticides with higher levels of toxicity and persistence are more likely to create problems. Toxicity can be defined in terms of short-term (acute) and longer-term (chronic) effects. Acute effects usually occur soon after spraying, as in the case of a fish kill from drift or runoff. Chronic effects can occur when a pesticide is present in an environment over months or years at concentrations high enough to trigger a response by one or more organisms. Some of the pesticides banned years ago, such as DDT, had these effects on many birds and other organisms. Most pesticides currently in use have few reported chronic effects at levels commonly found in the environment.

Persistence is a measure of how long the chemical remains in the environment, which can be from days to years. A more persistent pesticide could present more of a risk for environmental contamination. The use of highly persistent pesticides is generally limited to situations where repeated applications would be undesirable, such as in termite control around buildings or vegetation control along right-of-ways.

The threat to water quality is often dependent upon the combination of application location and method. The highest risk occurs when aerial insecticide spraying is located near open water. This poses such a high risk because the chance for drift is greatest in aerial spraying compared to other application methods and insecticides are more likely to affect aquatic organisms than other types of pesticides. However, pesticide residues in runoff and ground water also pose a risk to water quality. Herbicides, compared to other pesticides, are more likely to travel by means of surface runoff or ground water as they are more widely used and are persistent enough to be detected many weeks after application. Concentrations of pesticides in ground water are generally low because soil retains most of the infiltrated pesticide residue. In areas where pesticides are widely applied, surface water has an annual cycle of higher residues during the growing season and much lower residues during the rest of the year.

The primary routes of pesticide transport to aquatic systems are through (Maas, 1984):

❑ Direct application;

❑ Runoff;

❑ Aerial drift;

❑ Leaching;

❑ Volatilization and subsequent atmospheric deposition; and

❑ Uptake by biota and subsequent movement in the food web.

The amount of field-applied pesticide that leaves a field in the runoff (either dissolved or adsorbed) and enters a stream primarily depends on:

❑ The intensity and duration of rainfall or irrigation;

❑ The length of time between pesticide application and rainfall occurrence;

❑ The amount of pesticide applied and its soil/water partition coefficient;

❑ The length and degree of slope and soil composition;

❑ The extent of exposure to bare (vs. residue or crop-covered) soil;

❑ Proximity to streams;

❑ Soil loss/erosion rate;

❑ Soil organic carbon content;

❑ The method of application; and

❑ The extent to which runoff and erosion are controlled with agronomic and structural practices.

Pesticide losses are generally greatest when rainfall is intense and occurs shortly after pesticide application, a condition for which water runoff and erosion losses are also greatest.

A study of herbicides and nutrients in storm runoff from nine stream basins in the Midwestern states from 1990-1992 showed sharp increases in triazine herbicides (e.g., atrazine) in the post-planting period (Scribner et al., 1994). Atrazine levels increased from 1.0 ug/L to peaks of 10-75 ug/L. EPA's maximum contaminant level (MCL) for atrazine in public water supplies is 3.0 ug/L. In this and many other studies, EPA MCLs are utilized as reference points for assessing water quality. It should be noted that an exceedance of the MCL in these surface or ground water quality monitoring studies does not necessarily indicate violation of a water quality standard.

In the Scribner et. al study (1994), it was concluded that transport of herbicides to streams was seasonal, with peaks from early May to early July. In a related study of 76 Midwestern reservoirs from April 1992 through September 1993, atrazine was the most frequently detected and persistent herbicide, followed by alachlor ethane sulfonic acid, deethylatrazine, deisopropylatrazine, metolachlor, cyanazine amide, and cyanazine (Scribner et al., 1996). Eight reservoirs had concentrations of one or more herbicides exceeding EPA's maximum contaminant levels or health advisory levels for drinking water during late April through mid-May, 1992, while 16 reservoirs had these high contaminant levels in late June through July, 1992. The annual average concentrations on which the MCLs are based are usually not exceeded, however, because residues drop to low or undetectable levels at other times of the year.

Research at the 5,600-ha Walnut Creek watershed in Iowa also showed that atrazine levels in runoff increased to above the MCL with heavy rains after chemical application. The total loss of atrazine and metolachlor in stream flow was about 1% of the amount applied each year. Herbicide concentrations in tile drains were often near the detection limit of 0.2 ug/L, while only atrazine and metolachlor exceeded 3.0 ug/L once in more than 1,700 ground water samples. Water balance studies indicated that the predominant flow path in the prairie-pothole watershed is from the bottom of the root zone into the stream through tile drains (Hatfield et al., 1995).

Concentrations of atrazine, alachlor, cyanazine, and metolachlor in Midwestern streams and reservoirs increased suddenly during rainstorms following herbicide applications (Goolsby et al., 1995). Atrazine levels less than 0.2 ug/L also persist year-round in Midwestern streams, partly due to the discharge of contaminated waters from surface and ground water reservoirs.

Elevated monthly average pesticide concentrations in Lake Erie tributaries usually occur in May to August, and smaller tributaries had higher maximum concentrations, more frequent concentrations below the detection limit, and fewer intermediate concentrations than larger tributaries (Richards and Baker, 1993).

From calculations combining estimated pesticide use data with measured load data, it was estimated that less than 2% of applied pesticides reached surface waters in the Mississippi River basin (Larson et al., 1995). Since the relative percentages of specific pesticides reaching the rivers were often not in agreement with projected runoff potentials, it was concluded that soil characteristics,

weather, and agricultural management practices are more important than chemical properties in the delivery of pesticides to surface waters. Richards and Baker (1993) concluded that average pesticide concentrations in Lake Erie tributaries are correlated with amount applied, but are also affected by chemical properties and modes of application of the pesticides.

The rate of pesticide movement through the soil profile to ground water is inversely proportional to the pesticide adsorption partition coefficient or Kd (a measure of the degree to which a pesticide is adsorbed by the soil versus dissolved in the water). The larger the Kd, the slower the movement and the greater the quantity of water required to leach the pesticide to a given depth. Other factors affecting pesticide movement include pesticide solubility as well as soil pH and temperature.

Pesticides can be transported to receiving waters either in dissolved form or attached to sediment. Dissolved pesticides may be leached to ground water supplies. Both the degradation and adsorption characteristics of pesticides are highly variable.

Pesticides have been widely detected in ground water, with concentrations usually much lower than in surface water but with greater longevity (Barbash and Resek, 1996). The most common detected are corn and soybean herbicides, which were reported to occur in up to 30% of samples in a national water quality assessment (Barbash et al., 2001). Of those with detections, 98% were below 1.0 ug/L and only exceeded the MCL in 2 of 2,227 sites. In another study, herbicides, including atrazine, prometron, metolachlor, and alachlor were detected in 24 percent of shallow aquifers in the Midwest sampled by USGS (Burkhart and Kolpin, 1993). Reported concentrations for all compounds were less than 0.5 ug/l. In Walnut Creek, Iowa, herbicides were not generally found in concentrations above 0.2 ug/l in shallow ground water (Hatfield et al. 1993). In the Mid-Atlantic region, pesticide compounds, including atrazine and its metabolites, metolachlor, prometron, and simazine, have been detected in about half of ground water samples analyzed, but rarely at concentrations exceeding established MCLs (Ator and Ferrari, 1997). The occurrence of pesticides in ground water of the Mid-Atlantic region was related to land cover and rock type: agricultural and urban land use practices are likely sources of pesticides, and rock type affects the movement of these compounds into and through the ground water system. Recently, Kolpin et al. (2000) found that one or more pesticides were detected at nearly half of 2500 USGS NAWQA ground water sites sampled across the United States. Observed pesticide concentrations were generally low. Pesticides were commonly detected beneath both agricultural and urban areas.

Habitat Impacts

The functioning condition of riparian-wetland areas is a result of interaction among geology, soil, water, and vegetation. Riparian-wetland areas are functioning properly when adequate vegetation is present to

- ❏ Dissipate stream energy associated with high water flows, thereby reducing erosion and improving water quality;

- ❏ Filter sediment and aid floodplain development;

❒ Support denitrification of nitrate-contaminated ground water as it is discharged into streams;

❒ Improve floodwater retention and ground water recharge;

❒ Develop root masses that stabilize banks against fluvial erosion (scouring) and gravitational bank collapse (slumping);

❒ Develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses; and

❒ Support biodiversity.

Numerous land uses, such as silviculture, agriculture, and urbanization, have the potential to degrade riparian habitats. Improper livestock grazing affects all four components of the water-riparian system: banks and shores, water column, channel morphology, and aquatic and bordering vegetation (Platts, 1990). The potential effects of improper grazing management or improper use of grazing lands include:

Shore/banks

❒ Shear or sloughing of streambank soils by hoof or head action.

❒ Water, ice, and wind erosion of exposed streambank and channel soils because of loss of vegetative cover.

❒ Elimination or loss of streambank vegetation.

❒ Reduction of the quality and quantity of streambank undercuts.

❒ Increasing streambank angle (laying back of streambanks), which increases water width, decreases stream depth, and alters or eliminates fish habitat.

Water Column

❒ Excessive withdrawal from streams to irrigate grazing lands.

❒ Drainage of wet meadows or lowering of the ground water table to facilitate grazing access.

Riparian-wetland vegetation is essential for stable aquatic ecosystems.

❒ Pollutants (e.g., sediments) in return water from grazed lands, which are detrimental to the designated uses such as fisheries.

❒ Changes in magnitude and timing of organic and inorganic energy (i.e., solar radiation, debris, nutrients) inputs to the stream.

❒ Increase in fecal contamination.

❒ Changes in stream morphology, such as increases in stream width and decreases in stream depth, including reduction of stream shore water depth.

❒ Changes in timing and magnitude of stream flow events from changes in watershed vegetative cover.

❒ Increase in stream temperature.

Channel

❒ Changes in channel morphology.

❒ Altered sediment transport processes.

Riparian Vegetation

❑ Changes in plant species composition (e.g., shrubs to grass to forbs).

❑ Reduction of floodplain and streambank vegetation including vegetation hanging over or entering into the water column.

❑ Decrease in plant vigor.

❑ Changes in timing and amounts of organic energy leaving the riparian zone.

❑ Elimination of riparian plant communities (i.e., lowering of the water table allowing xeric plants to replace riparian plants).

Water temperature plays a key role in the life of fish and other aquatic organisms by influencing their distribution, growth rate, and survival (Barthalow, 1989; Holmes and Regier, 1990; Armour 1991), as well as migration patterns, egg maturation, incubation success, competitive ability, and resistance to parasites, diseases, and pollutants (Armour 1991). Increases in water temperature can also cause shifts in algal communities from cold-water diatoms to warm-water green and blue-green species which can cause other water quality problems (Horner et. al, 1994). In addition, water temperature affects the rates of in-stream chemical reactions, the self-purification capacity of streams, and their aesthetic and sanitary qualities (Feller 1981). Changes in channel morphology leading to an increased stream width and decreased depth, as well as loss of riparian vegetation, have the potential to alter stream temperature. A wider and shallower stream has a greater surface area and a greater air-water interface, where most energy exchanges occur; hence, the surface area of the stream is directly related to water temperature changes. Also, losses in riparian vegetation expose the stream to greater temperature fluctuations, resulting in potentially higher temperatures during the day and cooler temperatures at night. Riparian vegetation acts to moderate stream temperatures by absorbing short-wave radiation during the day and insulating the stream from loss of long-wave radiation at night.

> Improper livestock grazing can have devastating impacts on streambanks, hydrology, water quality, and aquatic habitat.

Improperly managed livestock grazing can significantly contribute to streambank erosion and riparian habitat degradation. In a study of 60 streams in the Intermountain West, it was found that grazed stream habitats were substantially degraded with poor riparian conditions (Robinson and Minshall, 1995). Problems associated with improper grazing management included reduced riparian cover, exposed streambanks, high sediment levels, elevated water temperatures, higher nutrient levels, and a shifting to more stress-tolerant invertebrates.

Soil erosion, primarily from poor grazing management and poorly maintained riparian areas, is causing excessive sedimentation to the Missouri River in South Dakota (Osmond et al., 1997). This sedimentation has impaired recreational uses and hydropower generation, and has increased flooding in the cities of Pierre and Ft. Pierre. Improper livestock grazing management has also contributed to declines in anadromous fish populations in the Upper Grande Ronde Basin in Oregon (Osmond et al., 1997). Increased stream water temperature and loss of habitat, caused largely by the loss in riparian vegetation, are key factors in the decline (Hafele, 1996). Improper grazing management in the Morro Bay, California, watershed has stripped riparian areas of their vegetation and decreased streambank stability, contributing to the excessive erosion in the watershed

(Osmond et al., 1997). Sedimentation has caused negative impacts to both the oyster industry and anadromous fish species. Streambank erosion in Peacheater Creek, Oklahoma, has impaired aquatic habitat (Osmond et al., 1997).

Mechanisms to Control Agricultural Nonpoint Source Pollution

There exists a considerable amount of jargon associated with the mechanisms to control nonpoint source pollution. Terms include *best management practices (BMPs), management practices, accepted agricultural practices, management measures, BMP systems, management practice systems, resource management systems (RMSs), total resource management systems*, and the like. Some of these terms are based in legislation or regulations such as the management measures specified by EPA for the section 6217 coastal nonpoint pollution control program (EPA, 1993a) and Vermont's accepted agricultural practices (Vermont Department of Agriculture, 1995), while other terms are found in technical manuals, journal articles, and informational materials.

The meanings of the terms also vary. Most practitioners consider *BMPs* to be individual practices or groups of practices that serve specific functions such as excluding livestock or routing water safely away from eroding or contaminated areas. *Management measures* are generally groups of affordable management practices that are used together in a system to achieve more comprehensive goals such as minimizing the delivery of sediment from a farm to receiving waters or maximizing the efficiency with which nutrients are applied to croplands to achieve reasonable yields. RMSs generally go beyond management measures in that they may contain practices that address natural resource concerns other than water quality, and must meet criteria for soil, water, air, and related plant, animal, and human resources. Since the focus of this guidance is water quality issues, the full complement of issues addressed in a typical RMS is not addressed. For example, water quality performance expectations are contained in the management measures, but criteria for animal resources are absent. Resource management *planning concepts* are discussed briefly in this chapter, however.

Because definitions of terms overlap, there is no clear hierarchy or levels of control that can be adopted for this guidance and agreed upon by all readers, but the following statements apply:

❒ Complete RMSs are not presented in this guidance, but resource management planning concepts are discussed. The water quality aspects and some of the soil, air, and plant criteria of an RMS are addressed through the management measures.

❒ Individual management practices are the building blocks for management practice systems and management measures.

❒ Implementation of all six management measures, as appropriate, will result in a comprehensive, technology-based water quality protection plan on most[1] farms.

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[1] In some cases, additional control practices may be needed to address problems that are not anticipated by the management measures.

Management Measures

Management measures are defined under section 6217 of CZARA as:

> economically achievable measures for the control of the addition of pollutants from existing and new categories and classes of nonpoint sources of pollution, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint source control practices, technologies, processes, siting criteria, operating methods, or other alternatives.

The management measures specified by EPA for section 6217 contain performance expectations and, in many cases, specific actions that are to be taken to prevent or minimize nonpoint source pollution (EPA, 1993a). For example, the performance expectations for erosion and sediment control for agriculture are "to minimize the delivery of sediment from agricultural lands to surface waters" or "to settle the settleable solids and associated pollutants in runoff delivered from the contributing area for storms up to and including a 10-year, 24-hour frequency." Individual management practices or specific actions needed to achieve these performance expectations are not included in the management measure statement. The management measure for pesticides, however, includes both performance expectations ("reduce contamination of surface water and ground water from pesticides") and specific practices and actions such as anti-backflow devices on hoses, and calibration of pesticide spray equipment. Thus, in most cases, there is considerable flexibility to determine *how* to best achieve the performance expectations for EPA's section 6217 management measures.

EPA's six management measures for agriculture are described in Chapter 4.

Management Practices

"Best" management practices, BMPs, are designed to reduce the quantities of pollutants that are generated at and/or delivered from a source to a receiving water body. In EPA's guidance for section 6217, the term *management practice* is used in lieu of *BMPs* since "best" can be a highly subjective and site-specific label. For example, the BMP manuals used by States to implement the Clean Water Act section 319 program are not identical although much consistency exists across States. Even within States, a practice may be considered best in one area (e.g., coastal plain) but inappropriate in another area (e.g., mountains). Criteria for determining what is best may include extent of pollution prevention or pollutant removal, ease of implementation, ease of maintenance and operation, durability, attractiveness to landowner (e.g., how willing will farmers be to implement the practice in a voluntary program?), cost, and cost-effectiveness. The relative importance assigned these and other criteria in judging what is best varies across States, within States, and among landowners, often for very good reasons (e.g., irrigation water management considerations are very different in western States with low rainfall and water rights laws, versus midwestern States with diminishing ground-water reserves, versus eastern States with plentiful rainfall and surface waters). For these reasons, this guidance is consistent with the section 6217 management measures guidance in its use of the term "management practice" rather than "BMP."

Management practices can be structural (e.g., waste treatment lagoons, terraces, or sediment basins) or managerial (e.g., rotational grazing, nutrient management, pesticide management, or conservation tillage). Management practices generally do not stand alone in solving water quality problems, but are used in combinations to build *management practice systems*. For example, soil testing is a good practice for nutrient management, but without estimates of realistic yield; good water management; appropriate planting techniques and timing; and proper nutrient selection, rates, and placement; the performance expectations for nutrient management cannot be achieved.

Each practice, in turn, must be selected, designed, implemented, and maintained in accordance with site-specific considerations to ensure that the practices function together to achieve the overall management goals. For example, a grassed waterway must be designed to handle all of the water that will be conveyed to it from upland areas, including all water re-routed with diversions and drainage pipes. Design standards and specifications must be compatible for practices to work together as effective systems.

A summary of agricultural management practices and how they function in systems is given in Chapter 3. Management practices that can be used to achieve each of the six agricultural management measures are described in Chapter 4.

Resource Management Planning Concepts

Resource management planning, also known as conservation planning, for agricultural operations is a natural resource problem solving and management process. The process integrates economic, social (including cultural resources), and ecological considerations to meet goals and objectives. It involves setting of personal, environmental, economic, and production goals for the farm or ranch. The challenge in resource management planning is to balance the short-term demands for production of food, fiber, wood, and other agricultural products, with long-term sustainability of a quality environment.

Resource management systems are combinations of conservation practices and resource management, identified by land or water uses, for the treatment of all natural resource concerns for soil, water, air, plants, and animals that meets or exceeds the quality criteria for resource sustainability. The quality criteria are described in the USDA Natural Resources Conservation Service (NRCS) Field Office Technical Guide (FOTG). See Appendix B for additional information on the FOTG.

> A resource management plan for the farm serves to maintain quality of life while achieving goals for profitability and water quality.

Resource management planning is preferred by land managers who have a negative reaction to "single purpose plans" that address individual economic or natural resource issues. Essential goals for a farm or ranch resource management plan include:

❐ Improving or ensuring profitability by finding solutions that save money, increase sales, improve product quality, or simplify/reduce the work;

❐ Reducing water pollution through application of appropriate systems of management practices;

❑ Coordinating regulatory input so that implementation of the resource management plan will assure compliance with all applicable regulations impacting the agricultural operation; and

❑ Incorporating the farm or ranch family's personal goals for quality of life.

NRCS and its cooperating conservation partners use a three-phase, nine-step planning process. This process is very dynamic, frequently requiring planners to cycle back to previous steps in order to fully achieve the goals set for the plan. Many states are developing their own resource management planning protocols. An example of one of these efforts is the Idaho One Plan. The Idaho program was developed to reduce diverse agency requirements and to produce a user-friendly product that allows farmers and ranchers to develop resource management plans unique to their operations.

Individuals interested in resource management planning should contact their local NRCS office, soil and water conservation district, cooperative extension service, land grant university, state department of agriculture, or other appropriate agency to learn more about locally available information.