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ABSTRACT

Nonpoint source pollution is both a relatively recent concern and a complex phenomenon with many unknowns. Knowing the extent to which agricultural sources contribute to the total pollutant load, the extent to which various control practices decrease this load, and the effect of reducing the pollutants delivered to a water body are basic to the achievement of water quality. The purposes of this guide are to provide information on the control of nonpoint sources of pollution from agricultural lands and to incorporate a water quality perspective into conservation planning and education. This guide covers agricultural lands and addresses the most common land uses: cropland, hayland, pastureland, rangeland, and woodland. It does not cover acid mine drainage or dryland saline seeps. It focuses on five major classes of pollutants from agricultural nonpoint sources and how they move into receiving waters. A glossary of applicable terms is appended. Twenty-six references are listed. (CW)

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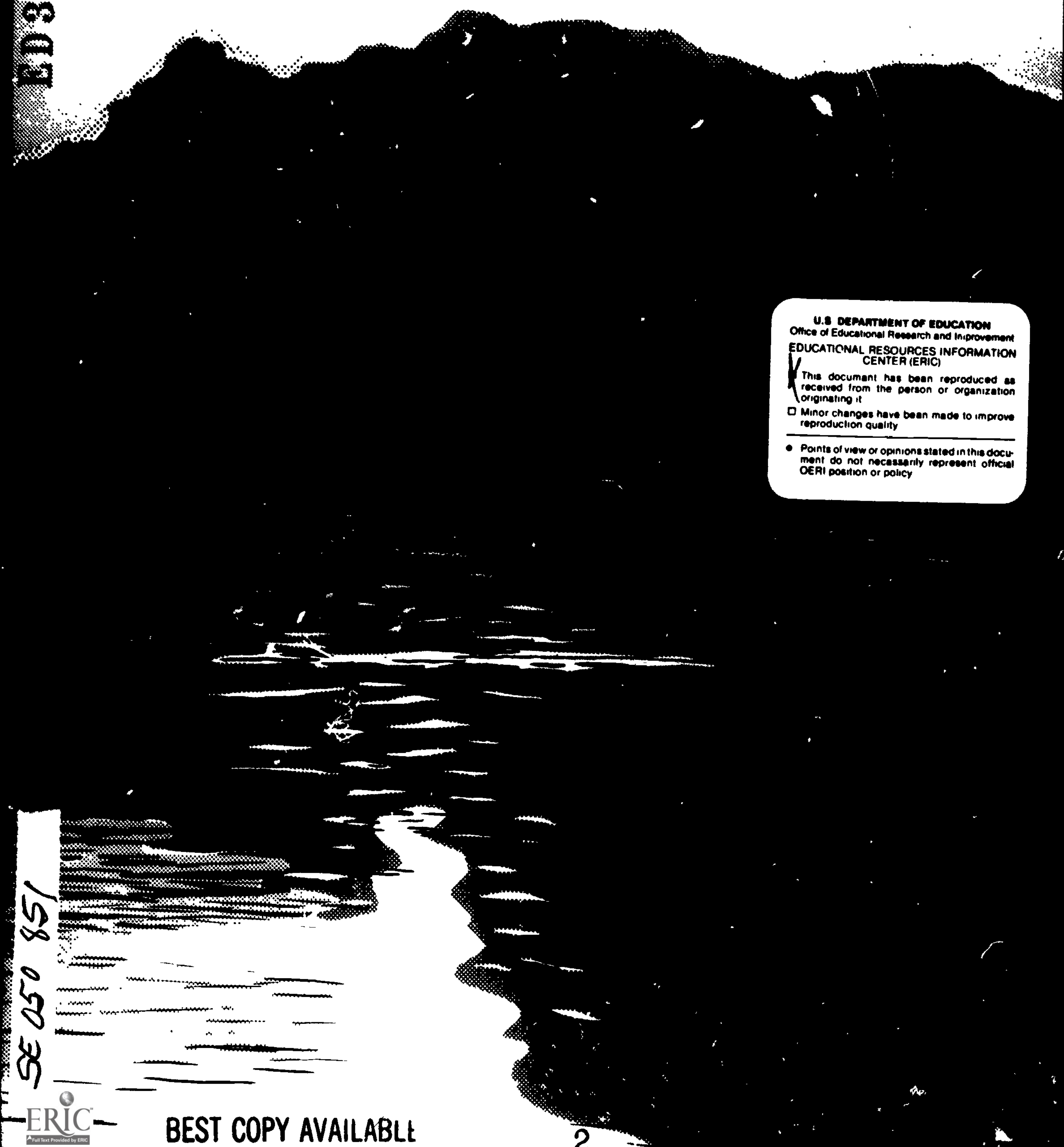
Water Quality Field Guide



United States Department of Agriculture

Soil Conservation Service

Water Quality Field Guide

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Chapter 1
Pollution Identification and Control

Purpose and Scope

The purposes of this guide are to provide information to Soil Conservation Service (SCS) Field Office Personnel on the control of nonpoint sources of pollution from agricultural lands and to incorporate a water quality perspective into all conservation planning. Nonpoint source pollution is both a relatively recent concern and a complex phenomenon with many unknowns. Knowing the extent to which agricultural sources contribute to the total pollutant load, the extent to which various control practices decrease this load, and the effect of reducing the pollutants delivered to a water body are basic to the achievement of water quality.

This guide covers all agricultural lands and addresses the most common land uses—cropland, hayland, pastureland, rangeland, and woodland. It does not cover acid mine drainage or dryland saline seeps. It focuses on five major classes of pollutants from agricultural nonpoint sources and how they move into receiving waters. The guide is to be used in conjunction with other SCS references such as the Field Office Technical Guide, the Agricultural Waste Management Field Manual, the Engineering Field Manual for Conservation Practices, the National Handbook of Conservation Practices, and the National Conservation Planning Manual. Personnel working primarily in silviculture should also refer to the "National Forestry Water Quality Training Program," developed jointly by the Forest Service and the Environmental Protection Agency.

Problem Identification

The first step when addressing water quality is to determine if there is a problem, and if so, its nature and magnitude. A problem occurs when there is an unfavorable condition in the receiving waters which adversely affects a designated use of water. Some of the more common uses are f[illegible]rigation, livestock, recreation, fish and wild[illegible] for domestic use. If any of these uses are impaired, there is a water quality problem.

Water quality is not easy to define. The desired level of water quality depends upon how the water will be used. Water for irrigation need not have the same chemical content as water for swimming or drinking. Even irrigation water quality may vary, depending on the salt tolerance of the crops to be irrigated. If, for example, irrigation water is so saline as to restrict plant growth, its use is impaired and we say the water quality is poor. It is in the context of use impairment that the term water quality will be used in this guide. Table 1-1 lists a number of agricultural pollutants and their impact on water use.

A water quality problem may be highly localized (fish kill in a farm pond) or regional, national and even international in scope. The water quality problems in Lake Erie, for instance, involve the U.S. and Canada and include recreation, drinking water, and commercial fishing uses, among others. Problem identification may be as simple as a complaint to a local health board or as structured as the national planning process that took place under Section 208 of the Water Quality Act. Many of the water quality management plans developed in this process identify water quality problems and prioritize them for action. Even if there is no known water quality problem, SCS needs to integrate water quality into all its activities. Chapter 5 discusses this and relates it to objectives in conservation planning. These objectives depend on whether or not there is an identified water quality problem.

Principles of Nonpoint Source Pollution Control

The following principles are important in developing a step-by-step procedure for nonpoint (diffuse) source pollution control:

1. *For a water quality problem to exist, the water must be impaired for some use*—drinking water supply, fishing, recreation, etc. The same body of water may have one or more totally different problems depending on its various uses. The physical, chemical, and biological characteristics of the water body will determine the severity of the water quality problem and the potential for improvement with implementation of control measures. Naturally occurring substances, such as phosphate or nitrate, are pollutants only when their concentrations in the water are high enough to cause a water quality problem.

2. *Once the pollutant or pollutants* causing the water quality problem *are identified, the roles of the pollutants* in deteriorating water quality *must be understood and the sources* of the pollutants *must be identified.*

3. *The process by which each agricultural nonpoint source pollutant is generated and transported to the water body must be identified.* The *availability* of a pollutant to be lost from the land, and its *detachment* and *transport* will depend on the physical, chemical, and biological properties of the pollutant and its reactions in soil and water. Pollutants that are strongly adsorbed by soil are susceptible to detachment and transport with the soil. Soluble materials that have a low affinity for soil particles are more susceptible to leaching losses. Some potential pollutants, such as heavy metals, do not change significantly in terrestrial or aquatic systems, and analysis of the water quality problem can focus on the total amount of the metal involved. Nitrogen, on the other hand, exists in many forms and is subject to chemical or biological transformations that may reduce or increase the water quality effect. Biological denitrification of nitrate to nitrogen gas (N_2) can reduce the nitrate concentration in a stream or lake, whereas nitrification of the NH_4 adsorbed on soil particles will increase nitrate levels. Phosphate adsorbed on a soil particle can be released into solution when it enters a lake with a low dissolved phosphate concentration.

4. *For a practice to be effective in reducing diffuse sources of pollutants, it must be able to interfere with the availability, detachment, or transport of a pollutant.* In other words, the practice must decrease the availability, prevent the detachment, or interrupt the transport process if the pollutant load is to be decreased. In selecting an appropriate practice, one must consider the relative merits of permanent practices that have high capital costs versus those that have lower capital costs but require careful continuous management by the farmer. Practices that solve one water quality problem must not increase the potential for another problem. Practices may be appropriate for certain types of problems (e.g., no till for reducing soil erosion), but if that practice does not adequately control the target pollutant, then it cannot be considered the "best management practice" for solving the existing water quality problem.

5. *SCS should integrate water quality into all its activities.* If a water use impairment exists, SCS should work to improve water quality. If there is no known problem, SCS should work to maintain existing water quality. No activity should be undertaken that will degrade water quality.

Summary

When solving a water quality problem (a) the problem must be clearly recognized, (b) the pollutant or pollutants causing the problem must be identified, (c) the cause-and-effect relationship between the pollutant and the water quality effect must be determined, (d) the source of the pollutant must be detected, (e) the pathway of the pollutant from its source to the water body must be described, and (f) the appropriate control practice(s) must be selected and applied.

Table 1-1. Typical water use impairment of agricultural source pollutants[1]

Pollutant category	Primary impact	Secondary impact	Notes
Nutrients nitrogen phosphorus	Lake enrichment causes aquatic plant growth which interferes with recreational uses. High ammonia concentration (.02 mg/l) can kill fish. High nitrate concentration (45 mg/l nitrate or 10 mg/l NO_3-N) exceeds safe drinking water standard.	Decreases oxygen levels. Changes color. Encourages nongame fish population. Produces objectionable odor. Increases need for treatment of water supply.	Threshold N & P concentrations of 0.30 mg/l and 0.05 mg/l have been associated with accelerated growth of aquatic plants.
Sediment	Fills drainage ditches, culverts, stream channels, and reservoirs. Plugs water intakes and filters. Increases wear on power turbines, sprinklers and pumps. Increases water treatment costs. Reduces recreational use of water. Harmful to fish and other aquatic life.	Reduces sunlight penetration. Changes color.	
Animal Waste nitrogen) phosphorus)	----------Same as that stated under "Nutrients"-------------		
oxygen-demanding materials pathogens	Decreases fish populations and recreational uses because of low oxygen levels and fecal contamination. Increases need for treatment of water supply.	Produces objectionable odor. Produces objectionable taste. Changes color.	
Salinity salt compounds	Can harm fresh water aquatic fish and plants. Causes corrosion of pumps and pipes. Greatly increases cost for treatment of water supply.	Delays or prevents crop germination for downstream irrigators. Reduces plant growth and yield.	
Pesticides herbicides insecticides fungicides miticides	Toxic to fish and aquatic plants.	Produces sublethal effects. Produces synergistic effects. Causes biotransfers in food chains. Produces long-term mutagenic effects on cell growth and development.	

[1]Adopted from a Planning Guide for the Evaluation of Agricultural Nonpoint Source Water Quality Controls, U.S. Environmental Protection Agency.

Chapter 2

Pollutants That Cause Water Use Impairment

The primary agricultural nonpoint source pollutants are nutrients, sediment, animal wastes, salts, and pesticides.

Nutrients

Nitrogen and phosphorus are the two major nutrients from agricultural land that degrade water quality. All plants, whether land based, aerial, or aquatic, require nutrients for growth. In an aquatic environment, nutrients usually limit plant growth. Nitrogen and phosphorus generally are present at background or natural levels below 0.3 and 0.05 mg/l, respectively. When these nutrients are introduced into a stream or lake 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.

Increased aquatic plant productivity results in additional organic material being added to the system that eventually dies and decays. The decaying organic matter produces unpleasant odors and depletes the oxygen supply required by aquatic organisms. Excess plant growth also may interfere with recreational activities such as swimming and boating. Depleted oxygen levels, especially in colder bottom waters where dead organic matter tends to accumulate, will reduce the quality of fish habitat and encourage fish which are adapted to less oxygen or to warmer surface waters. Highly enriched waters will stimulate algae production, with consequent increased turbidity and color. When such water is used by municipalities and industries, treatment costs are increased. Chapter 3 gives additional information on the classification (trophic levels) of lakes.

Nitrogen

In addition to cultural eutrophication, excessive nitrogen causes other water quality problems. Dissolved ammonia at concentrations above 0.2 mg/1 may be toxic to fish, especially trout. Nitrates in drinking water are potentially dangerous, especially 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 Environmental Protection Agency has set a limit of 10 mg/1 nitrate-nitrogen in water used for human consumption (22).

Nitrogen is naturally present in soils but must be added to increase crop production. 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 one time. Organic nitrogen normally constitutes the majority of the soil nitrogen. It is slowly converted (2 to 3 percent per year) to the more readily plant available inorganic ammonium or nitrate.

The chemical form of nitrogen affects its impact on water quality. The most biologically important inorganic forms of nitrogen are ammonium (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-). Organic nitrogen occurs as particulate matter, in living organisms, and as detritus. It occurs in dissolved form in compounds such as amino acid, amines, purines, urea, etc.

Three microbial processes of nitrogen transformation relate to the control of agricultural pollution. The first two are part of the mineralization process, which makes nitrogen available for crop uptake. Ammonia is the initial product of organic matter decomposition. When ammonia is oxidized, nitrites are formed which are readily converted to nitrates. Nitrates are an important plant nutrient but they are highly mobile in water and easily leached through the soil. The last reaction, denitrification, causes nitrogen to be lost to the atmosphere. It operates against the producer, who wants to maximize nitrogen availability and retention to maximize crop yields. Denitrification benefits water quality, however, by reducing the quantity of nitrogen available in the soil for leaching and surface runoff.

Nitrate-nitrogen is highly mobile and can move readily below the crop root zone, especially in sandy soils. It can also be transported with surface runoff, but not generally in large quantities. Ammonium on the other hand, becomes adsorbed by 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 convert to an available form later. All forms of transported nitrogen are potential contributors to lake eutrophication. Chapter 11 of the Agricultural Waste Management Field Manual gives additional information on nitrogen forms, losses, mineralization, and the nitrogen cycle.

Phosphorus

The phosphorus content in most soils is low, between 0.01 and 0.2 percent by weight. Most of this is unavailable for plant uptake. Manure and fertilizers are used to increase the level of available phosphorus in the soil to promote plant growth. If runoff and erosion occur, some of the applied phosphorus can reach nearby bodies of water. High-intensity storms increase the loss of particulate inorganic phosphorus from croplands because this form of phosphorus is associated with eroding sediments.

Phosphorus can be found in the soil in dissolved, colloidal, or particulate forms. (See the glossary for the definitions of the various phosphorus forms.) It occurs as inorganic orthophosphate or polyphosphate or as organic phosphorus. In many lakes, organic phosphorus comprises as much as 95 percent of the total phosphorus and will largely be in aquatic plants. However, dissolved inorganic phosphorus (orthophosphate phosphorus) is probably the only form directly available to algae. Algae consume dissolved inorganic phosphorus and convert it to the organic form. Phosphorous is rarely found in concentrations high enough to be toxic to higher organisms.

Phosphorus unavailable in the soil system may erode with soil particles and later be released when the bottom sediment of a stream or lake becomes anaerobic, creating water quality problems. Most researchers believe, however, that the conversion of particulate phosphorus to soluble phosphorus does not exceed 20-30 percent (8). Resuspended bottom sediment in shallow lakes continually provides a new supply of available phosphorus to algae.

Inorganic phosphorus can be either dissolved in surface or subsurface waters or associated with sediments. Although much of the sediment-held portion acts as if it were permanently fixed on the soil, some of it serves as a source of the dissolved (available) form. The portion of the phosphorus held by the soil that is subject to change is referred to as the labile fraction. This portion is normally several hundred times larger than the dissolved portion. The equilibrium between labile and dissolved inorganic phosphorus depends, in part, on the chemical and biological characteristics of the water regime in the soil or water body.

The amount of dissolved phosphorus changes during transport from cropland to stream and lakes. Estimating the potential impact of phosphorus on water quality is difficult because the relationships between various forms of phosphorus in the soil and sediments, water, and biota are poorly understood. Despite the lack of understanding, water quality practices are known which will significantly reduce phosphorus losses from agricultural lands.

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 air, water, gravity, or ice. The types of erosion that produce sediment are (1) sheet and rill erosion, (2) gully erosion, (3) stream channel erosion, (4) road and roadside erosion, and (5) other types of erosion, such as that associated with urban development, construction sites, etc. Sediments from the different sources vary in the kinds and amounts of pollutants that are adsorbed to the particles. Sheet and rill erosion mainly move soil particles from the surface or plow layer of the soil. Eroded soil is either redeposited on the same field or transported from the field in runoff.

Sediment which originates from surface soils will have 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.

Sediment from cropland usually contains a higher percentage of finer and less dense particles than the soil from which it originates. Large particles are more readily detached from the soil surface because they are less cohesive. They will 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. This selective erosion process can increase overall pollutant delivery, because small particles have a much greater adsorption capacity per mass than larger particles. As a result, eroding sediments generally contain higher concentrations of phosphorus, nitrogen, and pesticides than the original soil.

The concept of an enrichment ratio is used to characterize the quantity of a substance in sediment relative to that in the original soil. The enrichment ratio can be defined as the concentration of a substance in the sediment compared to the concentration of the substance *in situ* in the soil. Enrichment ratios are typically greater than unity. Factors affecting the enrichment ratio include soil, kind of erosion, and character of the runoff.

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, and clog the gills of fish. This reduces fish shellfish, and plant populations and decreases the overall productivity of lakes or streams. Turbidity interferes with feeding habits of fish. Recreation is limited because of the decreased fish population and the water's unappealing, turbid appearance. Turbid water reduces visibility, thus it is less safe for swimming.

Sediment fills farm drainage ditches, road ditches, culverts, and stream channels and shortens the economic life of reservoirs and farm ponds. It can plug water filters, erode power turbines and sprinkler nozzles, and damage pumping equipment. Maintenance costs are increased and additional treatment may be necessary before the water can be used for drinking or industrial purposes.

Sediment does not always have a detrimental effect, however. Its presence can contribute to streambank and channel stability. It can be beneficial as it may reduce dissolved inorganic phosphorus concentrations in surface waters. The clay-organic complexes in sediment act as scavengers as a result of their ability to adsorb some chemicals in runoff waters.

Chemicals such as some pesticides, phosphorus, and ammonium are transported with sediment in an adsorbed state. The toxicity of a pesticide does not necessarily decrease because of its adsorption to sediment, but its association with the sediment will normally cause much of it to settle out in the receiving water. However, the toxicity of some insecticides, such as toxaphene, decreases faster under anaerobic conditions, and adsorbed insecticides have a greater opportunity for exposure to anaerobic conditions. Changes in the aquatic environment, such as a lower concentration 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.

Animal Wastes

Animal wastes and manure are used interchangeably in this manual. They include the fecal and urinary defecation of livestock and poultry, process water (such as from a milking parlor), and the feed, bedding, litter, and soil with which they become intermixed. Animal wastes can contribute nutrients, organic materials, and pathogens to receiving waters.

Manure will be more easily removed in runoff when applied to the soil surface than when incorporated in 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. The problems associated with nitrogen and phosphorus, as discussed in the section *Nutrients,* also apply to animal wastes. If sufficient manure is applied to meet the nitrogen needs of a crop, phosphorus will generally be in excess. The soil generally has the capacity to adsorb any phosphorus leached from manure applied on land. However, as previously mentioned, nitrates are easily leached through soil into ground water or to return flows.

The demand for oxygen exerted by carbonaceous materials (individually or in combination with nitrogen) can deplete dissolved oxygen supplies in water, resulting in anoxic or anaerobic conditions. When the decomposition process becomes anaerobic, methane, amines, and sulfide are produced. The water acquires an unpleasant odor, taste, and appearance and becomes unfit for drinking, and for fishing and other recreational purposes.

Animal diseases can be transmitted to humans through contact with animal feces, but manure that has been incorporated is rarely a public health problem. The bacteria present in manure, including possible pathogens, are filtered by the soil and rarely infiltrate more than a few centimeters into the soil profile. Ground-water contamination is usually not a problem if manure is incorporated. Runoff from fields receiving manure will contain extremely high numbers of bacteria if the manure has not been incorporated or the bacteria have not been subject to stress.

Conditions which cause a rapid dieoff of bacteria are low soil moisture, low pH, high temperatures, and direct solar radiation. Manure storage generally promotes dieoff, although pathogens can remain dormant at certain temperatures. Composting the wastes is quite effective in decreasing the number of pathogens.

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 both surface and ground waters.

The salt content of water is usually expressed as the total dissolved solids (TDS) concentration (mg/1) or as electrical conductivity with units of

decisiemens/meter. (See Glossary.) The salt content of soil is usually expressed in percent salt or as electrical conductivity of the soil water extract.

The ions that make up a salt solution are those which are most soluble and in greatest abundance in nature: anions — Cl^-, SO_4^{2-}, HCO_3^-, CO_3^{2-} and cations— Na^+. K^+, Ca^{2+}, Mg^{2+}, H^+, Al^{3+}, Fe^{2+}. These elements can be considered to occur frequently in the soil and substrata as —

Compound	Cation (+) Anion (−)	Salt
$NaCl$	Sodium chloride	Table salt
$MgSO_4$	Magnesium sulfate	Epsom salt
Na_2SO_4	Sodium sulfate	Glaubers salt
Na_2CO_3	Sodium carbonate	Sal soda
$NaHCO_3$	Sodium bicarbonate	Baking soda
$CaCO_3$	Calcium carbonate	Lime
$CaSO_4$	Calcium sulfate	Gypsum

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 and lakes can harm freshwater aquatic plants just as excess soil salinity damages agricultural crops.

In addition to the total amount of salt, the sodium concentration can have specific damaging effects on soils and plants. Sodium, at high concentrations in the soil solution, causes clay particles to disperse and lose their permeability. A measure of the sodium content of soil is the sodium adsorption ratio (SAR), which is the fraction of the soil cation exchange capacity occupied by sodium.

The movement and deposition of salts depend on the amount and distribution of rainfall, the soil and underlying strata, evapotranspiration rates, and other environmental factors. In humid areas, salts have been naturally leached from the soil and substrata by rainfall. In arid and semiarid regions, salts have not been removed by natural leaching and are concentrated in the soil. Soluble salts in saline and alkali soils consist of calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, and chloride. They are fairly easily leached from the soil. Less soluble gypsum and lime also occur. The amounts present range from traces to more than 50 percent of the soil mass. The total dissolved quantities of ions in ground water and streams include the soluble salts, gypsum and lime.

Irrigation water, whether from ground water or surface water sources, has a natural base load of dissolved salts. As the water is consumed by plants or lost to the atmosphere by evaporation, the salts remain and become concentrated. This is referred to as the "concentrating effect." Thus, the addition of salts to agricultural land is an undesirable but inescapable consequence of irrigation.

To maintain productivity of irrigated land, the accumulations of soluble salts must be moved below the root zone. The amount of irrigation water applied to the field must exceed the evapotranspiration requirement of the crop to allow for leaching the soluble salts. Leaching creates another problem, however, by transporting salts to ground water and streams.

In addition to the salts leached out of the crop root zone, the leaching water and excess water from poor irrigation can pick up salts from substrata of marine or lacustrine origin. This is commonly referred to as "salt pickup." Many areas in the western part of the United States have highly saline marine or lacustrine materials underlying the soil layer. Deep percolation of irrigation water often brings large quantities of salt from these formations back to the streams in subsurface return flows.

The total salt load carried by irrigation return flow is the sum of the original salt in the applied water resulting from the concentrating effect plus salt pickup. 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 the 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.

Salinity control is complicated by the fact that salts can be pollutants both in the irrigated soils and in the water receiving the drainage. Efforts aimed at reducing salt leaching may reduce crop production. This is especially true if the quantity of irrigation water applied is decreased without increasing the efficiency.

Pesticides

Pesticides—insecticides, herbicides, fungicides, miticides, nematicides, etc.—are used extensively in agriculture to control plant pests and enhance production. However, despite the documented benefits, these chemicals may, in some instances, endanger surface

and ground water and ultimately human health. With agriculture accounting for over 70 percent of the pesticides used in the United States, it is important to understand all we can about them to prevent the loss of significant amounts into receiving waters.

Pesticides are lost from an agricultural field through volatilization, degradation (chemical and biological), leaching, and by removal in runoff water (in solution or on the sediment). Because volatilization does not appear to pose a major threat to water quality, only the last three processes will be discussed.

Although the benefits of pesticides are substantial, there are also environmental problems related to their use. Pesticides may harm the environment by eliminating or reducing populations of desirable organisms. Some types of pesticides or their metabolites are resistant to degradation. These pesticides or their degradation products may persist and accumulate in the aquatic ecosystems. The entire food chain, including man, can be affected. Sublethal effects include the behavioral and structural changes of an organism that jeopardize its survival. For example, certain pesticides have been found to inhibit bone development in young fish or affect reproduction by inducing abortion.

Herbicides in the aquatic environment can destroy the food source for higher organisms, which may then starve. Also, decaying plant matter causes a reduction in dissolved oxygen.

Sometimes a pesticide is not toxic by itself, but is lethal in the presence of other pesticides. This is referred to as a synergistic effect and may be difficult to predict or evaluate. Bioconcentration is a phenomenon that occurs if an organism ingests more of a pesticide than it excretes. During its lifetime, the organism will accumulate a higher concentration of that pesticide than is present in the surrounding environment. When the organism is eaten by another animal higher in the food chain, the pesticide will then be passed to that animal and up the food chain.

Pesticide Sorption

The partitioning of a pesticide or other chemicals, such as nitrogen and phosphorus, between the soil (or sediment) and water phase occurs as a result of what scientists term a sorption phenomenon. Because the process does not appear to be primarily either a surface phenomenon (adsorption) or an internal phenomenon (absorption), the general term sorption is preferred. However, for this guide, the common term adsorption will be used.

When equilibrium exists between the water and the sorbed-phase concentration of a pesticide (C and S, respectively), the relationship between C and S is referred to as a sorption isotherm. For most pesticides this relationship is linear,

$$S = KC \qquad [2\text{-}1]$$

where K (partition coefficient) is a measure of the extent to which the pesticide is sorbed to the solid phase. The larger the K, the greater the quantity of pesticide adsorbed by the soil.

The extent to which a pesticide is adsorbed by soils (or sediment) is determined by several physical and chemical properties of both the soil and pesticide. Regression analysis of K with several soil physical-chemical properties suggests that soil organic matter or organic carbon (organic matter divided by 1.7) may be the single best predictor of pesticide adsorption coefficients for nonionic and polar pesticides. For ionic or nonionizable pesticides, the speciation of the pesticide between ionic and molecular forms as well as surface charge characteristics of the soil must be considered. Thus, it now appears that the partition coefficient (K) normalized with respect to the organic carbon content of a soil or of sediment $K_{oc} = [K/(\%OM/1.7) \times 100]$ is essentially independent of soil type (Table 2-1). This means that the K_{oc} values given in Table 2-1, multiplied by (%OM/1.7) for a given soil, would provide a good estimate of the actual partition coefficient for a given pesticide and soil system (3). Note that, in general, as the water solubility of a pesticide increases the value of K or K_{oc} decreases.

For each runoff event, a certain amount of the applied pesticide is lost from the field, both in the runoff water and on the sediment. The relative amounts of pesticide lost in each of these two phases may be estimated as follows:

$$F_w = \frac{\rho_w}{\rho_w + \rho_s K} \qquad [2\text{-}2]$$

where F_w is the fraction of pesticide lost in the water phase, ρ_w is the density of water (g/ml), ρ_s is the sediment concentration in the runoff (mg/1), and K is the adsorption partition coefficient (ml/g). Using this equation, values of F_w were calculated for a broad range of ρ_s and K values. These values are listed in Table 2-2 (3). It is evident that most of the pesticide (greater than 90 percent) is lost in the water phase of surface runoff, except for highly adsorbed pesticides (K greater than 100) and for large sediment loads (ρ_s greater than 1000). Data from recent field studies con-

firm these conclusions. It should be recognized that pesticide concentrations in the sediment phase are generally much higher than those in the water phase. Because of the much larger volume of water in the runoff compared to the sediment mass, however, the total pesticide loss in the water phase is greater. In general, sediment loads are less than 10^4 mg/l.

The adsorption partition coefficients reported in Table 2-1 are for whole soils. The distribution of the adsorbed pesticide among the various fraction sizes of the soil was not considered. However, because of their larger specific surface areas and higher organic carbon content, the finer fractions are expected to adsorb larger quantities of pesticides than the coarser fractions, such as sand.

Runoff Losses

The amount of field-applied pesticide that leaves a field in the runoff and enters a stream primarily depends on—

a) the intensity and duration of rainfall, and

b) the length of time between pesticide application and rainfall occurrence.

Pesticide losses are largest when rainfall is intense and occurs shortly after pesticide application, a condition for which water runoff and erosion losses are also greatest. In general, the total amount of pesticide leaving a field in the runoff is small. Herbicide losses usually do not exceed 5 percent of that applied even when the application is followed by rain. In general, pesticide losses average 0.5 percent or less of that applied (26). However, it should be kept in mind that it is not the total mass but the pesticide concentration in the water that poses an environmental problem.

Pesticide Formulation

The formulation of the pesticide also may affect the pathway of movement, especially if runoff occurs shortly after application and before the chemical has "equilibrated" with the soil. For example, ester formulations of the herbicide 2,4-D applied to a sandy loam soil were found to be far more susceptible to washoff than an amine salt formulation. The amine formed a true solution with water and leached into the soil, whereas the relatively insoluble esters were adsorbed and moved with the sediment.

Pesticide Degradation and Persistence

Photochemical and microbiological transformations are the principal causes of pesticide degradation in field soils. Among these, photodecomposition may have little practical significance for pesticides located below the surface; therefore, microbiological degradations are more important because they frequently result in an extensive breakdown of the original pesticide molecule.

Factors that determine pesticide degradation rates and persistence include soil type, soil-water content, pH, temperature, clay content, and organic matter content. Increasing soil pH will generally increase the degradation rate (reduce the persistence) of many pesticides. The most profound and yet unpredictable factors in pesticide degradation are the soil microbial population and the soil environmental variables that control its activity. Temperature and soil-water content are two environmental factors that have been intensively studied in this regard. Increased microbial activity and decreased pesticide adsorption associated with higher temperatures generally enhance pesticide degradation. Pesticide degradation below the root zone (e.g., in the ground water) is often limited because of the absence of organic matter.

The persistence of a pesticide in a soil system is generally reported in terms of the time required for one-half of the applied material to disappear (half-life). The time required for 75 percent disappearance of the compound would be two half-lives, etc.

Half-lives of pesticides are known to increase with decreasing soil-water content. Greater adsorption and lower microbial activities may be responsible for this reduced degradation as the soil-water content decreases. Table 2-3 groups pesticides based on their persistence or half-life in soils under laboratory conditions (3). The persistence of a pesticide under field conditions may be less than that shown in table 2-3 owing to losses through processes other than microbial degradation.

Pesticide Leaching

The rate of pesticide movement through the soil profile to ground water is inversely proportional to the pesticide adsorption partition coefficient. The larger the K or K_{oc} the slower the movement and the greater the quantity of water required to leach the pesticide to a given depth. In general, it appears that only pesticides with K values less than 0.5 ml/g, water solubilities greater than 100 mg/l, and/or long half-lives pose a serious threat to deep ground water sources.

Summary

1. The primary agricultural nonpoint source pollutants are nutrients, sediment, animal wastes, salts, and pesticides.

2. Nutrients, especially nitrogen and phosphorus, introduced into streams and lakes in excess quantities result in cultural eutrophication. Excessive aquatic growth interferes with recreational activities, and low oxygen levels reduce the quality of fish habitat. Nitrogen in the nitrate form is highly mobile and can be leached through the crop root zone, especially on sandy soils. Phosphorus applied in manure and fertilizers moves into receiving waters primarily attached to soil particles.

3. Sediment, the result of erosion, has a number of adverse effects as a pollutant. In suspension it reduces the amount of sunlight available to aquatic plants, covers fish spawning areas and food supplies, and clogs gills of fish. It fills drainage ditches, road ditches, and stream channels and shortens the life of reservcirs. It reduces visibility, becoming a safety hazard to swimmers.

4. Animal wastes contribute nutrients, organic material, and possibly pathogens to receiving waters. Manure should be incorporated into the soil as soon as possible after application to reduce its availability as a pollutant.

5. Salts are a product of natural weathering and occur naturally in various degrees in both soil and water. Salt often becomes a serious problem in irrigated areas as a result of the concentrating efftect Deep percolation of irrigation water often brings large quantities of salt back to the receiving stream through salt pickup.

6. Pesticides provide a substantial hcnetit to crop production, but may damage the environment by eliminating or reducing populations of desirable organisms. Generally, less than 0.5% of the total pesticide applied reaches receiving waters. Most pesticides leave the field in the water, not attached to sediment.

Table 2-1. Summary of adsorption partition coefficients, water solubility and LD_{50} values.

[Compiled from published literature for several pesticides]

Pesticide	K[1] mean	K (%CV)[2]	K_{oc}[3] mean	K_{oc} (%CV)	Water Solubility (ppm)	LD_{50}[4] (mg/kg)
Atrazine	3.2	(90)	163	(49)	33	3080
Carbofuran	1.1	(112)	29	(30)	-	8
Chloroxuron	234	(71)	4343	(29)	2.7	3000
Chlorothiamid	5.6	(40)	98	(28)	950	757
Dicamba	0.11	(104)	2.2	(74)	-	1040
Dichlobenil	3.0	(71)	224	(77)	-	3160
Dipropetryne		(92)	1180	(75)	16	4050
Disulfoton	[illegible]	(92)	1603	(144)	-	2.6
Diuron	8.9	(151)	382	(72)	-	3400
Lindane	20	(14)	1080	(13)	-	88
Linuron	21	(100)	862	(72)	75	1500
Malathion	34	(67)	1796	(66)	-	1375
Methyl parathion	13	(67)	5101	(114)	55	9
Monolinuron	12	(84)	284	(55)	735	2250
Monuron	7.6	(123)	183	(61)	230	3600
Neburon	167	(68)	3110	(24)	-	11000
Parathion	22	(64)	10650	(75)	-	3
Picloram	0.63	(150)	26	(138)	-	8200
Prometone	7.2	(148)	524	(144)	-	2980
Prometryn	11	(124)	614	(99)	48	3150
Propazine	3.1	(136)	15[illegible]	(37)	-	5000
Simazine	2.3	(159)	138	(13)	5	5000
Terbacil	0.78	(145)	41	(42)	710	5000
Thimet	8.8	(78)	3255	(50)	-	2
2,4-D	0.78	(129)	20	(72)	900	375
2,4,5-T	1.6	(87)	80	(45)	-	300

[1]K is the partition coefficient.

[2]CV is coefficient of variation.

[3]K_{oc} is the partition coefficient normalized with respect to the soil organic carbon content.

[4]LD_{50} is the dose of a toxicant that is lethal to 50 percent of the organisms tested under the test conditions in a specified time.

Table 2-2. Influence of K and ρ_s on total pesticide lost in water phase during runoff.

[Values shown are % of the total loss]

Adsorption partition coeff., K (ml/g)	Sediment concentration, ρ_s (mg/l) 10^2	10^3	10^4	10^5	10^6
0.1	99.99	99.99	99.90	99.01	90.01
1	99.99	99.90	99.01	90.91	50.00
10	99.90	99.01	90.91	50.00	9.09
100	99.01	90.91	50.00	9.09	0.99
1000	90.91	50.00	9.09	0.99	0.11

Table 2-3. Grouping of pesticides based on their persistence* in soils under laboratory incubation conditions.

Nonpersistent $t_{1/2} < 20$ days	Moderately Persistent $t_{1/2} => 20$ days < 100 days		Persistent $t_{1/2} > 100$ days
2,4-D	Atrazine	Phorate	Trifluralin
2,4,5-T	Simazine	Carbofuran	Bromacil
Dicamba	Terbacil	Carbaryl	Picloram
Dalapon	Linuron	Aldrin	Paraquat
Methyl parathion	TCA	Dieldrin	DDT
Malathion	Glyphosate	Endrin	Chlordane
Captan	Parathion	Heptachlor	Lindane
	Diazinon	PCP	
	Fonofos		

*Persistence is determined by the rate of disappearance of the solvent-extractable parent compound under aerobic laboratory incubation conditions. $t_{1/2}$ is the time required for 50 percent of the applied pesticide to disappear. Soils differ considerably in their properties, affecting the persistence of different pesticides.

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Chapter 3
Factors Affecting Water Quality

The effect of a pollutant on receiving waters is determined by the quantity and nature of the pollutant and by the characteristics of the receiving water.

Factors Affecting Pollutant Delivery

A number of factors determine the quantity and nature of the pollutants leaving the land (delivered to a water body), some of which can be controlled. These factors include temperature, precipitation, topography, soils, cropping practices, and, if applicable, the method of irrigation.

Temperature

Temperature affects biological and chemical activity. At lower temperatures, plant growth and nutrient uptake are reduced. Thus, more nutrients in the soil are available for detachment and transport; however, less nutrients will be taken up by plants in the receiving waters. The effect of nutrients on receiving bodies of water during cold weather may be lessened because of the reduced activity of organisms. The hazard to freshwater systems may be further minimized if the nutrients are transported to the ocean before spring and summer. However, these materials could still have an undesirable effect in the estuaries and offshore ocean waters.

Precipitation

Precipitation directly affects the runoff of water and the dislodgement and transport of pollutants. Runoff will generally be greater if rainfall is of high intensity or soil moisture levels are high. High-intensity storms increase both detachment and transport. Raindrop impact on bare soil tends to seal the surface, reducing infiltration and further increasing runoff. Melting snow can also contribute to the runoff-erosion process through shear stresses induced by overland flow. An increase in runoff, especially from rapid snowmelt, provides greater energy to dislodge and transport soil and adsorbed substances and increases the volume of water for transporting soluble materials.

Topography

The capacity of water to detach and transport material increases with its velocity. The steeper the slope, the greater the velocity. The longer the slope, the greater the water volume and the velocity. Higher velocities promote erosion and inhibit infiltration. The result is increased surface runoff and decreased movement of soluble pollutants to ground water. Steeper slopes thus have a greater potential for erosion and surface runoff loss.

The shape of the slope is also important. Delivery of pollutants to a stream or lake generally is less from concave than from convex slopes. Transport capacity (velocity) decreases at the bottom of a concave slope, allowing some of the suspended solids (sediment primarily) to settle out. The reverse is true of convex slopes.

The pattern and development of drainage channels affect the delivery of pollutants to receiving waters. Well-developed, well-defined drainage systems reduce travel distance (particularly travel time), increase gradients, and, therefore, increase velocity and transport capacity. The pollution potential is generally increased with well-developed drainage systems because pollutants are transported more quickly to water bodies with less chance for filtration and deposition.

Soils

A soil's infiltration rate and its ability to adsorb pollutants depends in part on its physical, chemical, and biological characteristics. Also, the prior soil moisture content markedly affects the amount of water that can infiltrate.

The infiltration rate affects the ratio of surface flow to subsurface flow. With an increase in the infiltration rate, the pollutant load associated with (surface) runoff should decrease.

The amount of organic matter and clay particles determines the sorptive capacity of a soil. Sandy soils generally have high infiltration rates and low water-holding capacity because of large soil particles and relatively large pores through which water can percolate. Because the total (particle) surface area and the total negative charge of sandy soils are less, their adsorption capacity is generally much less than that of clay soils. Soils that are both well drained and contain a sufficient amount of clay and organic matter, will adsorb the most pollutants.

Subsoil characteristics may either retard or enhance internal drainage and influence the proportion of surface and subsurface flow. Natural barriers, such as claypans or fragipans, reduce the downward move-

ment of water through the soil. Conventional tillage practices, which compact and pulverize the soil, adversely affect soil structure, increase erodibility, and decrease the infiltration rate.

Soil fertility influences pollutant loss in several ways. The increased crop canopy resulting from increased fertility provides greater protection of the soil surface from raindrop impact. Increased fertility promotes more vigorous root systems, which provide more stable soil aggregates that decrease surface sealing and increase infiltration. The material eroded from a fertile soil, however, may have a greater content of nutrients.

Soil type can also affect pollutant impact by influencing the choice of cropping practice and irrigation system. A poorly drained soil requires certain cultivation practices, and the choice of crops is limited. Excessively drained soils require more frequent fertilization; smaller and more frequent irrigations, if irrigated; and are more subject to nitrate leaching.

Cropping Practice

Crop cover and surface residue protect the land from the impact of rainfall by absorbing the energy of the raindrops. Close-growing crops will generally have less pollution potential than row crops because of the additional canopy. Close-growing vegetation tends to reduce soil detachment and filters out suspended organic materials from surface runoff. Deep-rooted crops tend to increase soil stability, penetrate plow pans, and increase infiltration. The longer the growing period of the crop and the more residue that is left on the field after harvest, the less soil erosion will occur. Often, the only pollutants lost by the surface pathway from fields that have excellent cover will be from decaying crop residues (e.g., dissolved phosphorus).

Certain cropping practices can also decrease the pollution potential of a given field by decreasing the need for application of pesticides and fertilizers. For example, resistant crop varieties can reduce pesticide application rates, mechanical weed control techniques can decrease the need for herbicide use, and legumes can reduce the need for nitrogen fertilizer. Crop row alignment also affects the potential for pollutant loss, as rows that run up and down the slope greatly increase runoff and erosion.

Irrigation

Irrigation methods and practices have a significant effect on the pollution potential of irrigated fields, particularly in arid regions of the United States. While the benefits of irrigation are easily recognized, many water quality problems develop that are not, as noted in Chapter 2.

Irrigation techniques largely determine the effect a given irrigated area will have on the quality of the receiving water. Often poor irrigation methods are used because of the capital investment required to install the best or most efficient system. The magnitude of runoff and percolation losses depends on the method of irrigation, the level of irrigation water management, the physical characteristics of the area irrigated, and the kinds of soils. In humid areas, the increased moisture level supplied by irrigation may increase rainfall runoff.

Furrow irrigation is the method most likely to have the greatest pollution potential because of the characteristics of the fields on which it is commonly used and the lack of proper water management. The rows are located up and down the slope. Runoff and erosion from both irrigation and rainfall are increased. An increase in either stream size or furrow slope generally increases the detachment and transport capacity of the irrigation flow. In general, flatter slopes decrease erosion and increase percolation, with losses of dissolved nutrients, soluble chemicals, and salts. Steeper slopes increase runoff, sediment, and associated pollutants.

Another factor that is neglected is the set time. Set times are often regulated by the schedule of other farm activities, rather than by the irrigation need. Overirrigation causes excessive percolation losses, whereas underirrigation causes plant stress and decreased crop yields.

Characteristics Of Receiving Waters

As mentioned at the beginning of this chapter, the effect that a pollutant has on receiving waters is also determined by the characteristics of the receiving water. Each water body can be described according to its physical, chemical, and biological properties. Collectively these properties interact to give each water body an ability to absorb or assimilate a quantity of pollutant without becoming degraded. This natural assimilative capacity of surface water varies widely among water bodies. It is extremely important to consider the interaction of these variable properties of the receiving waters when attempting to determine the effect of a pollutant.

Physical Properties of Receiving Waters

Physical properties of surface water bodies include size (surface area), volume, depth, and temperature. The water may be moving (lotic), as in streams and rivers, making velocity an important variable; or it may be standing (lentic), as in ponds and lakes. Each water body has an exchange rate, which is the time it takes

to replace itself with an equal volume of water. Runoff ponds with small drainage areas in low rainfall regions may exchange once a year or less. A similar pond fed by a spring or perennial stream may exchange every month. At the other extreme are perennial streams and rivers that are constantly flushed. These physical properties affect the dilution of pollutants and the time available for them to have an effect.

Another key physical property is stratification or temperature layering. Distinct zones or layers develop in many ponds and lakes and some rivers because the density of water varies with the temperature. Stratified water bodies typically have a warm upper layer (epilimnion) of uniform temperature, a cooler bottom layer (hypolimnion) of uniform temperature, and a separating layer (metalimnion) with a temperature gradient (thermocline). These zones serve as physical barriers to some organisms and chemical processes, not unlike the layering effect of oil and water. Stratification is common in small, shallow water bodies protected from wind, deep open-water lakes, and in some large, low-gradient stream and river systems.

Another temperature-related characteristic of some ponds and lakes, is turnover. Turnover is the complete mixing of the water often triggered by temperature changes and wind action. It occurs commonly in fall and again in spring in the northern temperate regions. When a water body turns over, stratification is destroyed, resulting temporarily in a water body of homogeneous characteristics.

Turbidity is a physical property and refers to the decreased ability of water to transmit light. It is caused by suspended particulate matter that is either living (e.g., plankton) or nonliving (e.g., clay soil particles). The relationship of turbidity to chemical and biological properties will be described more fully in the following sections.

These and other physical properties strongly influence the behavior of pollutants in a water body. Sometimes dilution differences or other physical properties alone affect the impact of the pollutant. At other times it is an interactive occurrence whereby physical properties, such as temperature, affect chemical and biological processes (e.g., rates of decomposition and respiration).

Chemical Properties of Receiving Waters

The chemistry of a water body is a function of numerous on-land and in-the-water activities. The soils in a drainage area influence pH, nutrient composition, acidity and alkalinity (natural buffering capacity), hardness, and the presence of other important chemical elements in the water body. Equally important to these "natural" inputs are those influenced by man, such as land use and management practices in the watershed. Recently, even contributions from the atmosphere have become regionally important (e.g., acid rain). Turbidity from suspended clay particles can dramatically alter the effect of a pollutant. For example, the high sorptive capacity of clay particles effectively "scavenges" many soluble chemical elements from the water. Large quantities of nutrients, such as phosphorus and other chemicals, enter water bodies adsorbed to clay. However, because of the affinity of clay particles for ions of the opposite charge, some pollutants (e.g., pesticides) are rendered ineffective in water with high clay turbidity. Adsorbed nutrients such as phosphorus settle to the bottom with the sediment.

Nutrients and pesticides in the sediments are available to the overlying waters in varying degrees but not nearly as much as a dissolved chemical. Their availability depends on many processes. Chemical and biological activities are continuous in all parts of the water body, including the sediment, and they tend to release (detach) chemicals. Detachment and availability are also dependent on factors such as pH and oxygen concentration at the water-sediment interface. Availability also changes seasonally because of the turnover previously described.

Biological Properties of Receiving Waters

Water bodies are often referred to as aquatic systems. Important biological processes occurring in an aquatic system, or water body, are photosynthesis, respiration, and decomposition. These processes occur in or as a result of a number of life forms such as bacteria, fungi, plankton, algae, flowering plants, and a wide variety of animal groups. We began this section by recognizing a biological concept—water bodies have an inherent capacity to assimilate some pollution loading without seriously degrading their original quality. The type and amount of pollution affect certain chemical and physical properties of receiving waters and these properties in turn influence or control the biological processes. Generally, highly fertile (nutrient-rich) water bodies that support complex biological food chains and food webs have a greater assimilative capacity than do the more nutrient-poor and less biologically complex ones.

Resiliency is made possible by complexity. For instance, if a pollutant, such as excessive nutrients, is added to receiving waters naturally low in fertility, the system quickly changes from the characteristic clear water stream or lake with low overall biological productivity. The effect may be an almost explosive growth of aquatic plants and algae and a shift in fish

populations. Adding the same quantity of nutrients to an already enriched water body may not cause a noticeable difference or the impact may be a desirable increase in the already high biological productivity. Fertile water bodies can be adversely affected, however. Even naturally fertile water can be nutrient "loaded" to the point at which desirable biological processes cannot keep pace. For example, a properly designed aerobic lagoon system can assimilate only a specific quantity of nutrients and organic matter. If the biological oxygen demand becomes too great, the aerobic bacteria give way to anaerobic organisms and the system becomes anaerobic.

Some wetland types are perhaps the best examples of complex aquatic systems. They have a great capacity to assimilate certain pollutants, particularly excess nutrients. Numerous experiments are being conducted in natural and man-made wetlands to quantify their assimilative capacity and to evaluate them for use in wastewater treatment. Wetlands offer an opportunity to achieve efficient and effective nonpoint source pollution control, especially if they are situated between agricultural fields and a water body.

The inherent capacity of receiving waters to assimilate some pollution should not be overstated. It is discussed here to inform SCS personnel that efforts to control nonpoint source pollution should be only as intensive and extensive as necessary to achieve the water quality objective. The objective should take into account the characteristics of the receiving water as well as the planned use of the water resource.

Classification of Receiving Waters

Classification is discussed briefly to acquaint the user of the field guide with accepted and commonly recognized water body categories. Classification is an attempt to categorize water resources according to common characteristics. Inland fresh waters are broadly grouped into lakes, ponds, and streams. They can be subdivided further according to size, volume of flow, and numerous other physical factors or criteria. Lakes and ponds are also commonly classified according to their trophic state (nutrient level) when discussing water quality. The trophic state is dependent on nutrient levels, particularly phosphorus and nitrogen, but as previously discussed, every physical, chemical, and biological component influences the condition of aquatic environments. Lakes and ponds occur within one of three broad trophic categories; *oligotrophic*, *eutrophic*, or *mesotrophic*.

Oligotrophic lakes exhibit the least biological productivity. In other words, the quantity of available nutrients, particularly phosphorus and nitrogen, limits the production of plant and animal life in the lake. Oligotrophic lakes and ponds generally have clear water (high transparency), high levels of uniformly distributed dissolved oxygen, and small amounts of decomposed and accumulated organic matter. Lake Superior and Lake Tahoe are two very large and well-known oligotrophic lakes.

Eutrophic lakes and ponds are at the other end of the trophic spectrum. They have an abundance of nutrients and exhibit high biological productivity. At least seasonally, eutrophic lakes and ponds support prolific growths of aquatic plants ranging from microscopic algae to macrophytes. Eutrophic lakes and ponds generally support a high biomass of animal life as well. Dissolved oxygen in eutrophic lakes is subject to wide daily and/or seasonal variation. The high plant biomass characteristic of eutrophic lakes generates abundant oxygen during photosynthesis. Conversely, dissolved oxygen drops drastically, sometimes to zero, when environmental conditions inhibit or retard photosynthesis. Oxygen concentrations also decrease with depth in eutrophic lakes and ponds, much unlike oligotrophic lakes. This is due in part to the fact that the photosynthetic zone of eutrophic environments is limited by high populations of algae that restrict sunlight penetration to the top few feet. Dead and decaying organic matter accumulates and displaces lake capacity most rapidly in eutrophic environments. Lake Erie is now classified as a eutrophic lake. Mesotrophic lakes are those lakes of intermediate trophic condition between oligotrophic and eutrophic.

Streams are not similarly classified; however, nutrient levels and productivity vary as widely in streams. The dynamics of moving water make stream classification according to trophic state much less meaningful. Streams are much more complex ecosystems than ponds and lakes, primarily because of the constant exchange of the water. For example, the impact of nutrients on plant productivity is only partially captured in moving water by a select group of aquatic plants adapted to such conditions. Available nutrients can be fully used only in a more static environment (pond or lake) that permits sufficient time and environmental conditions for photosynthesis and other life processes to occur.

Ground water is particularly fragile. It has essentially no pollutant assimilative capacity because of the lack of biological activity. Most ground water aquifers have long "flushing rates," i.e., years or even hundreds of years.

Summary

1. The effect of a pollutant is determined both by the quantity and nature of the pollutant and by the characteristics of the receiving water.

2. Temperature, precipitation, topography, soils, grazing intensity, cropping practices, silvicultural activities, and irrigation determine the quantity and nature of pollutants delivered to receiving waters. As an example, the soil's infiltration rate affects the ratio of surface to subsurface flow and, thus, the pathway of the pollutant and the quantity of the pollutant discharged.

3. Even though pollutants may be delivered to a water body, they still may not have a measurable impact on the quality of that body, depending on the characteristics of the receiving water. Each water body has certain physical, chemical, and biological characteristics which interact to give it an ability to absorb or assimilate some level of pollutants. Ground water has little or no assimilative capacity.

4. The assimilative capacity of each water body should be considered in planning practices to control agricultural pollutants. Since the final increment of water quality improvement is often the most costly, it is prudent to consider the potential of natural processes to help meet the water quality objective. These natural processes have limits, however, and should not be abused. The extent to which the natural assimilative capacity can be relied on also depends on the quantity and type of pollutant being delivered and the water quality objective.

Chapter 4
The Pollutant Delivery Process

The process by which a pollutant is detached and delivered to a stream or other water body takes place in three stages; availability, detachment, and transport. Figure 4-1 illustrates these three stages and outlines some of the important factors that influence the process for chemical substances (13). A water pollution hazard exists *only* when a pollutant is *available* in some form at the field site, becomes *detached*, and is *transported* to a receiving body of water.

Adsorption Characteristics

The delivery process and pathway of the pollutant are influenced greatly by its adsorption characteristics. The degree to which a pollutant is adsorbed to the soil is quantified by the adsorption partition coefficient. The larger the adsorption partition coefficient, the greater the quantity of the pollutant adsorbed to the soil. Pollutants can be grouped into three categories based on their adsorption characteristics - strongly adsorbed, moderately adsorbed, and nonadsorbed. The principles that govern the adsorption coefficient and its use are detailed in Chapter 2 in the Pesticide section.

Availability

Obviously, a pollutant material must be available at the field site before it can become a potential pollutant. The quantity and nature of a material influence its availability. For example, the soil is always a' .l-able in large quantities. Chemicals, fertilizers, and pesticides vary not only in quantity but in the degree of their availability. The amount available at the time of a runoff-producing storm is what is significant.

The availability of a chemical to be detached and transported can be defined in several ways: amount, partitioning between soil and water, position, and persistence. All other factors being equal, the potential for chemical loss increases with the amount of the chemical in the soil. The partitioning of a chemical between water and soil determines the availability of a chemical to be lost by erosion, by deep percolation, or by some other pathway. The position of a chemical in the soil will determine its availability for loss by a particular pathway. Phosphate fertilizer placed below the soil surface is not available for loss in surface runoff; nitrate that has moved below the zone of root uptake is available for ultimate leaching to ground water. Manure left on the soil surface is much more available for surface runoff than that which has been incorporated. Finally, the availability of a chemical to be lost from soil increases the longer it persists in the soil system. Pesticides with short half-lives are much less available for loss than more persistent compounds such as the chlorinated hydrocarbons.

Detachment

Pollutant materials on the land not only must be available but must be detached from their original location (or made mobile) before they can become a pollutant in receiving water. Between runoff events, potential pollutants in a field are at rest on the soil surface or in the soil profile. Except for completely nonadsorbed substances, potential pollutants are bound in one way or another to the soil-water matrix.

The detachment process will usually be physical or chemical. Most physical detachment results from raindrop impact, but some results from overland flow. Two important mechanisms of chemical detachment are changes in equilibrium gradients and ion exchange. Chemicals reach an equilibrium concentration in the soil-water complex. If water with a lower concentration of the chemical is introduced into the system (e.g., rainfall) some of the chemicals previously held will be released into the water and possibly be transported off the field. Chemicals in ionic form are often attached to soil particles by ionic bonds. Ions in solutions can cause ions attached to soil particles to become detached. This may be important if the ions being replaced are potential pollutants. Thus, the detachment process results in pollutants being:

1. Dissolved (or released) into solution, moving off in the water by overland flow or through the soil, and/or

2. Detached as solid particles, either by themselves (such as manure) or attached to soil particles.

Highly soluble chemicals are easily detached by both surface runoff and water percolating through the soil. An example is any of the pesticides of methomyl and dimethoate compounds. Other pollutants that are not generally soluble, such as phosphorus, are moved with

soil particles to which they have become attached. The quantities and kinds of pollutants adsorbed to sediment are determined by the soil from which they originate and the type of erosion that occurs.

Solid particles are physically detached by raindrops or sprinkler drops and by the overland flow (shear stress) of water from rainfall or irrigation. Coarse soil materials—sand and coarse silt—are easily detached but do not transport readily. Clay and organic materials are more resistant to detachment, but once detached they are readily transported. Manure on the surface can be transported as a solid particle in suspension. Soil organic matter is not easily detached from the soil because of its cohesive properties.

Sheet and rill erosion remove soil from the plow layer. The resulting sediment will be finer textured and will contain higher proportions of nutrients and other adsorbed pollutants than sediment from other sources. Gully and streambank erosion remove larger soil particles, but this sediment will contain a much lower proportion of nutrients and adsorbed pollutants than sediment from surface soils.

Transport

Agricultural pollutants are primarily transported in water, although some substances are lost through wind drift and volatilization. The particular pathway by which a pollutant leaves an agricultural field depends on the hydrology of the field and the interaction of the pollutant with water and soil, i.e., the pollutant's adsorption-partition coefficient.

Several things can happen to rainfall or irrigation water once it falls on the soil surface. Water can be stored in surface depressions, flow above the soil surface (direct runoff), move vertically down toward the water table (deep percolation), or move within the soil over an impermeable layer (interflow). Flow emerging from below the water table is termed base flow.

Pathways

In general terms, pollutants from agricultural land are transported to receiving waters by two main pathways—over the surface and beneath the surface. The characteristics of the pollutant determine the pathway (13).

Direct overland runoff contains sediment, pollutants adsorbed to sediment, and dissolved materials. The type and quantity of chemicals in direct runoff depend on the soil, vegetation, organic residue, management, and the soil conservation practice(s) used in the field. The sediment load largely depends on the rainfall characteristics, topography, vegetation, soil type, and the soil conservation practice(s).

Beneath the surface, interflow and deep percolated water carry dissolved substances. The pathway of water movement beneath the soil surface depends on geology, weather and soil permeability. Figure 4-2 illustrates the pathways by which substances are transported.

As discussed in the section Detachment, the detachment process results in pollutants being dissolved into solution or being detached as particles (by themselves or adsorbed to soil). Thus, pollutants are transported in both the dissolved and particulate phases in surface runoff, but only in the dissolved phase in subsurface flow. The volume of surface runoff is much greater than the quantity of sediment yielded from a watershed. Therefore, even if the concentration of a certain pollutant is greater in the sediment, the quantity of the pollutant lost in the water will usually be greater. As an example, moderately adsorbed pollutants, like malathion, that are only slightly soluble will be carried off over the surface in both the water and attached to soil particles. Depending on the storm, a larger mass of pollutant will probably be carried off the field dissolved in the runoff water than will be carried with the sediment since the quantity of water is so much larger than the sediment.

The distribution between dissolved and sediment-adsorbed phases, classified by the adsorption-partition coefficient, determines the amount of substance that may be lost in a given storm runoff. This classification was chosen to account for the different possible pathways by which pollutants may leave the field. Strongly adsorbed substances are carried on the sediment in overland flow. Nonadsorbed substances are dissolved and leave by deep percolation or interflow, although they may be found in dilute concentrations in overland flow. Moderately and weakly adsorbed substances are lost in overland flow. As mentioned earlier, Figure 4-1 illustrates some of the factors that affect pollutant pathways.

Transport and Deposition of Dissolved Substances

Dissolved substances by their very nature move with the flow of water, primarily beneath the surface; however, a minor amount can be found in surface runoff. Normal control practices used in the transport phase (e.g., sediment basins) are ineffective in controlling dissolved substances, since dissolved materials cannot be trapped like solid particles.

Transport of Solid Particles

The transport and deposition of solid particles (sediment) depend on the characteristics of the material being transported, the characteristics of the flow, and, to a lesser extent the characteristics of the water in which it is being transported. Most important are the properties of the sediment and the kinetic energy of the flowing water. The characteristics of the transporting water are not significant to this discussion.

The characteristics of the transported material which are significant in transport and deposition are:

1. Particle size—Sand is not so easily transported as silt and clay. Coarse-textured materials are carried only by high-velocity flow. Fine silt and clay can remain in suspension as long as the water is moving at a moderate rate and, therefore, can be carried a long distance from their source. This is the most significant characteristic affecting transport and deposition.

2. Aggregate size and stability—Aggregation of individual particles influences their ability to be transported in the same manner as does particle size. While the aggregates are composed of fine material rather than sand, aggregates weigh more than an individual particle and, therefore, are not as easily transported. If the aggregate is not stable, it may break down during transport, and the material will be carried as individual particles. Aggregate size and stability are a function of crops, soil organic content, texture, natural soil wetness, and timing and type of tillage.

3. Specific gravity and shape—Materials that have low specific gravity are more easily transported than those that have high specific gravity. For example, organic materials are light and can be carried long distances. The shape of sediment particles influences transport and deposition slightly because it only affects the settling rate of the material being transported.

The characteristics of the flow that are important in transport and deposition are:

1. Turbulence—This is the irregular movement of water characterized by upward and downward currents and the presence of eddies. Turbulence keeps sediment in suspension, thus increasing transport and decreasing deposition.

2. Velocity—This affects detachment and transport. Generally the higher the velocity, the greater the energy and turbulence.

3. Volume—The volume of a flow directly affects the amount of material being moved. A large volume will transport more material than a smaller volume with the same sediment concentration.

4. Frequency—The number of times an event occurs in a given period affects the amount of material transported because it is related to the volume of discharge for the period.

5. Duration—The length of an event is important in the transport of sediment. An event of long duration will transport more material than an event of short duration with the same sediment concentration.

6. Depth—This factor affects detachment and transportation. Other characteristics being equal, a deep channel will dislodge more bed material than a shallow channel. Also, for the same stream, deposition will occur when the depth becomes shallower.

Deposition of Solid Particles

Sediment is deposited when the velocity of the flow decreases to the point where it can no longer carry some of the transported material. The decrease in velocity can be caused by a number of things: an obstruction to the flow, an increase in roughness over which the flow passes, a decrease in grade, etc. Deposition occurs at the foot of slopes, along edges of larger valleys, in flat areas, in wetlands, on stream flood plains, in fields, and in reservoirs. It also occurs in structural control measures, such as terraces and sediment basins.

Summary

1. The process by which a pollutant is detached and delivered to a water body takes place in three stages:

a. Availability,
b. Detachment (becomes mobile), and
c. Transport.

Pollutants can be controlled at any of these stages.

2. Pollutants can be grouped into three categories based on their adsorption charactertistics:

a. Strongly adsorbed,
b. Moderately adsorbed, or
c. Nonadsorbed.

Strongly adsorbed pollutants are associated with sediment, moderately adsorbed with both sediment and water, and nonadsorbed with water.

3. Pollutants are transported in one of three modes:

a. Dissolved,
b. Suspended as a solid particle, or
c. Attached to soil particles or other particles.

4. Pollutants are transported by two main pathways:

a. Over the surface (overland flow) and
b. Beneath the surface (subsurface flow).

Figure 4.1. Factors affecting chemical pollutant availability, detachment and transport

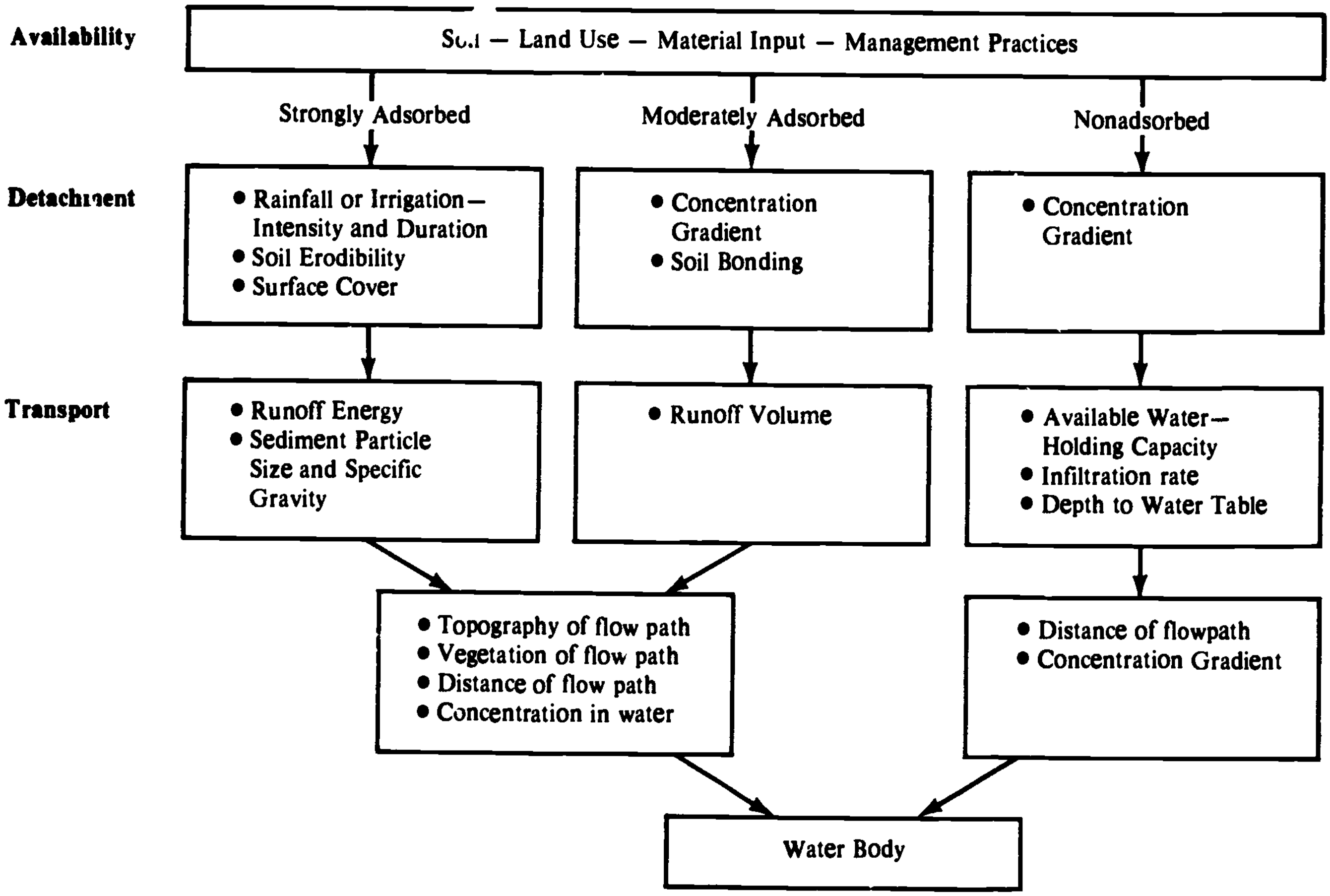
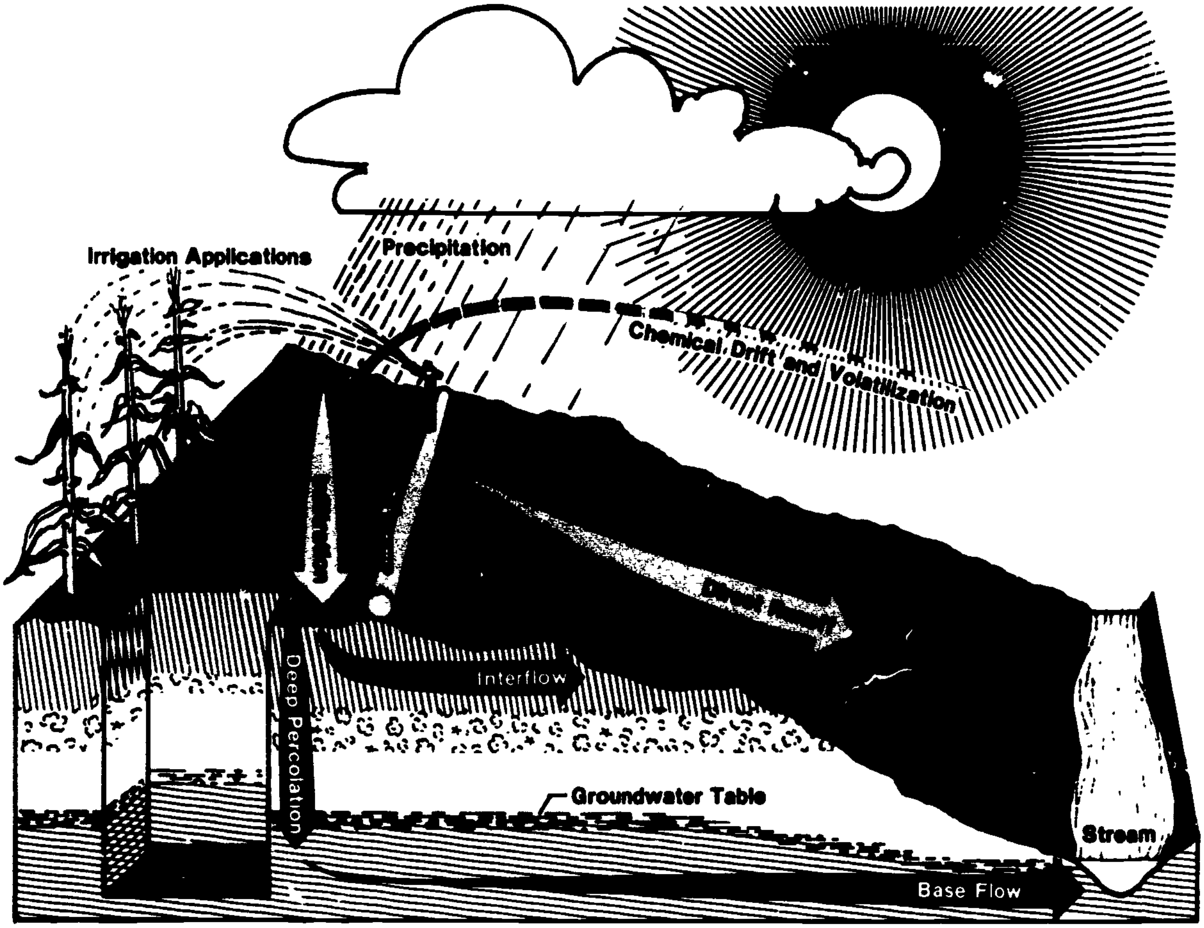


Figure 4.2. Pathways through which substances are transported from agricultural land to become water pollutants.



Chapter 5
Conservation Planning And Water Quality

The first sentence in Chapter 1 states that one of the purposes of this guide is "to incorporate a water quality perspective into all conservation planning." Most of the material presented to this point has dealt with identifying water quality problems, identifying the pollutants, and determining the effects of agricultural pollutants on receiving waters. A common theme runs throughout. If there is no impaired water use, then there is no water quality problem. There is, however, a need to consider the water resource in resource planning, even if there is no impaired water use.

The trend has been to emphasize the problem-solving approach in the development of project activities. These projects often have single-purpose objectives, such as economic development, soil erosion control, or water quality improvement. The project approach has proved to be a successful way to focus resources into a small area. When used with sound resource management planning, this approach is effective in reaching the objectives for which funds were allocated.

The objective of resource management planning in SCS has been defined as the protection of the resource base. This includes protection of the quality of the water as well as soil and related plants and animals. The goal of this field guide, as discussed in chapter 1, is to provide some of the tools and understanding about pollutant movement into water so that water quality protection can be integrated into all planning.

The resource base is defined in the SCS National Conservation Planning Manual (NCPM) in §507 (Glossary and References) as soil, water, and related plants and animals. The resource management planner in SCS must consider their interrelationships. Land users usually request planning assistance to solve a specific problem. Often, they already have a solution in mind, and it may be a good one. Rarely, however, is a request made for an ecologically balanced plan.

The NCPM provides the procedure to be followed for *all* planning activities. The 10 essential elements (steps) of planning are covered in §506.10 of the NCPM. The resource management planner in SCS follows this logical series of steps, beginning with providing information through reevaluation and updating. The planner may find the land user entering the process at any of the 10 steps. Often, many of these steps are carried on concurrently and/or repeated. For example, as new data or information becomes available, the development of alternative solutions may need to be reevaluated and updated.

The SCS planner should review the basic elements of the planning process, which includes determining which of the land user's objectives may need modification based on the planner's access to additional data and knowledge. This process will lead to the development of sound alternatives for solving a land user's original concern. The funding source for the implementation does not change the planning process.

It is the responsibility of the planner to help broaden the land user's horizons throughout the planning process. The professional planner, for example, does not lay out contour strips solely at the request of the land user. The planner completes a very rudimentary data-gathering process, which might include determining whether the land user has livestock to utilize the additional hay or whether it is a cash grain operation. The land user's objective, which may be to end excessive erosion, can be solved in a number of ways. The skilled resource planner needs to help refine the land user's concerns by supplying additional data and information to the land user. It is only through this process that firm objectives can be established and v[illegible] alternatives formulated.

The SCS planner must become aware of all the natural resource needs of the area in which he works. The limits of the planning considerations must be larger than the field or conservation treatment unit (CTU). The resource needs are often focused on a hydrologic unit (subbasin) in which a CTU is located. Balanced resource management planning requires the consideration of the total resource needs in developing plans for an individual field.

A broader planning scheme is particularly important when integrating concerns for water quality, since the impacts are usually offsite. The planner should be aware of the State Water Quality Management Plan that was developed during the "208" planning process. It identifies water quality problems, proposes solutions, and establishes priorities, usually by land resource area or critical subbasin. The current need to more clearly justify natural resource implementation efforts requires that we more stringently follow the planning process, have a broadened view of resource needs, and focus our efforts on problem solving. Bal-

anced resource management must include soil, water, and related plants and animals. In planning protective measures for one of these resources, the impacts on others are considered. The planning process should not be short circuited because of a narrowly focused objective.

Planning for Water Quality Improvement

What is the role of water quality in resource management planning? The Nation's course was altered in 1972 with the introduction of Public Law 92-500 (now called the Clean Water Act). This law established as a goal the need "to restore and maintain the Nation's waters." Herein lies the answer - to *restore* or to *maintain*. Or, in our terminology, to *improve* or *protect*. These represent two very different approaches. Resource management plans should never degrade existing water resources. If a problem exists, the objective of the plans should be to improve the water resource by reducing the pollutant load.

While the primary objective of resource management planning is the protection of the resource base, it is also possible to have specific objectives for improvement. The resource planner seldom plans for water quality protection as a primary objective. The protection of the water resource is an integrated part of resource planning and as such becomes a secondary objective in all planning activities. Again, the key words in this discussion are *protection* and *improvement*. All planning should consider protection of the resource base. The emphasis will shift to improvement when a problem has been identified. The improvement of the soil resource base can be as valid as improvement of water quality. The planning process remains the same. *The level of treatment* necessary to achieve improvement may increase. Planning for improvement of the resource base has to do with the level or intensity of the treatment, not a new or different planning process.

The data needs are more complex for water quality planning as you have seen from the preceding chapters. Since the damage to the water quality is downstream, it is much more difficult to locate the source or sources that may be contributing the pollutant. It is equally important to know and understand the pollutant pathway and the form in which the pollutant is transported.

The pollutant that impairs the use of the water resource typically has many sources. Since pollution is incremental, it follows that treatment will also be incremental. In order to "solve" water quality problems, it is necessary to control a sufficiently large increment of the pollution so that the water use is no longer impaired.

Two conclusions should be considered. One conclusion is that all sources of a pollutant do not need to be controlled to solve the problem. The other conclusion is that all of the sources are not equal. Some sources contribute more of the pollutant because of their relationship to the water body or because of other factors.

Some sources will also be easier and/or less costly to control than others. The resource management planner must use professional judgment in evaluating whether a major effort should be made to control a pollutant on a given CTU. The first consideration must be the delivery rate of the identified pollutant from the CTU. The second consideration is to determine whether the pollutant being delivered to the water body is attached to sediment or in solution.

Pollutants attached to sediment may have a very low delivery rate, depending on their pathway to the receiving waters. Soluble pollutants are transported in runoff with a high delivery ratio. The form of the pollutant and its pathway are major considerations in determining the level or intensity of effort to control or improve the quality of the water, i.e , determining how much will be spent. When dealing with sediment reduction and/or sediment-attached pollutants, not all of a hydrologic unit (subbasin) or CTU can be viewed as having equal priority for treatment because of differences in delivery.

Economic considerations (installation, maintenance and income impacts) may dictate protection of the water resource rather than improvement if the amount of improvement may be small. The same considerations must govern soil resource base protection rather than improvement if sediment reduction in a reservoir is the identified problem and only small increments of sediment can be controlled or the costs are high. The rationale for resource base protection or resource base improvement involves the same planning process regardless of the resource.

Developing Alternatives for Control of Pollutants

The development of alternatives for the treatment of a CTU follows the normal steps in planning, which lead to resource base protection. When the goal is the improvement of water quality, there are additional considerations—the form in which the pollutant is transported, the pollutant pathway, and the delivery rate, to name a few. If an identified water quality or use impairment exists, a number of decisions need to be made before any alternatives are developed. The

first consideration is whether the CTU is contributing the pollutant. The second is whether the pollutant is of sufficient quantity to justify a concerted effort to control it.

The development of alternatives, the selection of practices, and consideration of all the costs associated with those practices must be weighed against the benefits received. In this regard, planning for water quality protection is no different than any other type of resource management planning. The development of alternatives that provide for water quality improvement when little benefit in pollutant control results, is not sound resource planning. The fact that it is a water quality project area or that cost-share funds for water quality improvement are available should not be a factor.

Categories of Practices

The planning process continues with the selection of practices. The same categories of practices that are applicable for protection or improvement of the soil resource base are used where water quality is an objective (either protection or improvement). These categories are *management, vegetative, and structural.* It does not follow that a practice that provides soil resource protection is equally good for water quality improvement. The pollutant and the form in which it is transported need to be known. It is also important for the planner to closely examine the principles which underlie the development of the commonly accepted conservation practices. Most of these practices were not developed to control soluble pollutants. Their impact on this form of pollutant will not lead to either protection or improvement of water quality. Table 5.1 gives the qualitative effectiveness of selected practices to control various stages of the sediment delivery process.

Management practices are often the only method available to control soluble pollutants. The principle of this category is to limit the availability of the pollutant for transport in runoff. The methods can be to incorporate the pollutant, schedule the application to low runoff periods, reduce the quantities applied, or change the form in which it is applied.

Nutrient management and pesticide management are two general practices in this group. These practices have a great advantage because they are relatively inexpensive to initiate and often reduce costs to the land user. They also are very flexible and can be adjusted quickly. This flexibility can also be a disadvantage; a land user can quickly change the effectiveness of a practice by not following good management techniques. The landowner should be made aware of the impacts of changing the agreed-to system, both to himself and downstream water users.

Vegetative practices reduce pollutant movement by reducing soil detachment. They are effective where pollutants are attached to sediment or where sediment is the pollutant. The principle of this group of practices is to increase soil aggregate stability and protection of these aggregates from raindrop impact.

This group of practices has both soil and water resource protection qualities. Crop rotations, reduced tillage techniques, and using winter cover are general types of practices in this category. They are generally relatively inexpensive to implement but often have negative impacts on the landowner's income when increased grass crops are required. These practices have the advantage of being flexible; however, that can also be a disadvantage, since a land user can quickly undo any advantage by plowing at the incorrect time of the year. Again, thorough education is needed with good followup and reinforcement.

Structural practices are designed and constructed on the landscape. Most of them are based on the principles of reducing the length of slope to control the quantity of runoff and reducing the degree of slope to reduce the velocity of the runoff. Other practices, such as grass waterways, use a combination of structural and vegetative principles to reduce the depth of flow as well as the velocity. The central principle is the reduction of the erosive capacity of running water.

The main advantage of this group of practices is permanence. These practices generally become part of the farming system for a substantial period of time. The disadvantages are the relatively high initial cost and the need for continued maintenance. These practices also are difficult to change and limit the land user's flexibility.

Costs

Economic and environmental guidelines must be used in the evaluation and selection of resource management systems (RMS) for conservation and pollution control. An analysis of the expected costs of the system is frequently sufficient for the decisionmaking effort. An understanding of terms and principles used in cost analyses is essential. The estimated cost of a resource management system consists of (1) the actual cost of installing the system, and (2) the costs to be incurred to insure the proper functioning of the system throughout its intended life. The number of years

Table 5.1. Qualitative effectiveness of selected practices to control various stages of the sediment delivery process.

Practices	Practice effect			Sediment retention point		
	Raindrop detachment	Runoff detachment	Runoff transport	On-field	Swale	Stream
Cultural and land management						
Conservation tillage						
No till	H*	M	M	X		
Reduced tillage	M	L	M	X		
Ridge tillage	M	M-H	M	X		
Strip tillage	H	H[a]	M	X		
Winter cover crop	L-H	L	L	X		
Conservation cropping system	L-H	L-H	L-H[b]	X		
Critical area planting	H	H	H	X		
Runoff collection and disposal						
Contour farming	N	L-M	L-M[c]	X		
Contour stripcropping	M	M-H	M-H[d]	X	X	
Terrace	N	H[e]	M[f]		X	
Diversion	N	H[e]	H		X	
Parallel tile outlet terrace	N	H[e]	H	X	X	
Grassed waterways	L	H[e]	L		X	
Outlet protection structure	N	H	L			X
Subsurface tile drainage	N	N	L	X		
Sediment retention and trapping						
Sediment detention basins	N	L	M-H			X
Ponds and impoundments	N	L-H	H			X
Filter strip—vegetative	L	L	H[g]	X	X	
Other practices						
Stream bank protection	N	H	N			X

*H-High; M-Medium; L-Low; N-Not Significant or None
a) Controls detachment in rills
b) H for years when in sold, L for other years
c) Effectiveness depends on slope and slope length
d) Effectiveness depends on strip spacing
e) Controls detachment in gullies
f) Effectiveness depends on the reduction of transport energy which will depend on outlet design
g) Effectiveness depends on size and character of filter strip and uniformity of overland runoff Table 5.2 summarizes the general characteristics of the three categories.

Table 5.2. General characteristics of categories of practices.

Characteristic	Practice Category		
	Management	Vegetative	Structural
Flexibility to change	High	High	Low
Level of change required in farming system	Low	Low to high	Low
Cost			
Initial	Low	Low	Moderate to high
Operation & maintenance	Low	Low	Low
Income effects	Positive to negative	Positive to very negative	Usually positive

the system will be effective and the rate of interest to be used are required to express the total estimated costs in average annual terms. This process is known as amortization (see glossary)

The following example illustrates the process of expressing cost estimates in average annual terms.

Equation:

$$Caa = (Ci \times f) + (Ci \times OM) \text{ or } Caa = Ci\ (f + OM)$$

Where: Ci = cost of installing system

f = amortization factor based on effective life (years) and rate of interest (%)

OM = operation and maintenance costs incurred annually, expressed as a percentage of Ci

Caa = average annual cost of system

Definitions of these and other terms used in estimating average annual costs are in the glossary.

Costs may also be estimated by using flat rate schedules. These schedules are included in Section V of the SCS Technical Guide.

The ANCOST (acronym for annual cost) slide rule has been developed as a tool for converting costs to annual values or converting annual values to total capitalized amounts. Instructions are contained in the General Manual, Part 609, National ANCOST Slide Rule Handbook. The slide rule eliminates the need to refer to amortization tables.

Cost Effectiveness

It is usually difficult to determine the monetary value of the benefits derived from the reduction of agricultural source pollutants and the improved water quality. A more practical approach is to evaluate the practices or RMS on the basis of cost effectiveness.

The cost effectiveness of reducing erosion can be expressed in terms of the lowest cost per ton of reduced soil erosion. Utilization of sediment delivery ratios from individual CTU's will permit an evaluation of the lowest cost per ton of sediment not delivered for various RMS's. This is a better method to use in evaluating costs and effectiveness of water pollution control methods.

Estimates can be made of the cost effectiveness of practices for controlling sheet and rill erosion by using the flat rate schedules and the Universal Soil Loss Equation. For example, if the flat rate schedule indicates that terraces with tile outlets have an annual cost of $61.00 per acre and USLE computations indicate an annual soil erosion reduction of 39 tons per acre, the cost effectiveness of this practice would be $1.56 per ton of soil erosion reduced. It needs to be emphasized that, if the primary objective is to reduce delivery of sediment or sediment-bound pollutants to a lake or reservoir, the amount of sediment that is kept from being delivered should be used in calculating cost effectiveness.

Where input data are available, an analyses of many alternatives can be made by using a computer. A procedure has been developed for determining the cost effectiveness of many RMS combinations on sheet and rill erosion. SCSCOSTS is a simplified, low-cost version of a procedure described in the publication, "A Computerized System for Estimating and Displaying Shortrun Costs of Soil Conservation Practices." This computer program is accessible via existing terminals. The output displays the cumulative effect of adding a variety of practices and compares the cost of the combinations. Soils can be grouped according to crop response and treatment needs to reduce the number of data sheets that need to be generated.

Summary

1. The project approach has proven to be an effective way to focus resources into a small area to solve identified natural resource problems.

2. The natural resource base includes land, water, and related plants and animals. Natural resource planning involves the protection of all of these resources.

3. The planning process is the same for all natural resources and the protection of all of the resources is a necessary element. When one of the resources is identified as needing improvement, the level of treatment necessary to achieve improvement may increase.

4. A planning perspective that is larger than the CTU being considered should be adopted. This is of critical importance when considering the water resource since the impacts are usually off site.

5. All portions of the landscape do not contribute pollutants equally. The form in which the pollutant is transported, the pollutant pathway, and delivery ratio must be considered in determining whether a high level of treatment is justified on a CTU.

6. Most soil and water conservation practices were designed to reduce soil erosion. The basic principles which underlie the development of these practices must be understood in order to evaluate their potential for reducing pollutant movement to receiving waters.

Chapter 6
Controlling Nutrient Pollution

Principles of Controls

Nutrients are essential for adequate crop production, and must be available as they are needed by the growing crop. Nutrients are used by growing plants, are lost from the soil by leaching, are lost in direct runoff both in solution and attached to eroded soil particles, and are lost by volatilization or denitrification from agricultural lands. In controlling nutrient losses from agricultural fields, it is important that the nutrients present are used as efficiently as possible. Any nutrient in excess of crop needs becomes a potential pollutant.

The relative potential of a nutrient as a pollutant depends on its *availability* for loss, which involves not only the amount of the nutrient present in or on the soil, but also its position in the soil. The farmer can decrease nutrient *availability* by management of fertilizer rates, by monitoring the buildup of available nutrient levels in the soil (particularly phosphate), and by incorporating fertilizers.

The loss of nutrients by the *detachment* of soil particles is particularly important for nutrients whose major environmental chemical forms are strongly held by the soil, i.e., they have high partition coefficients. Phosphorus is the best example. On the other hand, the most important environmental form of nitrogen is nitrate, which is not held by soil particles because it has a very low partition coefficient. Thus, soil detachment is not an important process in determining nitrate loss. In many instances, more nitrogen is lost from land in the organic form in sediment and residues than as nitrate. However, most of the organic nitrogen is environmentally unimportant because it is converted to more environmentally significant nitrate and ammonia at very slow rates.

Like *detachment*, the importance of the *transport* process in the loss of pollutants from land is a function of the affinity of the chemical form of the nutrient for soil particles (partition coefficient). Nutrient forms such as phosphate or ammonium ion (NH_4^+) have high partition coefficients and are transported primarily with the eroded soil particles in surface runoff. Nitrate, a nutrient form with little affinity for soil, is more susceptible to leaching losses to ground water or via subsurface drains to surface waters.

Three groups of practices are available to the farmer to control nutrient losses: *management*, *vegetative*, and *structural*. The potential of these types of practices to control the loss of a particular nutrient form, will depend on their ability to decrease the *availability*, prevent *detachment*, and interrupt the *transport* process. Practices which primarily control soil loss will be effective in controlling soil-borne pollutant losses, while practices which also reduce surface runoff volume (e.g., terraces) will reduce the surface runoff losses of dissolved nutrient forms such as nitrate. Unlike phosphate which will not leach, reducing surface runoff may reduce runoff losses of nitrate but increase its loss by leaching. *Management* practices, then, are important for a nutrient form such as nitrate which is not easily controlled by practices which interfere with the *detachment* and *transport* processes and must, therefore, be controlled by its *availability*.

Methods of Control

1. Fertilizer management is a management measure used to decrease the availability of nutrients, thus minimizing surface and ground water pollution while providing optimum amounts of plant nutrients for crop production. It includes rates, placement, timing, and type of fertilizer. It is the most important practice in controlling pollution of water by nutrients from agricultural lands.

Fertilizer rates are significant in the control of nutrient pollution. Fertilizers should not be used unless they are needed. The Cornell Nutrient Simulation Model (CNS) indicated that when nitrate nitrogen was applied at twice the quantity used by the crop, nitrogen losses were increased by 70 percent (13).

A proper balance of essential nutrients and soil moisture is needed to ensure proper plant growth. A deficiency of one element may reduce the plant uptake of other nutrients, thus making them available as pollutants. Soil tests are probably the most important guide to the proper use of fertilizers. These tests, combined with information about soil type, previous cropping, and the anticipated soil moisture level, should be used to estimate fertilizer requirements. Fertilizer rates should be based on reasonable yield goals. Excessive applications of nutrients, especially nitrogen and phosphorus, must be avoided.

Commercial fertilizers have a specific nutrient content, so it is easy to select the application rate needed to meet the desired goal. It is more difficult, however, to match animal waste application rates to crop needs. The nature of manure and the method of handling affect its nutrient content, especially nitrogen.

The method of application has a significant impact on the quantity of nutrients lost in surface runoff from a field or pasture. If practical, all fertilizer should be incorporated into the soil to reduce the loss by volatilization and surface runoff. Fertilizers are incorporated by disking or plowdown and by injection.

It may not be possible to incorporate the nutrients on pasture and grassland. When surface application is necessary, it should be scheduled to reduce nutrient losses caused by rain or snowmelt. Liquid or very soluble fertilizers should be considered fc surface application. They provide higher infiltration thereby reducing runoff losses. If the crop is to be irrigated, the fertilizer can be injected into the irrigation water; however, there should be no runoff during irrigation.

Fertilizer timing can be effective in reducing potential losses of nutrients. Nitrogen, especially, should be applied as close to plant demand periods as possible. Fall and early spring applications are often made in order to avoid the competition for labor and equipment, which occurs if the application is delayed until planting time. Fall applications of nitrogen for the spring season can be leached below the root zone before the growing season begins if there is considerable winter precipitation. If fall applications of nitrogen are necessary, ammonia forms should be selected to minimize leaching. They should be applied after the soil has cooled below 10°C (50°F) at a depth of 10 cm (4 in) to prevent microbial conversion to the readily mobile nitrate form. Early spring applications can also result in considerable losses as a result of percolation from heavy rainfall. The timing of nitrogen applications is very important on sandy soils, which are subject to leaching by both rainfall and irrigation water.

For such crops as corn, the most efficient use of nitrogen is accomplished by using a light pre-plant application followed by side-dress applications when the crop reaches knee height.

The fertilizer type can be an aid in reducing nutrient pollution. Fertilizers are available in granular, gaseous, liquid, suspension, or slurry forms. When the pollution pathway has been determined, a fertilizer can be selected that will reduce the pollution potential. As previously stated, nitrate forms are highly soluble, and fall applications should be avoided where leaching is a problem. Some nitrogen compounds are available that release their nitrogen over a long period of time. These fertilizers are intended to constantly supply nitrogen as it is needed by the plants; however, they generally are more expensive and are used primarily on turf.

Nitrification inhibitors slow the rate at which ammonium fertilizers are changed to the nitrate form. This will reduce nitrogen loss when conditions are favorable for leaching and denitrification.

2. A conservation cropping system can be an effective practice for improving both water quality and agricultural production. It improves soil structure, which increases infiltration, decreases runoff, and increases aggregate stability. In a continuous one-crop system such as corn, with heavy annual fertilizer applications, nitrogen buildup in the soil is often a source of nutrient pollution. Using crop rotations can reduce this buildup of nitrogen and the potential for it to become a pollutant. Using crops that require little or no nitrogen, such as soybeans, in rotation with crops requiring large amounts of nitrogen reduces the potential for nutrient loss. This practice is also effective in reducing losses of solid-phase nitrogen and phosphorus through the reduction of sediment to which these nutrients are attached.

3. Grasses and legumes in rotation can reduce nutrient losses, aid in improving soil structure, and provide large amounts of nitrogen for use by succeeding crops. A deep-rooted crop like alfalfa or a perennial grass can utilize nitrates below the normal root zone of other crops and, thereby, reduce nitrate leaching.

Legumes are host plants for nitrogen-fixing bacteria that take nitrogen from the air. The amount of nitrogen fixed depends on the type of legume and environmental conditions. Annual nitrogen fixation by red clover and alfalfa is generally in the range of 40 to 110 kg/ha (30 to 100 lbs/acre) although as much as 560 kg/ha have been reported. If the legume is left in the rotation for two or more years, significant quantities of nitrogen will be available for use by successive crops. This will greatly reduce the need for commercial nitrogen fertilizer. Nitrogen can be lost as the legume decomposes, but it is not as available for detachment and transport as large applications of commercial fertilizer.

Model studies by Cornell University of farms in Georgia, Iowa, and New York indicate that a rotation of 4 years of corn followed by 4 years of alfalfa could produce the following reduction in the mean annual nutrient losses (13):

Dissolved nitrogen in runoff -------55 to 80 percent
Dissolved phosphorus in runoff----30 to 35 percent
Dissolved nitrogen in percolation--25 to 50 percent
Solid-phase nitrogen in runoff------60 to 70 percent
Solid-phase phosphorus in runoff--60 to 70 percent

The use of perennial grasses in the rotation also can aid in improving soil structure and greatly reduce nutrient losses. Nitrogen loss from continuous corn can be as great as ten times that of sod pasture. The use of sod-based rotations can significantly reduce losses of solid-phase and dissolved forms of nitrogen and phosphorus.

4. Cover and green manure crops such as small grain, sorghum, millet, or legumes protect the soil during the period when it is normally bare or low on crop residues. If the land has a vegetative cover when erosive rain and wind occur, soil erosion will be greatly reduced and the cover crop will use nutrients which would otherwise be lost. It will improve soil structure and provide nutrients for the following crop. When a crop such as corn is harvested for silage, a fortyfold reduction in losses of sediment, nitrogen, and phosphorus can be achieved by using a winter cover crop such as ryegrass (13).

The disadvantages of this practice are that additional farming operations, labor, fuel, seed, and sometimes chemicals are required which increase the farm operating cost. The winter cover crop usually must be seeded in early fall and killed in the spring. In areas of lower rainfall, soil moisture is used that may be needed by the following crop. Where climatic conditions are favorable, double cropping (the use of two cash crops) can be used to provide adequate cover and increase the economic return to the farmer.

5. Conservation tillage systems consist of a number of noninversion tillage methods that leave residues on the soil surface to provide erosion protection and improve water infiltration. The effectiveness of this practice depends on the method of tillage used and the type of conventional tillage it replaces. The type of equipment used in conservation tillage affects the amount of residues left on the surface and the surface storage capacity for rainfall.

In general, conservation tillage can reduce the solid-phase nitrogen and phosphorus lost by 40 to 70 percent and the dissolved nitrogen lost in runoff by 15 to 30 percent (13). The dissolved nitrogen lost by leaching may increase. No till and other reduced tillage methods leave large quantities of residue on the soil surface. These residues along with broadcast phosphate fertilizer can increase the loss of dissolved phosphorus in runoff, particularly during freezing and thawing periods. Generally, however, this loss is low when compared to the total phosphorus lost with conventional tillage.

6. Terracing and contour farming are practices that can be very effective in reducing losses of both solid-phase and dissolved nutrients. Both practices, however, can increase the loss of dissolved nitrogen by leaching as a result of increased infiltration.

The Cornell University study previously mentioned indicates that terraces can reduce solid-phase nitrogen and phosphorus loss by 95 percent. The reduction of dissolved nutrient losses by runoff for the three locations ranged from 20 to 50 percent for contour farming and from 30 to 70 percent for terraces (7).

7. Field border, filter strip, and stripcropping are practices that can be used to reduce the edge-of-field losses of nutrients. These practices are particularly useful in reducing the transport of solid-phase nitrogen and phosphorus in runoff because of their trapping effect.

8. Wetlands, both artificial and natural, remove dissolved and particulate nutrients. A high percentage is removed because of their long detention times.

9. Irrigation water management is very effective in reducing the amount of nitrogen leached from irrigated fields. There is generally a high potential for nitrogen leaching on irrigated sandy soils. It is important that both the nitrogen and water be managed in a coordinated program. As previously discussed, the timing and rate of nitrogen applications are most important. Irrigation efficiency also must be kept high to reduce the amount of leaching that takes place as a result of deep percolation. Many factors contribute to nitrogen losses by leaching during the growing season. Included are deep percolation losses of water from both irrigation and rainfall, the form of nitrogen used, the timing and method of nitrogen application, the amount and distribution of residual nitrate in the soil profile at the start of the season, and the amount and rate of plant uptake of nutrients.

Overirrigation generally occurs during the early stages of crop growth. Many surface irrigation systems are so designed that small applications of water needed during early crop stages cannot be made. Furrows may

be too long to provide uniform distribution of water to the entire length. In border irrigation, the border strip may be too wide for the head of water that is available. Another cause of overirrigation is the irrigator's lack of understanding of the soil-water-plant relationships. This often occurs with sprinkler irrigation of sandy soils.

Overirrigation contributes greatly to the nitrogen leaching problem. If irrigation water is accurately controlled and applied, timing and the method of applying nitrogen become less critical. To allow for miscalculations in irrigation applications and/or heavy rains during the growing season, use the following practices to help reduce loss of nitrogen by leaching:

(1) Make a light preplant application of nitrogen;

(2) Use a starter fertilizer containing a small amount of nitrogen placed under the seed; and

(3) Apply the remaining needed nitrogen during the period of rapid nitrogen use. This can be side dressed or distributed through the irrigation system, or a combination of both.

Regardless of the method of irrigation used, good irrigation water management is essential.

10. Animal waste management will be primarily discussed in Chapter 9. Animal waste has an advantage as a fertilizer because nitrogen becomes available over a longer period of time; thus, less nitrate is available at any one time for leaching. When using animal wastes to supply crop nutrients, the following is essential: (1) determine the amount of nitrogen actually being applied to the land, (2) determine the rate at which nitrogen will become available for crop use, and (3) prevent loss of nitrogen before the manure is incorporated into the soil. The SCS Agricultural Waste Management Field Manual provides guidance in making these determinations.

Animal wastes can be applied as a solid, a liquid, or a slurry. Regardless of the method of application, manure should be incorporated into the soil as soon as possible. This will reduce the loss of nitrogen to the atmosphere (volatilization) and will provide a safeguard against loss in runoff waters.

Summary

1. Proper fertilizer application rates, timing, types cf fertilizer, and methods of application reduce the availability of nutrients to become pollutants.

2. Crop rotations and the use of legumes reduce the nitrogen buildup and the need for commercial fertilizer. Sod-based rotations significantly reduce dissolved and particulate nitrogen and phosphorus losses.

3. Conservation tillage systems, contour farming, terraces, cover crops, and sod-based rotations will reduce the detachment and loss of nutrients associated with sediment, thus reducing the losses of solid-phase nitrogen and phosphorous.

4. Field borders, filter strips, and stripcropping practices also reduce nutrient losses associated with sediment because of their trapping ability.

5. Where land is irrigated, irrigation water management has a significant effect on the loss of dissolved nitrogen by leaching. On sandy soils, it has a greater impact on nitrogen leaching than the nitrogen application rate and timing.

Chapter 7
Controlling Sediment Pollution

Principles of Control

Chapter 4 discussed the three stages of the pollutant delivery process - availability, detachment, and transport. Soil is obviously always available on the surface of the earth. It can vary in its degree of availability in that some soils are more erodible than others. Thus, nothing can really be done about decreasing its availability. Sediment must, therefore, be controlled in the *detachment* stage by preventing erosion (the preferred method), or in the *transport* stage by trapping sediment.

To reiterate information from Chapter 4, soil particles are primarily detached by raindrops (or in some cases by sprinkler drops) but can also be detached by the shear forces resulting from overland or channel flow. Large sediment particles are less cohesive and, therefore, are more readily detached from the soil surface than fine particles. However, because of their large size, they settle out of suspension more readily. Clay particles and organic residues, on the other hand, stay in suspension for longer periods of time and will be transported more readily in low-velocity flow. Thus, they are transported greater distances and are less prone to become trapped.

Since primary clay particles and organic matter are easily transported, it is easier to control them through practices that control detachment. Sand, coarse silt, and soil aggregates can be controlled in either the transport or detachment stages. Table 7.1 lists qualitatively the potential effectiveness of detachment and transport controls for several sediment-associated sources.

Table 7-1. Potential effectiveness of soil detachment and transport controls on several sediment associated sources of pollution (23).

Source of pollution	Control mechanism	
	Detachment	Transport
Clay	High	Low
Sand	Medium	High
Aggregates	High	High
Adsorbed substances	High	Low
Organic matter	High	Low
Suspended solids	High	Low
Total sediment yield	High	High

Sediment can result in a variety of types of water pollution. Some of these types of water use impairment are specific to a portion of the total sediment load. Therefore, when possible, sediment control practices should be designed to control that portion of the total sediment load that is impairing water use. For example, the clay and organic fractions are associated with problems resulting from substances adsorbed to sediment and turbidity. If water use is impaired because of sediment deposition, the total sediment load needs to be controlled.

Methods of Control

1. A conservation cropping system is a planned system in which all necessary measures are installed to maintain or improve soil, water, and air. Crops are grown in combination with needed cultural and management measures. This system includes rotations that contain grasses and legumes as well as rotations without such crops.

2. Conservation tillage involves the use of tillage methods that leave a protective cover of crop residue on the soil surface. The residue provides protection from erosion during the year, but it is especially important during the period from harvest until the following crop provides protective cover. The practice is especially effective at reducing detachment of soil particles.

The effect of various tillage methods is normally evaluated by comparing the erosion on land managed under these systems to the erosion on conventionally tilled land. Conventional tillage varies in different parts of the country. It normally includes moldboard plowing, disking and harrowing before planting, and one or more cultivations after plantings. Conservation tillage may include such methods as no tillage (zero tillage), chisel plant, strip tillage, till plant, plow plant, or wheel track planting. Conservation tillage reduces erosion by increasing infiltration, reducing raindrop splash, increasing surface storage of water, and improving the physical condition of the surface layer of the soil.

No tillage is a method of planting the crop into existing cover crop, sod, or crop residue, thereby eliminating previous and subsequent tillage operations. It is best adapted to well-drained soils in areas where the growing season is relatively long. No till is very effec-

tive in reducing erosion. It can reduce soil erosion by 80 to 90 percent over conventional tillage on slopes of 5 to 12 percent and slope lengths of 60 to 90 meters (200 to 300 feet) (13).

The effectiveness of various tillage methods for erosion control depends on the residue that remains on or near the surface. (Table 7.2)

Table 7.2. Percentage of residue covered by tillage method.

Tillage method	Residue covered (percent)
Moldboard plow	Almost 100
Chisel plow and two diskings	80 to 95
Chisel plow & one disking	65 to 80
Chisel plow	30
No till (slot planter)	5

Conservation tillage and a conservation cropping system can usually be implemented with little change in farm income. Consequently, they generally have high cost effectiveness.

3. Contour farming is used on sloping land. Plowing, seedbed preparation, planting, and cultivation are done on the contour. Contouring is most effective on slopes of 2 to 7 percent. As the field slope increases, the length of slope that can be effectively controlled by contouring decreases. On slopes of 2 to 7 percent and slope lengths of 30 to 60 meters (200 to 300 feet), contouring can reduce erosion by 40 to 50 percent. If contour farming is combined with conservation tillage under these same conditions, erosion can be reduced by 70 to 80 percent.

Contouring provides excellent erosion control by reducing transport for moderate rainfall intensity. If accumulated rainfall exceeds the row capacity, contouring becomes ineffective, and gullying can be intensified. Contouring on long slopes and in intense rainfall areas should be supported by stripcropping or terraces.

4. Stripcropping is planting crops in a systematic arrangement of straight or contour strips to reduce water erosion. The crops are arranged so that a strip of sod or a close-growing crop is alternated with a strip of clean-tilled crop or fallow, or a strip of sod is alternated with a close-growing crop. Stripcropping can further reduce soil losses and associated pollutants as compared to contouring alone, especially on long slopes and in intense rainfall areas. This practice is effective in reducing both detachment and transport of soil and sediment.

Contour stripcropping slows the runoff water, thereby reducing the transport capacity of the flow. The runoff water spreads out in the strips of close-growing crops where much of the sediment is deposited. Additionally, the soil is protected from raindrop impact in the strips of close-growing crop or sod, so fewer soil particles are detached from the surface.

Contour stripcropping on slopes of 2 to 7 percent can reduce erosion by as much as 75 percent as compared to planting row crops up and down the hill. Grassed waterways may be needed to control gully erosion in areas where runoff water tends to concentrate.

5. Cover and green manure crops are close-growing legumes or grasses grown primarily for seasonal protection and soil improvement. They may be grown for part of a year to provide cover when the soil surface is bare following harvest and the erosion potential is greatest. In some areas, they may be used to provide a permanent protective cover within an existing crop area, such as in orchards. Cover crops provide protection from wind and water erosion during periods when the major crop does not provide adequate cover. In some instances they may be plowed into the soil as a green manure crop to improve soil structure and provide nutrients for the following crop.

Cover crops can be very effective in reducing the detachment of soil by rainfall on fields where crops have been removed for feed or silage. The disadvantage of using cover crops is the additional farming operations, greater labor, and higher energy required in their establishment and subsequent elimination. In the lower rainfall areas, cover crops may take away moisture that is needed by the following crop.

6. Critical-area planting is the use of vegetation such as perennial grasses, trees, shrubs, vines, and legumes on highly erodible or critical eroded areas. It is used in areas that are the source of large amounts of sediment. These areas usually cannot be stabilized by ordinary conservation treatment and management. Usually the practice will be used in areas such as those that are severely gullied, surface-mined, or under construction and where vegetation is difficult to establish. These areas may need protection from livestock and vehicular travel.

7. A diversion is a channel constructed across the slope with a supporting ridge on the lower side that is used to transport excess water from areas that need protection to sites where the water can be used or disposed of safely. A diversion is particularly useful for diverting runoff water that is damaging cropland, pastureland, feedlots, or other conservation measures such as terraces and stripcropping.

The diversion is not a sediment-reducing practice within itself. Unless constantly maintained, the diversion must be protected from high sediment delivery from its drainage area and must be designed to carry the sediment in the runoff water to its disposal point. Its effectiveness as a sediment-reducing measure is in diverting the runoff which would otherwise flow across erosion susceptible areas, detaching and transporting soil particles.

8. A filter strip is an area of vegetation established for the purpose of removing sediment, organic matter, and other pollutants from runoff water. Removal is by filtration, infiltration, absorption, adsorption, decomposition, and volatilization. This practice can be effective on cropland at the lower edge of the field; on fields adjacent to streams, ponds, and lakes; and as part of a waste management system to treat polluted runoff and waste water. It can also be used at construction or forest harvesting sites to reduce sediment delivery to receiving waters. This practice should be considered as a supplement to other measures that are intended to keep the soil particles in place or as a temporary measure.

9. A grade stabilization structure is used to stabilize the grade or to control gully head erosion in natural or artificial channels. These structures may range from small metal or wooden drops to sizable concrete structures to large earthen fills. The type of structure used will depend upon the grade to be controlled, the expected volume of flow, and the site conditions. A more detailed description of these structures is given in the SCS Engineering Field Manual. By reducing velocity, these structures are very effective in preventing the detachment of sediment by gully and channel erosion. They also reduce the transport capacity.

10. A grassed waterway or outlet is a natural or constructed waterway or outlet which is shaped or graded and established in suitable vegetation for the safe disposal of runoff. Waterways prevent the formation of gullies in fields and are used to transport water from contour rows, terraces, or diversions downhill to a stable discharge point. The only significant direct benefit of grassed waterways in reducing pollution by sediment is in reducing gully erosion. If sediment is trapped in the waterway, the protective grass cover may be destroyed, the cross section is changed, and the stability of the waterway decreased. Waterways sometimes make farming with large equipment difficult and their vegetation can be damaged by herbicides.

11. A forest land erosion control system is a combination of measures implemented to reduce erosion on logging roads and forest land. Overland flow rarely happens on an undisturbed forest floor. Sediment is best controlled by maintaining good forest cover and a protective forest floor, which can be accomplished through proper grazing and fire control.

When it is necessary to harvest forest products, special erosion control measures should be applied. Most erosion during harvesting begins with forest roads; therefore, most soil erosion in forests can be controlled by some combination of proper road location, minimum density, adequate drainage, and regular maintenance.

12. Permanent vegetative cover (pasture and hayland planting and range seeding) is the establishment or reestablishment of long-term stands of adapted species of perennial grasses and forage plants to reduce erosion, make land use adjustments, and improve water quality. These practices include the seeding of adapted plants on pastureland, rangeland, and woodland that can be grazed, and the establishment of long-term stands of forage plants on land being converted from another use.

These practices protect and stabilize the soil, increase surface water storage, improve infiltration, and decrease surface runoff and erosion. They are the most effective measures for reducing erosion and potential pollution by sediment. A good stand of permanent sod and good grazing management can reduce erosion by 95 percent as compared to a conventionally farmed row crop.

These practices require a livestock program for grazing or a market for grass or hay. Often, the practices either do not fit the farm enterprise or they cannot be economically justified.

13. Proper grazing use is grazing at an intensity that will maintain enough cover to protect the soil and maintain or improve the quantity and quality of desirable vegetation. The desired degree of use is attained by managing the size of the grazing area and the time (length of the grazing period) and intensity (number of grazing animals) of grazing. Proper use is the single most important factor in controlling erosion and sediment on permanent grazing lands.

14. A terrace is an earth embankment, a channel, or a combination of a ridge and channel constructed across the slope. Its purpose is to (1) reduce slope length, (2) reduce erosion, (3) reduce sediment content in runoff water, (4) intercept and conduct surface runoff at a nonerosive velocity to a stable outlet, (5) retain runoff for moisture conservation, (6) prevent gully development, (7) re-form the land surface, (8) improve farmability, and (9) reduce flooding.

Terraces support contour farming by preventing gully development when runoff breaks through the contour rows. Terraces decrease the slope length by breaking it into sections equal to their horizontal spacing. Where level terraces are feasible, runoff water is stored until it has time to infiltrate the soil. All sediment and associated pollutants are eliminated. When graded terraces are used, runoff is removed from the field at a nonerosive velocity by grassed waterways or underground outlets. Graded terraces are most effective at reducing transport capacity and controlling channel and gully erosion.

Considerable erosion may occur between terraces; however, from a sediment pollution standpoint, terraces are one of the best controls. Terraces with open outlets trap as much as 60 percent or more of the sediment that moves between terraces if the terrace grade is 0.5 percent or less. Terraces with underground outlets trap 90 percent or more of the sediment (4).

Terraces are an expensive control measure to install, but they provide a more positive, permanent control than do those practices that are of an annual nature. Terraces also permit more intensive cropping on sloping land.

15. Sediment basin and water- and sediment-control basin are practices used to reduce the transport capacity of flow by trapping and collecting sediment and debris.

The sediment basin is used to trap and store sediment, and sometimes debris, to reduce or abate pollution. It is used to prevent the siltation of reservoirs, ditches, canals, diversions, waterways, and streams; to trap sediment originating from construction sites; and to prevent undesirable deposition on bottom lands and developed areas. It is not an erosion control measure but it can be very effective in trapping sediment. Clay and fine silt, which remain in suspension for long periods of time, are less likely to be trapped than larger soil particles (coarse silt and sand).

The water- and sediment-control basin is used to trap sediment, reduce onsite erosion, reduce peak rates of flow at downstream locations, reduce gully erosion, re-form the land surface, and improve the potential of areas for farming. This practice is normally used with conservation tillage on cropland that has irregular topography.

16. An irrigation system may have a significant impact on erosion and soil losses from irrigated land. From an erosion control standpoint, the irrigation system selected must be suitable for the soils, topography, and for the crops to be grown. The adaptations and limitations of the major irrigation methods are given in SCS National Engineering Handbook, Irrigation, "Planning Farm Irrigation Systems," and in many SCS State Irrigation Guides. Practices such as land leveling, canal and ditch linings, underground pipelines, water control structures, and water measuring devices are components of irrigation systems that can be used to reduce erosion.

Controlling sediment losses on irrigated fields may require a complete change in the method of irrigation used or a simple modification of elements in the existing system. Changing from furrow irrigation to sprinkler irrigation is an example of a change of method. Relocating and lining an irrigation ditch and land leveling are examples of a modification of elements in the existing system.

Erosion control needs must be considered when the irrigation method is selected. This is true of both irrigation projects and on-farm irrigation development by individual farmers. Irrigation often intensifies erosion problems. While irrigation can provide a more vigorous and dense crop canopy, which in itself tends to reduce erosion, this is often offset by the higher soil moisture which reduces infiltration and increases runoff from rainfall.

Some irrigation methods, such as furrow irrigation, increase the potential for erosion. Cultural operations and crop rows are conducted up and down the slope rather than across the slope. This increases the potential for erosion.

Some of the factors to be considered in the selection of irrigation systems for sediment control are:

(1) The system must be compatible with the needed erosion control measures. For example, a center-pivot sprinkler is not compatible with stripcropping.

(2) The system must be adjustable to soil intake rates and desired irrigation applications to control erosion.

(3) Cultural measures such as conservation tillage can be used to improve infiltration, increase surface storage of water, and retard erosion.

17. Irrigation water management is usually the goal of most irrigation system improvements. This includes applying the right amount of water at the proper time with proper distribution within the field and without significant erosion. The length of runs must be such that efficient irrigation can be carried out without having erosive stream sizes at the head of the run. Length of runs also can be restricted by erosion caused by rainfall.

Summary

1. Erosion control measures required to control pollution by sediment are site specific, involving such factors as topography, soils, rainfall, plant cover, sediment delivery, and crops to be grown.

2. Sediment can result in a variety of types of water pollution. Some of these types of water use impairment are specific to portions of the total sediment load. Control practices should be designed to control the portion that is impairing the water use.

3. Detachment control practices are most effective in controlling primary clay particles and organic matter.

4. Transport control practices are effective in controlling coarser particles such as sand and aggregates.

5. As a general rule, management practices should be the first alternative selected since they provide the quickest and most economical means of reducing pollution by sediment.

6. Permanent vegetative cover provides the most significant and permanent solution if properly managed. It is not always practical for every farm and often cannot be economically justified.

7. Erosion control practices, such as contour farming, terraces, and conservation tillage, are designed to keep the soil in place or reduce the edge-of-field loss of sediment.

8. Sediment control measures, such as sediment basins and filter or buffer strips, serve to control the pollutant in the transport phase by trapping sediment in the runoff.

9. Structural measures are the most costly but generally are long lasting, provide good control, and permit more intensive cropping.

10. Most erosion on forest land is on logging roads. Practices that control water movement, including proper road layout, are highly effective.

Chapter 8
Controlling Animal Waste Pollution

This guide deals with manure that is spread on cropland, pasture, and range or dropped there by grazing animals. It does not cover control measures for concentrated waste sources such as manure storages, milkhouses, and milking centers and from animal confinement areas such as feedlots and barnyards. The Agricultural Waste Management Field Manual addresses these.

Principles of Control

Manure is a valuable resource for crop production. It contains not only nutrients but also organic matter. A basic principle is that if manure is utilized to the maximum extent possible, very few pollutants will be discharged to receiving waters. Stated another way, if the nutrients in manure are conserved and judiciously reused, there will be few water quality problems attributable to this source.

This guide focuses on controlling the major pollutants in three stages - availability, detachment, and transport. The most effective controls for animal waste are those that limit the availability. The availability of manure as a pollutant is reduced by the proper application rate, the proper timing of the application, incorporating the manure whenever possible, and by the judicious selection of the application site. These measures will often require the storage of manure; however, storage by itself gives no water quality benefits. Storage is only a means to better utilize the nutrients and avoid spreading the manure during critical runoff periods, for example, when the ground is frozen or covered with snow and ice.

Detachment controls are not as effective as limiting availability. Detachment controls are effective primarily in reducing the impact of rainfall on soil particles, i.e., controlling erosion. Thus, this type of control is effective mainly for manure nutrients attached to soil particles, such as the ammonium ion, a portion of the phosphorus, and potassium.

Transport controls are effective primarily for attached manure nutrients and manure particles. However, grass filters are particularly effective because of both their trapping characteristics and their infiltration ability, which would reduce the transport of soluble nutrients as well.

Methods of Control

1. A waste management system is a planned system in which all necessary components are installed to manage liquid and solid animal waste in a manner that does not degrade air, soil, or water resources. The system may consist of a single component such as a diversion, or it may have numerous components such as a storage facility, a method of transporting the waste to the application area, and the necessary equipment. The structural components most commonly used to control manure pollution as addressed in this guide are waste storage ponds and structures, and waste treatment lagoons.

Waste storage ponds and *waste storage structures* may be required where animal waste is temporarily stored until it can be applied without creating a water quality problem. *Waste treatment lagoons* are used to biologically treat animal wastes to reduce the nutrient content and the oxygen demand. They are not a nutrient conservation practice. They are most often used with large animal enterprises where the manure is removed from confinemen y flushing. Lagoons benefit water quality by returning nitrogen to the atmosphere from their surfaces. This is important where land and animals are out of balance; that is, the manure produced greatly exceeds the capacity of the land to utilize the nutrients in the manure.

The various components of a waste management system are covered in more detail in the SCS Agricultural Waste Manager it Field Manual and the National Handbook of Conservation Practices.

2. Waste utilization is a management practice and probably the most important control practice of all. Normally, manure is applied to pastures and cropland to recover plant nutrients.

Water quality problems related to manure application sites can be effectively solved by practices that reduce the availability of pollutants for transport during runoff events, such as: (1) elimination of excessive application rates, (2) proper timing of manure applications, (3) proper method of manure application, and (4) selection of application sites.

Application rates of manure should be based on soil nutrient levels, the nutrient needs of the crop, and the available nutrients in the manure. An exception is where pathogens are a problem, such as in watersheds above shellfish growing areas. Both nitrogen and phosphorus requirements should be considered in determining proper application rates. Applying manure to satisfy crop nitrogen requirements may result in excess phosphorus being applied. The SCS Agricultural Waste Management Field Manual provides instructions for determining the application rate.

Salt content of animal wastes can have an effect on application rates, especially in arid and semiarid areas. If sufficient manure is applied to meet the nitrogen needs of the crop, salt may be excessive. When these areas are irrigated, excess salt can become a problem in crop production and in water quality.

The timing of manure applications should coincide as nearly as possible with crop needs to maximize plant nutrient utilization and reduce the potential for nutrient losses in runoff. Applications should also be timed to coincide with tillage operations where possible.

The frequency of manure application is highly variable, ranging from daily to once per year, depending on the availability of manure, availability of labor, storage capacity, access to the disposal area, and the amount of land available. Daily spreading of manure is often practiced when animals are confined and storage facilities are not available. When manure is stored, a common design in the cool and cold areas of the country is to provide 6-month storage capacity. This results in two intensified periods of manure application, early spring and late fall.

Spreading manure on frozen or snow-covered soil is generally a practice that should be avoided because of the potential for losses during rainfall or snowmelt runoff. Manure storage is considered a pollution control practice because it avoids spreading during adverse periods. Applying manure that has been stored over winter may become critical in conjunction with spring tillage operations and spring rainfall. Applying manure in the fall increases the potential for nitrogen loss through leaching.

The *method of manure application* can greatly affect its availability for becoming a pollutant. The physical incorporation of manure by injection, immediate plowing, or disking will dramatically reduce the runoff losses of manure nutrients. If manure is not injected in cropland, surface spreading should not be scheduled until the manure can be incorporated by a tillage operation.

When fall applications of manure are incorporated into the soil by plowing or disking, the loss of vegetative cover during the winter months may increase the potential for soil erosion, thereby negating other water quality benefits. It is important in these cases to select fields that have low erosion potential.

Manure is normally topdressed on hay crops and topdressed or injected on pastures. Losses will generally be small if surface applications are light and the legumes or grasses provide good cover. Applications can be made after the animals have been removed from the pasture or following the cutting of the hay crop.

The *proper selection of application areas* is critical in avoiding the loss of nutrients from applied manure. The hazard of specific areas depends on their location, rainfall intensity, slope, vegetative cover, and soil characteristics. In selecting areas, land next to streams, lakes, and waterways should have low priority or be avoided if possible.

Where storage facilities are not available, field priorities for winter spreading should be established to reduce water quality hazards. This requires the ranking of available areas with respect to potential pollutant discharge. The proximity to streams and major drainage channels, slope, and the vegetative cover should be considered. Areas that have a high runoff potential should be avoided.

3. Soil and water conservation practices can aid in the reduction of pollution by animal wastes. All of the soil and water conservation practices discussed under the section "Controlling Sediment Pollution" are applicable in reducing the loss of manure pollutants, particularly when manure is surface applied. Such practices as contour stripcropping, terraces, and conservation tillage are included.

Vegetative cover that provides soil protection during all or part of the nongrowing season can influence pollutant loss in several ways. The increased cover and surface residue decrease soil erosion. Vegetative growth, especially from a well-established winter cover crop, can take up nutrients which would otherwise be lost and can serve as a filter to trap sediment and adsorbed nutrients.

If pollutants are not being controlled adequately at the source, grass filter strips can be placed at field edges. These areas filter and trap sediment, manure, and other pollutants. Potential pollutants will then either decay, infiltrate the soil, or be taken up by growing

plants. For the areas to be effective, they must slow runoff sufficiently to allow the sediment and organic materials to settle out in the filter. Filter strips can also be located along streams.

In some areas of the country, manure from dairy cows is applied only to hayland and pasture, often on soils that have a seasonal high water table. Here, the problem is not erosion and sedimentation but rather one of incorporation, being able to travel over the field, and preservation of the soil structure.

Manure in these areas is often applied as a liquid, either by a liquid tank spreader or, if it has been diluted a number of times, by sprinklers. Incorporation by tillage is not possible, and injection is impractical. Thus, incorporation occurs only by infiltration. In this case it is imperative that the water table be low enough to allow the manure liquids to infiltrate readily into the soil. Subsurface drainage is necessary to lower the water table, allowing the manure liquids to infiltrate. Drainage also improves the trafficability of the soil, permitting hauling equipment to travel more of the land and for longer periods during the year without damage to the soil structure.

4. Pastureland and rangeland properly managed and not overgrazed usually have no problem of pollution by animal waste. The key practices to be used with pastureland and rangeland are livestock exclusion, pasture management, proper grazing use, selected salt and feed sites, and selected shade areas. Principal water quality problems occur where animals congregate, where they have access to streams, and where supplemental feed is provided at wintering sites. Grazing livestock also tend to congregate in shaded and protected areas, adjacent to watering facilities, and close to salt locations. In addition to increased manure accumulation, soil compaction and destruction of vegetative cover occur in these areas. This results in soil erosion, increased runoff, and the discharge of pollutants associated with manure.

Livestock on pastureland and rangeland frequently have access to streams. This results in the direct deposition of feces and urine into surface waters. Animal traffic may cause streambanks to become unstable and create erosion.

Animal densities in wintering areas are much higher than those on grazing areas. This results in an increase in manure and pollutant concentrations in rainfall and snowmelt runoff. Fecal coliforms and fecal streptococci increase significantly around areas of greater livestock activity.

Water quality problems related to pastureland and rangeland are most effectively controlled by using sound management practices. Overgrazing should be avoided. Stocking rates and grazing systems that sustain good forage yields will minimize manure accumulations and reduce surface runoff. Maintaining good vegetative cover and minimizing soil compaction will greatly reduce runoff. The SCS National Range Handbook and SCS Technical Guides provide information on appropriate stocking rates for various animal species, types of vegetation, grazing systems, and geographic regions.

Winter pastures and areas of animal concentration, such as shaded and protected areas and water and salt facilities, should be located in areas hydrologically remote from streams and major drainage channels. This will minimize water quality impacts by allowing runoff waters to move through vegetative areas before entering the receiving stream. Manure accumulation around these areas can be reduced by periodic relocation of these facilities. Relocating the facilities will also help to alleviate overgrazing in the area immediately adjacent to them. Accumulations of manure in heavily concentrated areas can be removed periodically and applied to cropland or distributed more evenly on pasture.

Animal access to surface waters should be restricted. Providing shade and using insecticides can help reduce the need for animals to congregate in streams to obtain relief from heat and insects. It may be necessary to develop alternative sources of drinking water and restrict livestock access to the stream by fencing.

Summary

1. A basic principle in controlling animal waste pollution is to conserve the nutrients in manure and reuse (utilize) them to the maximum extent possible.

2. The primary control method is to reduce the availability of manure as a pollutant. This is accomplished by selecting the least critical site and using the proper rate, timing, and method of application. Storage will almost always be necessary to meet these objectives.

3. Detachment controls are effective only to the extent they control erosion of soil particles to which manure nutrients may be attached and, to a lesser extent, the erosion of manure particles themselves.

4. Manure pollutants can be controlled to a limited extent in the transport stage. If filter areas are used, manure particles and manure nutrients attached to sediment will be trapped.

5. Soil and water conservation practices are most effective when manure is surface applied and not physically incorporated.

Chapter 9 Controlling Salt Pollution

Principles of Control

Irrigation water is essential for crop production in the arid and semiarid regions of the United States. Unfortunately, irrigation water in many of these regions contains a natural load of dissolved salts. As the water is consumed by plants or lost by evaporation, the salts remain and are concentrated in the soil profile. To maintain the productivity of irrigated lands, the accumulation of soluble salts must be moved (leached) below the root zone. Thus, the amount of irrigation water applied to the soil profile must exceed the evapotranspiration requirement in order to meet the leaching needs. If too much water is applied for leaching, however, salts are often "picked up" from saline substratas. Thus, the amount of irrigation water and the timing of its application (irrigation water management) become critical in salinity control.

As discussed earlier, pollutants can be controlled in the availability, detachment, and transport stages. However, salts can be controlled primarily in the detachment stage, because most salts are lost to receiving waters through leaching. Salts are always available in the soil, in the irrigation water, and occasionally in the substrata; thus, very little can be done in the *availability stage.* The only solution in this stage is to limit the amount of irrigation water applied, thereby limiting the amount of natural salts applied (and made available). For example, if the irrigation efficiency can be increased from 30 to 60 percent, the gross amount of water applied would be reduced by one half, with only half as much salt applied (and available). In areas where water quality problems from salinity are the greatest, however, the major source of salt is not from irrigation water but rather from saline substrata. Therefore, salt can be controlled only to a minor extent in the availability stage.

The *detachment* process is, for all practical purposes, the only phase in which salts can be effectively controlled. Control is accomplished by limiting the amount of water applied, particularly the amount which is allowed to leach through the soil. Very little can be done in the *transport* process because salts are dissolved and do not lend themselves to being trapped like particulate matter. Structural measures such as evaporation basins and desalting plants are effective control measures; however, they are seldom feasible because of their high installation and operating costs.

Methods of Control

The control measures discussed in this section are those that have general applicability, but certain practices will be better adapted to specific sites.

1. Irrigation water management is a management measure to effectively use available irrigation water to minimize soil and nutrient loss and to protect water quality. It is the process of determining and controlling (1) the time to irrigate, (2) the rate of water application, and (3) the quantity of water to be applied.

Irrigation water management requires that the irrigator have the knowledge and the capability of managing and applying irrigation water to effectively use the available irrigation water, control the soil moisture environment of the crops, minimize erosion, minimize deep percolation and loss of plant nutrients, and provide for sustained agricultural production.

Improving irrigation efficiency generally is effective in reducing salt pollution. However, in some furrow irrigation systems, salt loading may be reduced by managing the irrigation water to increase tail water and reduce deep percolation, slightly sacrificing irrigation efficiency.

One of the more important tools in irrigation water management is proper irrigation scheduling. Details on various scheduling methods are given in the SCS Engineering Field Manual and in SCS State Irrigation Guides. Regardless of the scheduling method used, there must be an understanding of the effect that application rate and application time have on the irrigation efficiency. A water management plan is an important tool in managing the irrigation water to achieve the desired efficiency.

2. Crop selection can provide a solution in some instances. By selecting a salt tolerant crop, the leaching requirement is reduced. Salt tolerance of crops varies with climatic conditions and with crop varieties. Table 9-1 gives the expected decrease in yield of various crops based on their salt tolerance. The values given in the table are the electrical conductivity (σ_e) of the soil saturation extract in decisiemens per meter (dS/m) at the point where a 50 percent reduction in yield would occur as compared to yields on nonsaline soils under comparable growing conditions.

3. An irrigation system is the onfarm irrigation facility for conveying, distributing, and applying irrigation water to the crop and disposing of excess water. The three basic methods of applying water are: (1) surface and subsurface irrigation, (2) sprinkle irrigation, and (3) trickle irrigation. Each of these methods has certain adaptations and limitations. The system used will vary with the topography, soil conditions, crops to be grown, value of crops, cultural practices, available water supply, and land preparation needed. When the irrigation system does not fit the existing soil-crop-topography combination, proper applications of water are difficult or impossible to make. For example, irrigation grades may be too steep and length of the irrigation run too long. The design of the system may be such that changes in application cannot be made to fit the rooting depth and water requirement of the crop being grown.

With *surface irrigation* methods, the water is applied directly to the soil surface either by controlled flooding or in some kind of furrow. Some of the different types of controlled flooding are graded borders, basins or level borders, contour levee, and contour ditch. Consult the SCS Engineering Field Manual and the State Irrigation Guide for description, limitations, and advantages of these methods.

As mentioned, one of the principles in controlling salt pollution is to minimize deep percolation and the excessive leaching of salts. Methods of water control which improve furrow irrigation efficiency and decrease the high-salt return flow are: (1) cutback furrow stream, (2) furrow ponding or impoundment, and (3) tail-water recovery system.

In the cutback furrow stream, the inflow stream must be large enough to reach the end of the furrow in about one-fourth or less of the time required to apply the desired amount of water to the root zone of the crop. In order to keep the deep percolation low and at the same time reduce the runoff, the large furrow stream must be cut back to a smaller stream after water has reached the end of the furrow. Cutback procedures have not been readily accepted because they require increased management and labor.

A time clock or a master control panel can be used to completely automate gated pipe for furrow irrigation. The length of set time can be automatically controlled, and the stream size can be automatically cut back when the stream reaches the end of the field.

In the furrow impoundment procedure, a furrow stream is selected that will move the water quickly to the end of the furrow. Water is then impounded or held in place until the required time to apply the desired depth of water has elapsed. This procedure does not require a tail-water recovery system. It does require that the furrows be level or have a very slight grade. Ponding at the lower end of graded furrows is often practiced. If the ponding time exceeds the required irrigation time, then deep percolation takes place at the lower end of the furrow as well as at the upper end. The tail-water recovery system is discussed later.

The *sprinkle method* is adapted to most crops and is suited to all soils having an intake rate higher than the sprinkler application rate. This method is especially suited to sandy soils that have high water intake rates. Soils that are too shallow to be leveled for surface methods can be irrigated with sprinklers. This method can be used on steep slopes and irregular topography without extensive land preparation. Where soil erosion is a hazard, normal soil erosion control measures should be used with the sprinkler system. These measures include such practices as mulching, conservation tillage, and terraces. Normally, land leveling is not required except where some smoothing or grading is needed to provide surface drainage. Sprinkler irrigation has a distinct advantage where light applications of water are needed to germinate a seeding or to water seedlings and young plants.

Under most field conditions, the efficiency of sprinkle irrigation is normally good. Efficiency can be low under climatic conditions of high temperature, low humidity, and moderate to high wind conditions. Under such conditions, surface methods are usually more efficient. Sprinkle irrigation is very effective in controlling deep percolation. If the system is properly designed and properly operated, little or no water runoff should occur.

There is available a large variety of sprinkler equipment. Each type has its own application characteristics, labor requirements, crop adaptations, energy consumption, and economic considerations. The following types of equipment are a few of the many available: (1) hand-move lateral, (2) side-roll lateral, (3) solid set, (4) center pivot, and (5) traveling gun.

The *trickle or drip irrigation method* is a system where water is applied directly to the root zone of the plants to provide them with near optimal soil moisture. In widely spaced crops, such as orchards, water losses are reduced because only a small portion of the soil surface is subject to evaporation. Little water is lost to deep percolation if the system is properly designed and operated. The only irrigation return flow associated with trickle irrigation is the occasional leaching that may be necessary to prevent excessive salt buildup in

the root zone. Salts and nutrients tend to build up at the periphery of the wetted bulb. When return flow does take place, nitrate concentrations can be exceptionally high. There is no surface runoff with this method.

4. Tail-water recovery is used to collect irrigation runoff and return it to the same field or an adjacent field for irrigation use. The system normally consists of tail-water ditches to collect the runoff from the furrows, a drainage ditch or waterway to convey the water to the collection area, a sump or reservoir for water storage, a pump and power unit, and a ditch or pipeline to deliver the water to the field or fields where it will be reused. This system is effective in reducing deep percolation by permitting the use of the initial furrow stream throughout the irrigation period. It also prevents surface runoff from reaching receiving waters.

5. Irrigation land leveling is the reshaping of the land surface to permit the uniform and efficient application of irrigation water without causing erosion, deep percolation, runoff, or damage to land by water-logging and without adversely affecting water quality. Land leveling is used on areas that are or will be surface irrigated. It is very rare that fields to be surface irrigated have topography that does not need some improvement. Changes in the slope within an irrigation run, reverse grades, and irregularities need to be removed if high efficiency is to be accomplished in surface irrigation. Leveling assists in efficiently managing the irrigation water, thus reducing excess leaching—the primary source of salinity.

6. Irrigation water conveyance consists of ditches, pipelines, control structures, and other appurtenances necessary to convey water from the source to the area to be irrigated. Water conveyance includes the off-farm conveyance system and the on-farm conveyance system. Seepage losses from unlined delivery canals and laterals and irrigation field ditches are high in many irrigated areas. The combination of seepage losses and deep percolation losses from the irrigated area can cause waterlogging (the rise of ground water levels to near the soil surface). Water moves upward in the soil carrying the salts with it and evaporates, leaving the salts. This process can result in extensive soil salinization if allowed to continue for any length of time. If conditions are such that adequate drainage prevents the water level buildup, the excess water passes through the soil and returns to the ground water or to the stream as return flow.

The off-farm conveyance losses can be primarily attributed to permeable canals, obsolete facilities, improperly maintained facilities, excessive vegetative growth in the canals, and poor management. The losses from the on-farm conveyance system include such problems as unlined ditches, excessive vegetative growth, poor farm layouts, and the lack of proper maintenance.

The following measures are applicable for improving water delivery and reducing seepage losses in either off-farm or on-farm conveyance systems:

1. Lining ditches will reduce the seepage losses from canals, laterals, and field ditches. Lining material may be compacted earth material, concrete, soil cement, or membranes such as asphalt or plastic. The material used will generally depend on its initial cost, maintenance requirements, length of life, and local availability. Regardless of the lining material selected, proper maintenance is essential.

2. Pipelines used to replace open ditches are very effective in reducing seepage loss and improving the operation of the system. Where pipeline systems have been installed, conveyance efficiencies of 95 percent or greater have been obtained.

3. Control of vegetative growth in ditches can increase water flow, reduce the seepage loss, and reduce the consumptive use of water by phreatophytes. Vegetation retards the flow velocity and increases the flow depth, causing a larger area to be subject to seepage loss.

4. Canal or ditch realignment in many situations can considerably reduce the length of ditch that is subject to seepage losses. Ditches often are constructed on the approximate contour because that was the most economical method of construction. Cutting and filling to improve alignment, in conjunction with pipelines, flumes, siphons, etc., can greatly reduce the length of the water delivery system and reduce seepage.

5. Structures such as diversion structures, drops, checks, and turnouts are necessary to properly control the water level at the desired elevation, divert water as desired, and eliminate unnecessary losses. Water measurement structures are necessary but often absent in many systems. Good water measurements are necessary for proper management of the irrigation water, but they are also needed to determine where losses are occurring. This information will provide a valuable means of determining what areas or portions of the system need attention and improvement.

6. Proper maintenance of the water conveyance system is a necessity. Removal of sediment and debris from ditches and structures is important in the management of the system and in reducing water loss. Rodent damage and ditch breakouts should be repaired properly to reduce water loss. Cracks in concrete lining should be sealed. Where excessive breakage occurs, the lining should be removed and replaced. Woody plants and Johnson grass should not be allowed to grow on ditch banks. In addition to their consumption of water, they can have a detrimental effect on ditch lining. Proper maintenance can eliminate many operating problems and reduce water losses.

7. Other measures such as land use conversion and evaporation ponds are extreme and not generally used.

Summary

1. Practices which are most effective in controlling salt pollution are those which reduce detachment. This is accomplished mainly through irrigation water management.

2. Very little can be done to decrease the availability of salt except to reduce the amount of irrigation water applied, increasing the efficiency of the system. This reduces the amount of salt applied, thus somewhat decreasing the availability.

3. Very little can be done to control salt in the transport stage because it is dissolved and cannot be trapped like sediment.

4. Increasing the irrigation efficiency may require changes in the irrigation method, improvement of the land surface by leveling, using lined canals and ditches, and using buried pipelines.

5. Selecting a salt tolerant crop is a management practice that reduces the leaching requirement, thereby reducing the amount of salt in irrigation return flow.

Table 9.1. Crop salt tolerance[1] [Expected decrease in crop yield based on conductivity of soil water extract when common surface irrigation methods are used]

Crop	Yield decrease 0%	10%	25%	50%
	Conductivity $(\sigma_e)^2$			
Field crops				
Barley (Hordeum vulgare)[3]	8.0	10	13	18
Cotton (Gossypium hirsutum)	7.7	9.6	13	17
Sugarbeet (Beta vulgaris)[4]	7.0	8.7	11	15
Wheat (Triticum aestivum)[3,5]	6.0	7.4	9.5	13
Safflower (Carthamus tinctorius)	5.3	6.2	7.6	9.9
Soybean (Glycine max)	5.0	5.5	6.2	7.5
Sorghum (Sorghum bicolor)	4.0	5.1	7.2	11
Groundnut (Arachis hypogaea)	3.2	3.5	4.1	4.9
Rice (Ozyza sativa)	3.0	3.8	5.1	7.2
Sesbania (Sesbania macrocarpa)	2.3	3.7	5.9	9.4
Corn (Zea mays)	1.7	2.5	3.8	5.9
Flax (Linum usitatissimum)	1.7	2.5	3.8	5.9
Broadbean (Vicia faba)	1.6	2.6	4.2	6.8
Cowpea (Vigna sinensis)	1.3	2.0	3.1	4.9
Beans (Phaseolus vulgaris)	1.0	1.5	2.3	3.6
Fruit crops				
Date palm (Phoenix dactylifera)	4.0	6.8	10.9	17.9
Fig (Ficus carica)	2.7	3.8	5.5	8.4
Olive (Olea europaea)				
Pomegranate (Pucia granatum)				
Grapefruit (Citrus paradisi)	1 8	2.4	3.4	4.9
Orange (Citrus sinensis)	1.7	2.3	3.2	4.8
Lemon (Citrus limon)	1.7	2.3	3.3	4.8
Apple (Malus sylvestris)	1.7	2.3	3.3	4.8
Pear (Pyrus communis)				
Walnut (Juglans regia)	1.7	2.3	3.3	4.8
Peach (Prunus persica)	1.7	2.2	2.9	4.1
Apricot (Prunus armeniaca)	1.6	2.0	2.6	3.7
Grape (Vitis spp.)	1.5	2.5	4.1	6.7
Almond (Prunus dulcis)	1.5	2.0	2.8	4.1
Plum (Prunus domestica)	1.5	2.1	2.9	4.3
Blackberry (Rubus spp.)	1.5	2.0	2.6	3.8
Boysenberry (Rubus ursinus)	1.5	2.0	2.6	3.8
Avocado (Persea americana)	1 5	1.8	2.5	3.7
Raspberry (Rubus idaeus)	1.0	1.4	2.1	3.2
Strawberry (Fragaria spp.)	1.0	1.3	1.8	2.5

Crop	Yield decrease 0%	10%	25%	50%
	Conductivity $(\sigma_e)^2$			
Vegetable crops				
Beets (Beta vulgaris)[4]	4.0	5.1	6.8	9.6
Broccoli (Brassica oleracea italica)	2 8	3.9	5.5	8.2
Tomato (Lycopersicon esculentum)	2.5	3.5	5.0	7.6
Cucumber (Cucumis sativus)	2.5	3.3	4.4	6.3
Cantalope (Cucumis melo)	2.2	3.6	5.7	9.1
Spinach (Spinacia oleracea)	2.0	3.3	5.3	8.6
Cabbage (Brassica oleraoea capitata)	1.8	2.8	4.4	7.0
Potato (Solanum tuberosum)	1.7	2.5	3.8	5.9
Sweet corn (Zea mays)	1.7	2.5	3.8	5.9
Sweet potato (Ipomoea batatas)	1.5	2.4	3.8	6.0
Pepper (Capsicum frutescens)	1.5	2.2	3.3	5.1
Lettuce (Lactuca sativa)	1.3	2.1	3.2	3.6
Radish (Raphanus sativus)	1.2	2.0	3.1	5.0
Onion (Allium cepa)	1.2	1.8	2.8	4.3
Carrot (Daucus carota)	1.0	1.7	2.8	4.6
Beans (Phaseolus vulgaris)	1.0	1.5	2.3	3.6
Forage crops				
Tall wheatgrass (Apropyron elongatum)	7.5	9.9	13.3	19.4
Bermuda grass (Cynodon dactylon)[6]	6.9	8.5	10.8	14.7
Barley (hay) (Hordeum vulgare)[3]	6.0	7.4	9.5	13.0
Perennial ryegrass (Lolium perenne)	5.6	6.9	8.9	12.2
Trefoil, birdsfoot narrowleaf (Lotus tenuis)	5 0	6.0	7.5	10
Harding grass (Phalaris stenoptera)	4.6	5.9	7.9	11.1
Tall fescue (Festuca arundinacea)	3.9	5.8	8.6	13.3
Crested wheatgrass (Agropyron desertorum)	3.5	6.0	9.8	16
Vetch (Vicia sativa)	3.0	3.9	5.3	7.6
Sudangrass (Sorgum sudanense)	2.8	5.1	8.6	14.4
Wildrye, beardless (Elymus triticoides)	2.7	4.4	6.9	11
Trefoil, big (lotus uliginosus)[7]	2.3	2.8	3.6	4.9
Alfalfa (Medicago sativa)	2.0	3.4	5.4	8.8
Lovegrass (Eragrostis spp.)[8]	2.0	3.2	5.0	8.0
Corn (forage) (Zea mays)	1.8	3.2	5.2	8.6
Clover, berseem (Trifolium alexandrinum)	1.5	3.2	5.9	10.3
Orchardgrass (Dactylis glomerata)	1.5	3.1	5.5	9.6
Meadow foxtail (Alopecurus pratensis)	1.5	2.5	4.1	6.7
Clover, alsike, ladino, red, strawberry (Trifolium spp.)	1.5	2.3	3.6	5.7

[1] Adapted from Ayers and Westcot (1).

[2] These values are the electrical conductivity (σ_e) of the soil-water extract in deciseimens per meter (dS/m - formerly millimhos per centimeter) at 25 degrees C. For example, if barley is to be grown, and the σ_e is 13 dS/m, a 25% decrease in yield can be expected.

[3] Barley and wheat are less tolerant during germination and seedling stage. σ_e should not exceed 4 or 5 dS/m.

[4] Sensitive during germination; σ_e should not exceed 3 dS/m for garden beets and sugar beets

[5] Tolerance data may not apply to new semi-dwarf varieties of wheat.

[6] An average for Bermuda grass varieties Suwannee and Coastal are about 20% more tolerant; common and Greenfield are about 20% less tolerant.

[7] Broadleaf birdsfoot trefoil appears to be less tolerant than narrowleaf.

[8] Average for Boer, Wilman, sand, and weeping varieties Lehman appears about 50% more tolerant.

Chapter 10
Controlling Pesticide Pollution

Principles of Control

To reiterate what was stated in Chapter 2, agriculture uses over 70 percent of the pesticides in the United States. For this reason it is important to prevent significant losses of pesticides to receiving waters. Although losses average 0.5 percent or less of the total amount applied, pesticides can still pose a serious threat to water quality and have been responsible for serious damage to the environment in a number of cases.

Chapter 4 states that pollutants can be controlled in any of three stages—availability, detachment, and transport. Chapter 2 states that pesticides are lost from agricultural land by volatilization, degradation, and by removal in runoff (over the surface and leaching). Volatilization and degradation are the two major processes which decrease pesticide concentration, thereby decreasing availability, without harming water quality. The quantity of pesticide associated with the water and the sediment is determined by the partitioning coefficient. The larger the coefficient, the larger the amount of pesticide adsorbed to the sediment; thus, the greater the chance for pesticide leaving the field attached to sediment. With all this as background, we can now look at the principles involved in controlling pesticide pollution.

The first and most effective principle is to use less pesticide, thereby decreasing its availability as a pollutant. This is achieved through plant variety selection, varying planting dates, better timing of pesticide application, and pest scouting. Integrated pest mangement is a key practice.

The second principle is to use pesticides which are less persistent (have a higher degradation rate). Those which degrade faster are less available as a pollutant.

The third principle is to apply soil and water conservation practices according to the partitioning coefficient, thus controlling pesticides in the detachment and transport stages. The larger the partition coefficient, the larger the amount of pesticide adsorbed to soil, and the larger the proportion leaving by the sediment route. In this case, the principle is to reduce erosion losses (reduce detachment) or to interrupt the transport of sediment, thus trapping or filtering out part of the adsorbed pesticides. If the partition coefficient is small (less than 10 ml/g), as is the case for most pesticides on the market today, the pesticide will be associated primarily with the water phase of the runoff. If this is the case, it is much more difficult to reduce pesticide losses as most soil and water conservation practices are more effective in reducing erosion than in reducing runoff. The leaching of pesticides into ground water has recently become a serious problem associated with those pesticides with very low partition coefficients, that is, those less than 0.5 mg/l.

The fourth and last principle is to use pesticides that have lower toxicity (those with greater LD_{50} values shown in Table 2-1). This principle is another form of reducing the availability, because a less toxic material is less available to be harmful in the environment.

Methods of Control

1. Integrated pest management is a management measure utilizing two or more control methods to minimize the pollution of surface and ground waters and to provide an economic control of pests. It involves an understanding of the pest, its host crop and its natural enemies. An integrated pest management program could include such practices as scouting, selection of a special resistant crop variety, pest suppression rather than elimination, and the judicious use of pesticide to protect the natural enemies of the pest being controlled.

An example of integrated pest management can be seen in the control of cotton pests. This program uses scouting, a short season cotton variety, and the protection of natural enemies through the use of selective insecticides. Pesticides are applied only when field scouting indicates that they are necessary. The amount of pesticide used is substantially less than in a conventional pest control program. The use of a short-season cotton variety makes it possible to use fewer pesticide applications to control the boll weevil before it causes significant damage. Azinphosmethyl is used because it does not harm the natural biological control agents.

The economic and environmental benefits of this type of program are substantial. The use of improved technology in integrated pest management makes it possible to simultaneously decrease pesticide use and to increase farm income.

The following are some of the practices that have potential use in integrated pest management.

(a) Pest biological control is the use of biological organisms to suppress pest populations. Insect parasites and predators can significantly decrease the size of pest populations, sometimes to the point where pesticide applications are not needed. One example of this was the introduction of pest parasites to control the olive parlatoria scale. This insect was a serious pest of olives in California before parasites were introduced. These parasites have been so effective that pesticides are seldom used for control. The advantage of biological control is that once it is established it continues at no additional cost.

Biological control can involve increasing the effectiveness of natural enemies of the pest which are already present in the crop field. The application of pesticides to suppress or control pest populations often adversely impacts insect parasites and predators. Reduction or elimination of pesticide applications during periods when the natural enemies are susceptible can greatly improve the effectiveness of natural control measures.

Another form of biological control is the use of pathogens which attack pest populations. Commercial mixtures of such pathogens used for short-term pest control are called microbial pesticides. The most commonly used microbial pesticide is *Bacillus thuringiensis* which is used for the control of lepidopterous insects, such as the cabbage looper.

The main advantages of a microbial pesticide are—

1. It only attacks a specific range of lower organisms;
2. It is not expected to harm natural enemies; and
3. It is not expected to persist in the environment in the absence of a host species.

Microbial pesticides have several disadvantages:

1. They sometimes are not as toxic to the target species or as economical as chemical pesticides;
2. Microbial pesticides must be extensively tested before registration to prove that the organism or its mutants will not be a hazard to nature; and
3. The expense of testing and the small market for materials that are toxic to only a narrow range of pests cause only a few microbial pesticides to be available.

(b) Pest cultural control involves the physical alteration of the crop ecosystem. One cultural control procedure is the changing of planting and harvesting dates. Planting wheat later in the fall reduces the potential for Hessian fly infestations. Such changes affect the synchronism of the crop with the insect host plant and reduce both the amount of crop damage and the amount of pesticides needed. The use of scouting and weather data can help in selecting the best time to cut alfalfa to reduce the damage from weevils. Planting and harvesting dates are often changed in conjunction with altered irrigation schedules and special plant varieties. Crop varieties that have shorter maturity periods can signficantly reduce the need for insecticides.

Crop rotation is a cultural means of controlling pests. Many pests require the continuous presence of the host crop to complete their life cycle. By rotating corn with a nonhost crop like soybeans, the Southern corn rootworm can be suppressed to nondamaging levels. Before the development of pesticides, this was a widely used method of control. Under a continuous single cropping system (monoculture), however, the use of pesticides will generally remain necessary to control pests and insure good crop production.

(c) Pest scouting is a term used to describe visual inspection techniques which trigger certain control practices. Control procedures should be implemented only when they are economically justified. This concept, referred to as "economic threshold," is the determination of the minimum pest density that justifies a pesticide application. Below this density, no pesticide should be applied.

To implement an "economic threshold" procedure it is necessary to sample the field in order to determine the pest population density. This sampling program, called "scouting," has in some instances reduced pesticide use by at least 20 percent.

(d) Crop selection is a method of reducing the use of pesticides through the use of pest-resistant plant varieties. This procedure has been widely used for many years and will continue to be an important means of pest control. In some situations this method is limited by the lack of high-yielding crop varieties that are pest resistant. It often takes years, even decades, to develop a commercially available resistant variety that has satisfactory yield characteristics. Some examples are the wheat varieties that are resistant to Hessian fly and cotton varieties resistant to b weevils.

(e) Pest attractants are used to monitor pest populations and as a direct control method. Attractants in traps can be useful as a method of scouting in estimating pest population densities and in determining the best time to apply pesticides to maximize their effect and reduce the pesticide needed. Attractants used with a pesticide can serve as a direct control measure. The advantage of using attractants is that much less insecticide is required than would have otherwise been necessary.

Traps containing live females are effective in attracting males from long distances. The female releases a chemical called a sex pheromone. Males can detect it even in extremely low concentrations. For some insects the chemical structure of the pheromone has been discovered and synthesized commercially for use in traps. As a direct control measure, pheromones have been applied to crop fields to disrupt insect mating and reduce the size of subsequent generations of pests. Although pheromones and microbial pesticides have environmental advantages, they are not as common as other pest control measures because of the cost of developing and testing.

Crops also are sometimes used as traps. For example, a trap cotton crop for boll weevil can be used by planting about 5 percent of the cotton 2 or 3 weeks before the rest of the crop is planted. The emerging boll weevils are attracted to the early cotton which is then heavily sprayed with insecticide. This reduces the amount of insecticide necessary to control the pest over the entire area.

Many other practices are being developed for improving the effectiveness of pest control programs. Among these are the application of juvenile hormones and the release of sterile males. The males are sterilized by chemicals or radiation and released into the natural population to mate with mature females. This method is effective if the sterile males greatly outnumber the fertile males and if the female mates only once.

2. Pesticide selection can have a significant impact on reducing the potential for pollution. Such factors as adsorption, persistence, solubility, volatilization, and toxicity are important in the selection of alternative pesticides, where the use of a particular one is creating a water quality problem.

(a) While general statements can be made regarding the behavior of pesticides from a specific group, the characteristics of each individual pesticide are unique. Group properties do not necessarily apply to every pesticide in that group. Some also are limited in their use. For these reasons, the individual properties of each specific pesticide should be evaluated along with the management practice selected to reduce or eliminate potential water quality problems.

(b) Persistence is an important characteristic of a pesticide. A common method of evaluating the persistence of a pesticide is to consider its half-life in the soil. Half-life is defined as the amount of time required for 50 percent of the original material applied to the soil to disappear. Table 2-3 gives the half-life of some of the common pesticide groups.

(c) Volatilization is a major factor in the loss of some pesticides from target sites. The rate at which volatilization occurs depends upon the vapor pressure of the pesticide. It also depends on certain environmental factors such as soil-water content, soil temperature, air flow rate across the soil surface, soil type, and organic matter content. The loss of pesticides by the volatilization process is an economic loss to the farm operator. One obvious way to reduce pesticide volatilization is to replace a highly volatile pesticide with a less volatile one. Another management practice that can be used to reduce volatilization is to incorporate the pesticide into the soil during application. Pesticides incorporated into the soil are not lost through volatilization as rapidly as those left on the surface, and are not as available for runoff.

(d) Solubility and adsorption characteristics of a pesticide are important in selecting effective control. A pesticide's affinity for soil particles is quantified through the partitioning of the pesticide between soil and water. The adsorption characteristics of selected pesticides were discussed earlier and are given in Table 2-1.

(e) Toxicity of a pesticide refers to the adverse effect of the compound on the health or life of living organisms. Toxic levels have been established for most pesticides for various forms of aquatic life, fowls, and mammals, including humans (Table 2-1). When considering alternative agricultural controls to prevent pollution by pesticides, the risk of pesticides reaching nontarget areas must be considered. The impact on specific organisms must be considered within the context of their role and position in the food chain. A pesticide may be only moderately toxic to fish but may be highly toxic to organisms that serve as fish food.

3. The pesticide application method used may provide a simple way of controlling potential pollution. Airborne drift loss is four to five times more with aerial application of pesticides than with high-clearance ground sprayers. Low clearance sprayers are even more effective in reducing the quantity of compound needed and airborne losses.

While ground applications are more effective at reducing drift losses, aerial applications are often preferred for a variety of reasons:

(a) They are generally less expensive;

(b) They can cover a large area more quickly than is possible with ground equipment;

(c) Ground equipment may be limited by field conditions, particularly wetness. Ditches, irrigation equipment, and other such obstacles may obstruct the movement of ground equipment.

Ground application does, however, have advantages over aerial application:

(a) More of the pesticide remains in the target area where it is more effective in killing target pests.

(b) The pesticide can be incorporated directly into the soil, thereby decreasing its availability.

(c) More thorough coverage of the crop results in more effective pest control.

Droplet size is extremely important in controlling drift losses. Droplets ranging from 10 to 50 microns (μm) in diameter are likely to drift up to several kilometers, whereas droplets greater than 100 microns (μm) in diameter rarely drift except under windy conditions.

4. Pesticide application timing should be used to avoid the likelihood of unfavorable weather conditions. As discussed previously, windy conditions can cause excessive drift losses during application.

The amount of a pesticide carried off the site by runoff is closely related to the time interval between application and the first significant rainfall. Pesticides in runoff can be greatly reduced if they are not applied just before a runoff-producing rain. The impact of rainfall also can be reduced if the pesticide application can be delayed until there is a good crop canopy.

5. Pesticide and container disposal can be a source of pollution if containers and unused pesticide materials are not disposed of properly. Instructions for disposing of pesticides must be followed.

6. Soil and water conservation practices are site specific and their effectiveness in controlling pollution by pesticides depends on the characteristics of the pesticides. Practices such as conservation cropping systems, conservation tillage systems, contour farming, stripcropping, and terraces that reduce sediment losses will also reduce the loss of strongly sorbed pesticides. Pesticides that are moderately or strongly sorbed are retained by the soil particles and do not move readily through the soil into ground water; thus, the possibility of their polluting the ground water is reduced.

Summary

1. Pesticides are specific, each with its own properties and uses.

2. Pesticides may degrade water quality and pose unacceptable risks by moving via surface runoff, either in the water or attached to sediment, or by leaching into ground water. A pesticide will move via particular pathways, depending primarily on its tendency to partition toward the sediment.

3. The selection of effective controls for reducing pesticide loadings must consider the pesticide's characteristics and the efficacy of the control measure for reducing runoff, erosion, or leaching potential. Soil and water conservation practices, for example, that reduce soil loss will also reduce the loss of moderately and strongly adsorbed particles.

4. A more effective approach to controlling pesticide pollution may be to consider reducing pesticide use or using substitutes. Pesticide use must be assessed in the context of the entire pest management program, which considers scouting, crop rotations, and alternative application technologies.

cost effectiveness - a term used to compare alternatives on the basis of cost (inputs) per unit of benefits (outputs), such as dollars per unit of pollutant load reduction.

cover and green manure crop - a crop of close-growing grasses, legumes, or small grain grown primarily for seasonal protection and soil improvement. It is usually grown for 1 year or less, except where there is permanent cover as in orchards.

crop consumptiveuse - the amount of water transpired during plant growth plus that which evaporated from the soil surface and foliage in the crop area.

crop root zone - the depth of soil penetrated by crop roots.

crop rotation - the growing of different crops in a specified sequence on a given area of land.

cut-back irrigation - an irrigation management technique in which a large stream of water is introduced into the furrow so that it quickly advances the flow downslope to the end of the field. The furrow stream is then reduced to a smaller flow to reduce runoff while water continues to infiltrate in the entire furrow until the desired application is accomplished.

D -

deep percolation - the downward movement of water through the soil below the crop root zone.

denitrification - the process by which nitrates or nitrites in the soil or organic deposits are converted to gaseous forms of nitrogen.

desalination - the removal of salts from soil by artificial means, usually leaching.

desorption - the removal of sorbed ions or compounds from surface of solids.

dissolved oxygen - the oxygen dissolved in water and readily available to aquatic organisms. It is usually expressed in milligrams per liter or as the percent of saturation.

diversion - a channel with a supporting ridge on the lower side constructed across the slope to divert water at a nonerosive velocity to sites where it can be used or disposed of through a stable outlet.

drainage - the removal of excess soil water from the soil profile.

E -

effluent - the discharge of a pollutant, or pollutants, in a liquid form from a containing space.

electrical conductivity (σ_e) - a term used to express the salt content of water or a water-extract of soils in units of decisiemens/meter (dS/m - formerly millimhos per/centimeter). Total dissolved solids (TDS) also used to indicate salt content.

EPA - The United States Environmental Protection Agency.

epilimnion - the upper waters of a thermally stratified lake subject to wind action.

erosion - detachment and movement of rocks and soil particles by gravity, wind, and water.

eutrophication - natural or artificial process of nutrient enrichment whereby a water body becomes filled with aquatic plants and low in oxygen content.

eutrophic lake - a lake that has a high level of plant nutrients, a high level of biological productivity, and low oxygen content.

evapotranspiration - the loss of water from an area by evaporation from the soil and plant surfaces and by transpiration of plants.

F -

Federal Water Pollution Control Act Amendments (PL 92-500) - legislation governing the discharge of point and nonpoint source pollutants to attain water quality goals. Referred to herein as "The Act."

fecal coliform - that portion of the coliform group of bacteria originating in the intestinal tract of man and other warm-blooded animals.

fertility (soil) - the quality that enables a soil to provide the proper elements in the proper amounts and in the proper balance for the growth of specified plants when other factors, such as light, temperature, and the physical condition of the soil, are favorable.

filter strip - a strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater.

cost effectiveness - a term used to compare alternatives on the basis of cost (inputs) per unit of benefits (outputs), such as dollars per unit of pollutant load reduction.

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filter strip - a strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater.

fungicide - a chemical used to destroy fungi.

furrow irrigation - an irrigation method in which water travels through the field by means of small channels between each row or groups of rows.

G -

grassed waterway - a natural or constructed watercourse or outlet that is shaped or graded and established in suitable vegetation for the disposal of runoff water without erosion.

ground water - the subsurface water supply in the saturated zone below the water table.

gully erosion - severe erosion in which trenches are incised to a depth greater than 30 centimeters (12 inches). In general, ditches that are deep enough to be difficult to cross with farm machinery are considered gullies.

H -

half-life - the time required for one-half of a specified substance to disappear.

herbicides - chemicals used to kill undesirable vegetation.

hypolimnion - the bottom waters of a thermally stratified lake. The hypolimnion of a eutrophic lake is usually low or lacking in oxygen.

I -

infiltration - the downward entry of water into the soil.

infiltration rate - the quantity of water that can enter the soil in a specified time interval, usually expressed in millimeters per hour or inches per hour.

inorganic - materials not derived from hydrocarbons.

insecticides - chemicals used to kill insects.

irrigation efficiency - the amount of water stored in the crop root zone compared to the amount of irrigation water applied.

irrigation return flow - surface and subsurface water which leaves the field following the application of irrigation water.

L -

labile - readily changed or removed, not fixed.

labor intensive - practices or systems that require a large labor input as compared to capital requirements.

land leveling - earthmoving to alter the slope, slope length, or surface configuration of the land to aid in the efficient application of irrigation water.

leaching - the removal of salts and other materials from the soil by water movement through the soil profile.

loading - the quantity of a substance entering the receiving waters.

M -

managerial controls - control measures which involve changes in timing, chemical application rates, or tillage systems for the purpose of reducing the loss of pollutants.

mesotrophic - a term used to describe the trophic level of a lake, intermediate between oligotrophic and eutrophic.

mineralization - the microbial conversion of an element from an organic to an inorganic state.

mulch - any substance which is spread or allowed to remain on the soil surface to decrease the effects of raindrop impact, runoff and other adverse conditions.

N -

net irrigation requirement - the crop consumptive use less the effective seasonal rainfall.

nitrification - the biochemical transformation of ammonium to nitrite and thence to nitrate.

nitrogen fixation - the biological or chemical process by which elemental nitrogen is converted to organic or available nitrogen.

nonpoint source - entry of effluent into a water body in a diffuse manner with no definite point of entry and where the source is not readily discernible.

no till (zero till) - a management practice of planting a crop without prior seedbed preparation, into an existing cover crop, sod, or crop residues and eliminating subsequent tillage operations.

O -

oligotrophic lake - a lake that has a low nutrient level, low biological productivity, and high levels of dissolved oxygen.

organic matter - residue of plant or animal origin.

overland flow - water that moves across the surface of a field. Contributions to overland flow are from both direct runoff and the surfacing of subsurface flows before they reach the receiving stream or defined drainage channel.

P -

particulate matter - any solid so finely divided as to be capable of being wind-blown or suspended in air or gas.

partition coefficient - a measure of the sorption phenomenon, whereby a pesticide is divided between the soil and water phase, expressed in ml/g (also referred to as a sorption partition coefficient).

pathogens - disease-causing organisms.

percolation - the downward movement of water through the soil.

percolation rate - the rate, usually expressed as a velocity, at which water moves through saturated granular material.

persistence - the resistance to degradation measured by the period of time required for complete degradation of a material (see half-life).

pesticide - a chemical substance used to kill or control pests such as weeds, insects, algae, rodents, and other undesirable agents. As used in this guide, it includes herbicides, insecticides, miticides, nematicides, rodenticides, fungicides, plant growth regulators, and desiccants.

pH - the symbol for the logarithm of the reciprocal of hydrogen ion concentration. Expressed in moles per liter of solution, and used to indicate an acid or alkaline condition. A pH of 7 indicates neutrality, less than 7 is acid, and greater than 7 is alkaline.

phosphorus - see total dissolved phosphorus, total particulate phosphorus, and total phosphorus.

point source - the release of an effluent from a pipe or discrete conveyance into a water body or a watercourse leading to a body of water.

pollutant - any substance of such character and in such quantities that when it reaches a body of water, soil, or air, it is degrading in effect so as to impair its usefulness or render it offensive.

R -

receiving waters - all distinct bodies of water that receive runoff such as streams, rivers, ponds, lakes, and estuaries. Also, all navigable surface waters and, in certain instances, ground water, if there is a direct connection.

rill - the process which forms small, well-defined incisions in the land surface less than 30 centimeters (12 inches) in depth.

runoff - that portion of the precipitation or irrigation water which leaves the field over the surface and appears in surface streams or water bodies.

S -

salinity - the quality of water based on its salt content. Also, in this guide, a measure of the soluble salts present in the soil.

salinization - process whereby salts accumulate in the soil.

salts - in this guide, products of the natural weathering of soil and geologic material found in irrigation water and irrigation return flow.

sand - soil particles between 0.05 and 2 mm in diameter.

scavenger - the removal of pollutant materials from water by soil particles.

sediment - the solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

sediment yield - the quantity of sediment arriving at a specific location.

seepage - the percolation of water through the soil from unlined canals, ditches, laterals, watercourses, or water storage facilities.

silt - soil particles between 0.05 and 0.002 mm in equivalent diameter.

soil and water conservation practices (SWCPs) - control measures consisting of managerial, vegetative and structural practices to reduce the loss of soil and water.

soil erodibility - an indicator of a soil's susceptibility to raindrop impact, runoff and other erosional processes.

soil salinity - see salinity.

soil structure - the arrangement of soil particles into aggregates.

soil texture - the proportions of soil particles (sand, silt and clay) in a soil profile.

sorption - the process of taking up and holding by either absorption or adsorption.

stream size (irrigation) - the size of the irrigation water stream delivered to the head of irrigation furrows usually expressed in terms of liters per second or gallons per minute.

structural controls - erosion control measures which require a capital investment and construction activities to install.

suspended loads - sediment particles maintained in the water column by turbulence and carried with the flow of water.

T -

tail water - the runoff of irrigation water from the lower end of an irrigated field.

terrace - an earth embankment, channel, or a combination ridge and channel constructed across the slope to decrease the slope length and to control runoff.

tillage - plowing, seedbed preparation and cultivation practices.

total dissolved phosphorus - total phosphorus content of all material that will pass through a filter, which is determined as orthophosphate without prior digestion or hydrolysis. Also called "soluble P," "ortho-P," "reactive-P." When filters with pore diameters 0.45 μm are used, the term "filtered" rather than "dissolved" should be used.

total dissolved solids (TDS) - all material that passes the standard glass fiber filter (0.45 μm); now called total filtrable residue and is used to reflect salinity.

total particulate phosphorus - total phosphorus content of all material retained by a filter of 0.45 μm pore diameter. Also called "sediment-P."

total phosphorus - the sum of all phosphate forms. Measured by orthophosphate analysis following digestion with strong acid.

toxicity - the degree to which a chemical detrimentally affects an organism.

trickle irrigation - an irrigation method in which water drips to the soil from perforated tubing or emitters.

U -

Universal Soil Loss Equation (USLE) - a method of estimating the average soil loss from sheet and rill erosion that might be expected to occur over an extended period under specified conditions of soils, vegetation, climate, cultural operations, and conservation measures.

V -

variable costs - those costs which change relative to production levels.

vegetative controls - control measures or practices which usually involve the use of cropping systems, permanent grass, or other vegetative cover to reduce erosion and control pollutants.

volatilization - the loss of a substance through evaporation or sublimation.

W -

water table - the upper level of a saturated zone below the soil surface.

wilting point - soil moisture content below which plants irreversibly wilt.

waster storage pond - an impoundment made by excavation or earth fill for temporary storage of animal or other agricultural waste.

waste treatment lagoon - an impoundment made by excavation or earth fill for biological treatment of animal or other agricultural waste.

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