4C: Erosion and Sediment Control

Management Measure for Erosion and Sediment

Apply the erosion component of a Resource Management System (RMS) as defined in the Field Office Technical Guide of the U.S. Department of Agriculture–Natural Resources Conservation Service (see Appendix B) to minimize the delivery of sediment from agricultural lands to surface waters, *or*

Design and install a combination of management and physical practices to settle the settleable solids and associated pollutants in runoff delivered from the contributing area for storms of up to and including a 10-year, 24-hour frequency.

Management Measure for Erosion and Sediment: Description

Application of this management measure will preserve soil and reduce the mass of sediment reaching a water body, protecting both agricultural land and water quality.

This management measure can be implemented by using one of two general strategies, or a combination of both. The first, and most desirable, strategy is to implement practices on the field to minimize soil detachment, erosion, and transport of sediment from the field. Effective practices include those that maintain crop residue or vegetative cover on the soil; improve soil properties; reduce slope length, steepness, or unsheltered distance; and reduce effective water and/or wind velocities. The second strategy is to route field runoff through practices that filter, trap, or settle soil particles. Examples of effective management strategies include vegetated filter strips, field borders, sediment retention ponds, and terraces. Site conditions will dictate the appropriate combination of practices for any given situation. The United States Department of Agriculture (USDA)–Natural Resources Conservation Service (NRCS) or the local Soil and Water Conservation District (SWCD) can assist with planning and application of erosion control practices. Two useful references are the USDA–NRCS Field Office Technical Guide (FOTG) and the textbook "Soil and Water Conservation Engineering" by Schwab et al. (1993).

Sedimentation causes widespread damage to our waterways. Water supplies and wildlife resources can be lost, lakes and reservoirs can be filled in, and streambeds can be blanketed with soil lost from cropland.

Resource management systems (RMS) include any combination of conservation practices and management that achieves a level of treatment of the five natural resources (i.e., soil, water, air, plants, and animals) that satisfies criteria contained in the Natural Resources Conservation Service Field Office Technical Guide (FOTG). These criteria are developed at the State level. The criteria are then applied in the provision of field office technical assistance.

The erosion component of an RMS addresses sheet and rill erosion, wind erosion, concentrated flow, streambank erosion, soil mass movements, road bank erosion, construction site erosion, and irrigation-induced erosion. National (minimum) criteria pertaining to erosion and sediment control under an RMS will be applied to prevent long-term soil degradation and to resolve existing or potential off-site deposition problems. National criteria pertaining to the water resource will be applied to control sediment movement to minimize contamination of receiving waters. The combined effects of these criteria will be to both reduce upland soil erosion and minimize sediment delivery to receiving waters.

The practical limits of resource protection under an RMS within any given area are determined through the application of national social, cultural, and economic criteria. With respect to economics, landowners should implement an RMS that is economically feasible to employ. In addition, landowner constraints may be such that an RMS cannot be implemented quickly. In these situations, a "progressive planning approach" may be used to ultimately achieve planning and application of an RMS. Progressive planning is the incremental process of building a plan on part or all of the planning unit over a period of time. For additional details regarding RMS, see Appendix B.

Sediment Movement into Surface and Ground Water

Sedimentation is the process of soil and rock detachment (erosion), transport, and deposition of soil and rock by the action of moving water or wind. Movement of soil and rock by water or wind occurs in three stages. First, particles or aggregates are eroded or detached from the soil or rock surface. Second, detached particles or aggregates are transported by moving water or wind. Third, when the water velocity slows or the wind velocity decreases, the soil and rock being transported are deposited as sediment at a new site.

Sheet, rill, and gully erosion can occur on cropland fields. Streambank and streambed erosion can occur in intermittent and perennial streams.

It is not possible to completely prevent all erosion, but erosion can be reduced to tolerable rates. In general terms, tolerable soil loss is the maximum rate of soil erosion that will permit indefinite maintenance of soil productivity, i.e., erosion less than or equal to the rate of soil development. The USDA–NRCS uses five levels of erosion tolerance ("T") based on factors such as soil depth and texture, parent material, productivity, and previous erosion rates. These T levels are expressed as annual losses and range from about 1–5 tons/acre/year (2–11 t/ha/year), with minimum rates for shallow soils with unfavorable subsoils and maximum rates for deep, well-drained productive soils.

Water Erosion

Water erosion is generally recognized in several different forms. *Sheet erosion* is a process in which detached soil is moved across the soil surface by sheet flow, often in the early stages of runoff. *Rill erosion* occurs as runoff water begins to concentrate in small channels or streamlets. Sheet and rill erosion carry mostly fine-textured, small particles and aggregates. These sediments will contain higher proportions of nutrients, pesticides, or other adsorbed pollutants than are contained in the surface soil as a whole. This process of preferential movement of fine particulates carrying high concentrations of adsorbed pollutants is called *sediment enrichment*.

Gully erosion results from water moving in rills which concentrate to form larger and more persistent erosion channels. Gullies are classified as either ephemeral or classic. Ephemeral gullies occur on crop land and are temporarily filled in by field operations, only to recur after concentrated flow runoff. This filling and recurrence of the ephemeral gully can happen numerous times throughout the year if untreated. Classic gullies may occur in agricultural fields but are so large they cannot be crossed by farming equipment, are not in production nor planted to crops, and are farmed around. Classic gullies are characterized by headward migration and enlargement through a combination of headcut erosion and gravitational slumping, as well as the tractive stress of concentrated flows.

Streambank and streambed erosion typically increase in streams during runoff events. Within a stream, the force of moving water on bare or undercut banks causes streambank erosion. Streambank erosion is usually most intense along outside bends of streams, although inside meanders can be scoured during severe floods. Stream power can detach, move, and carry large soil particles, gravel, and small rocks. After large precipitation events, high gradient streams can detach and move large boulders and chunks of sedimentary stone. Streambank and shoreline erosion are addressed in greater detail in EPA's guidance for the coastal nonpoint source pollution control program (EPA, 1993a).

Gully and streambank erosion can move and carry large soil particles that often contain a much lower proportion of adsorbed pollutants than the finer sediments from sheet and rill erosion. Sheet and rill erosion are generally active only during or immediately after rainstorms or snowmelt. Gullies that intercept groundwork may continue to erode without storm events.

Excessive irrigation water application can detach and transport soil particles.

Irrigation may also contribute to erosion if water application rates are excessive. Erosion may also occur from water transport through unlined earthen ditches. See the Practices for Irrigation Erosion Control discussion in Chapter 4F: Irrigation Water Management for additional information regarding erosion from irrigation.

Water erosion rates are affected by rainfall energy, soil properties, slope, slope length, vegetative and residue cover, and land management practices. Rainfall impacts provide the energy that causes initial detachment of soil particles. Soil properties like particle size distribution, texture, and composition influence the susceptibility of soil particles to be moved by flowing water. Vegetative cover and residue may protect the soil surface from rainfall impact or the force of moving water. These factors are used in the Revised Universal Soil Loss Equation (RUSLE), an empirical formula widely used to predict soil loss in sheet and rill erosion from agricultural fields, primarily crop land and pasture, and construction sites:

Revised Universal Soil Loss Equation (RUSLE)

$$A = R * K * LS * C * P$$

where

A = estimated average annual soil loss (tons/acre/year)

R = rainfall/runoff factor, quantifying the effect of raindrop impact and the amount and rate of runoff associated with the rain, based on long term rainfall record

K = soil erodibility factor based on the combined effects of soil properties influencing erosion rates

LS = slope length factor, a combination of slope gradient and continuous extent

C = cover and management factor, incorporating influences of crop sequence, residue management, and tillage

P = practice factor, incorporating influences of conservation practices such as contouring or terraces

Prediction equations such as the RUSLE and WEQ help planners make quantitative assessments of soil loss and BMP effectiveness.

RUSLE may be used as a framework for considering the principal factors affecting sheet and rill erosion: climate (R), soil characteristics (K), topography (LS), and land use and management (C and P). Except for climate, these factors suggest areas where changes in management can influence soil loss from water erosion. Although soil characteristics (K) may be changed slightly over a long period of good management practices by an increase in organic matter, it should generally not be considered changed by management.

It is important to note that the RUSLE predicts **soil loss**, not sediment delivery to receiving waters. Even without erosion control practices, delivery of soil lost from a field to surface water is usually substantially less than 100%. Sediment delivery ratios (percent of gross soil erosion delivered to a watershed outlet) are often on the order of 15–40% (Novotny and Olem, 1994). Numerous factors influence the sediment delivery ratio, including watershed size, hydrology, and topography.

Ephemeral gully erosion can be predicted by the Ephemeral Gully Erosion Model (EGEM), (http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models.html). EGEM has two major components: hydrology and erosion. The hydrology component is a physical process model that uses the soil, vegetative cover and condition, farming practices, drainage area, watershed flow length, average watershed slope, 24-hour rainfall, and rainfall distribution to estimate peak discharge and runoff volume. Estimates of peak discharge and runoff volume drive the erosion process in the model. The erosion component uses a combination of empirical relationships and physical process equations to compute the width and depth of the ephemeral gully based on hydrology outputs. The model may be used to estimate ephemeral gully erosion for a single 24-hour storm or for average annual conditions.

Erosion control in humid tropical areas like Hawaii and Puerto Rico may present special problems. Soil loss by water erosion may be drastically higher than in temperate regions, especially in areas of steep slopes (El-Swaify and Cooley, 1980). High annual rainfall and the energy of intense storms often result in high erosion rates. Sediment yields of up to 3000 t/sq km/yr from montane basins in Puerto Rico have been reported, where mass wasting contributed most of the sediment to the receiving streams (Simon and Guzman-Rio, 1990). Land clearing and changes in soil characteristics (e.g. exhaustion of soil organic matter) can result in catastrophic soil erosion in tropical regions.

Erosion control practices that succeed in temperate regions are often less effective in the tropics. Engineered practices like terracing, contour ridging, diversions, terraces, and grassed waterways are frequently overwhelmed by torrential rains (Troeh et al., 1980; Lal, 1983). Agronomic practices that conserve the soil, such as mulch farming, reduced tillage, mixed cropping with multistorey canopy structure, and strip cropping with perennial sod crops are more likely to be successful (Troeh et al., 1980; Lal, 1983). El-Swaify and Cooley (1980) reported that pineapple and sugarcane provided adequate protection from soil erosion only a few months after planting.

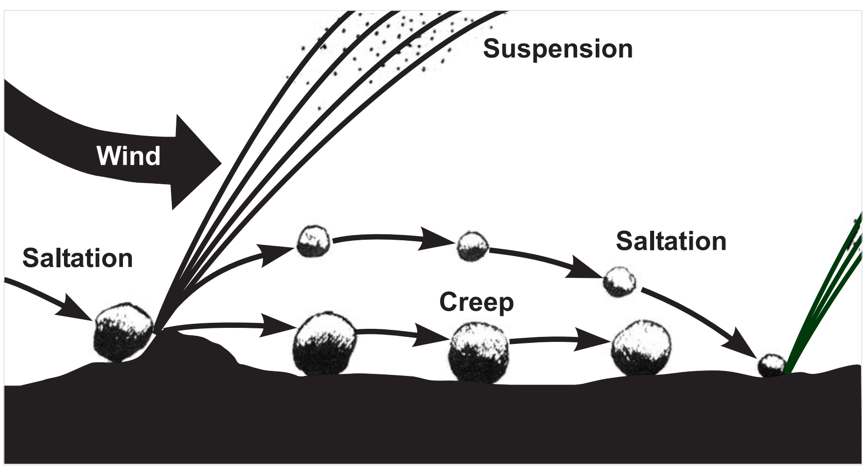
Wind Erosion

Wind detaches soil particles when, at one foot above the ground surface, wind velocity exceeds 12 mph. Detached soil is moved by wind in one of three ways (Figure 4c-1):

1. Soil particles and aggregates smaller than 0.05 mm in diameter may be picked up by wind and carried in *suspension*. Suspended dust may be moved great distances, but does not drop out of the air unless rain washes it out or the velocity of the wind is dramatically reduced.
2. Intermediate sized grains — 0.05 to 0.5 mm (very fine to medium sand) — move in the wind in a series of steps, rising into the air and falling after a short flight in a motion called *saltation*.
3. Soil grains larger than 0.5 mm cannot be lifted into the wind stream, but particles up to about 1 mm may be pushed along the soil surface by saltating grains or by direct wind action. This type of movement is called *surface creep*.

Wind can erode and transport soil particles of various sizes causing damage to land and waterways.

Figure 4c-1. The different ways soil can move during wind erosion.



Source: *Soil Erosion by Wind*. 1994. USDA-SCS, Agriculture Information Bulletin Number 555.

Wind erosion rates are determined by factors similar to those affecting water erosion rates, including the detachment and transport capacity of the wind, soil cloddiness, soil stability, surface roughness, residue or vegetative cover, and length of exposed area. These factors are expressed in the Wind Erosion Equation (WEQ). The WEQ is an empirical wind erosion prediction equation that is currently the most widely used method for estimating average annual soil loss by wind for agricultural fields. The equation is expressed in the general form of:

Wind Erosion Equation (WEQ)

$$E = f(I,K,C,L,V)$$

where **E** is the potential average annual soil loss (tons/acre/year), a function of:

- **I**, the soil erodibility index;
- **K,** the soil ridge roughness factor;
- **C,** the climate factor;
- **L**, the unsheltered distance across the field; and
- **V**, the vegetative cover.

Ground Water Protection

Although sediment movement into ground water is generally not an issue in most locations, there are places, such as areas of karst topography, where sediment and sediment-borne pollutants can enter ground water through direct links to the surface. More important from a national perspective, however, is the potential for increased movement of water and soluble pollutants through the soil profile to ground water as a result of implementing erosion and sediment control practices.

It is not the intent of this measure to correct a surface water problem at the expense of ground water. Erosion and sediment control systems can and should be designed to protect against the contamination of ground water. Ground water protection will also be provided through implementation of the nutrient and pesticide management measures.

Erosion and Sediment Control Practices and Their Effectiveness

The strategies for controlling erosion and sedimentation involve reducing soil detachment, reducing sediment transport, and trapping sediment before it reaches water. Combinations of the following practices can be used to satisfy the requirements of this management measure. The NRCS practice number and definition are provided for each management practice, where available. Additional information about the purpose and function of individual practices is provided in Appendix A.

Practices to Reduce Detachment

For both water and wind erosion, the first objective is to keep soil on the field. The easiest and often most effective strategy to accomplish this is to reduce soil detachment. Detachment occurs when water splashes onto the soil surface and dislodges soil particles, or when wind reaches sufficient velocity to dislodge soil particles on the surface.

Crop residues (e.g. straw) or living vegetative cover (e.g. grasses) on the soil surface protect against detachment by intercepting and/or dissipating the energy of falling raindrops. A layer of plant material also creates a thick layer of still air next to the soil to buffer against wind erosion. **Keeping sufficient cover on the soil is therefore a key erosion control practice.**

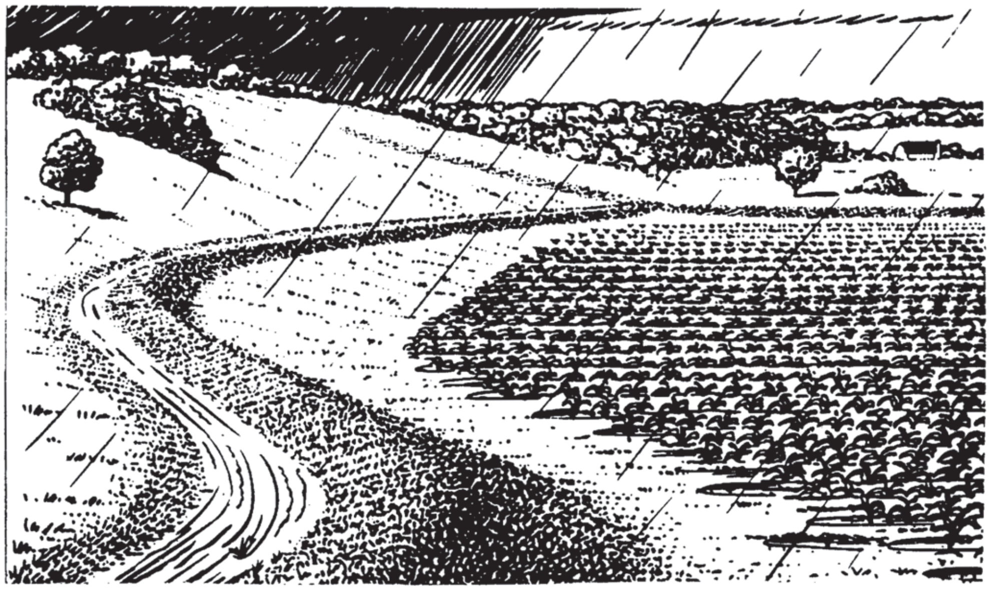
Source area stabilization is fundamental to erosion and sediment control.

The implementation of practices such as conservation tillage also preserves or increases organic matter and soil structure, resulting in improved water infiltration and surface stability. In addition, creation of a rough soil surface through practices such as surface roughening will break the force of raindrops and trap water, reducing runoff velocity and erosive forces. This benefit is short-lived, however, as rainfall rapidly decreases effectiveness of surface roughness. Reducing effective wind velocities through increased surface roughness or the use of barriers or changes in field topography will reduce the potential of wind to detach soil particles. Practices which increase the size of soil aggregates increase a soil's resistance to wind erosion.

The following practices can be used to reduce soil detachment:

- **Chiseling and subsoiling (324):** Loosening the soil without inverting and with a minimum of mixing of the surface soil to improve water and root penetration and aeration.
- **Conservation cover (327)**: Establishing and maintaining perennial vegetative cover to protect soil and water resources on land retired from agricultural production.
- **Conservation crop rotation (328)**: An adapted sequence of crops designed to provide adequate organic residue for maintenance or improvement of soil tilth.
- **Residue Management (329)**: Any tillage or planting system that maintains at least 30% of the soil surface covered by residue after planting to reduce soil erosion by water; or, where soil erosion by wind is the primary concern, maintains at least 1,000 pounds of flat, small-grain residue equivalent on the surface during the critical erosion period.
- **Contour orchard and other fruit area (331):** Planting orchards, vineyards, or small fruits so that all cultural operations are done on the contour.
- **Cover crop (340):** A crop of close-growing grasses, legumes, or small grain grown primarily for seasonal protection and soil improvement. It usually is grown for 1 year or less, except where there is permanent cover as in orchards.
- **Critical area planting (342):** Planting vegetation, such as trees, shrubs, vines, grasses, or legumes, on highly erodible or critically eroding areas (does not include tree planting mainly for wood products).
- **Seasonal Residue Management (344):** Using plant residues to protect cultivated fields during critical erosion periods.
- **Diversion (362):** A channel constructed across the slope with a supporting ridge on the lower side (Figure 4c-2).
- **Windbreak/shelterbelt establishment (380):** Linear plantings of single or multiple rows of trees or shrubs established next to farmstead, feedlots, and rural residences as a barrier to wind.

Figure 4c-2. Diversion (USDA-SCS, 1984).



- ❒ **Windbreak/shelterbelt renovation (650):** Restoration or preservation of an existing windbreak, including widening, replanting, or replacing trees.
- ❒ **Mulching (484):** Applying plant residue or other suitable material to the soil surface.
- ❒ **Irrigation water management (449):** Effective use of available irrigation water to manage soil moisture, reduce erosion, and protect water quality.
- ❒ **Prescribed Grazing (528A):** The controlled harvest of vegetation with grazing or browsing animals, managed with the intent to achieve a specified objective.
- ❒ **Cross wind ridges/stripcropping/trap strips (589):** Ridges formed by tillage or planting, crops grown in strips, or herbaceous cover aligned perpendicular to the prevailing wind direction.
- ❒ **Surface roughening (609)**: Roughening the soil surface by ridge or clod-forming tillage.
- ❒ **Tree planting (612):** Establishing woody plants by planting or seeding.
- ❒ **Waste utilization (633)**: Using agricultural or other wastes on land in an environmentally acceptable manner while maintaining or improving soil and plant resources.
- ❒ **Wildlife upland habitat management (645)**: Creating, maintaining, or enhancing upland habitat for desired wildlife species.

The following additional practices, although typically applied for a different primary purpose, may have significant secondary benefits in erosion control:

- ❒ **Brush management (314):** The management of undesirable brush species through use of living organisms, herbicides, prescribed burning, or mechanical methods.

- ❒ **Irrigation System, Microirrigation (441)**: A planned irrigation system in which all necessary facilities are installed for efficiently applying water directly to the root zone of plants by means of applicators (orifices, emitters, porous tubing, or perforated pipe) operated under low pressure (Figure 4f-19).
- ❒ **Irrigation system - sprinkler (442)**: Distribution of water by means of sprinklers or spray nozzles to efficiently and uniformly apply irrigation water to maintain adequate soil moisture.
- ❒ **Pasture and hayland planting (512):** Establishing and re-establishing long-term stands of adapted species of perennial, biannual, or reseeding forage plants.

Practices to Reduce Transport within the Field

Sediment transport can be reduced in several ways, including the use of crop residues and vegetative cover. Vegetation slows runoff, increases infiltration, reduces wind velocity, and traps sediment. Reductions in slope length and steepness reduce runoff velocity, thereby reducing sediment carrying capacity as well. Terraces and diversions are common techniques for reducing slope length. Runoff can be slowed or even stopped by placing furrows perpendicular to the slope, through practices such as contour farming that act as collection basins to slow runoff and settle sediment particles. By decreasing the distance across a field that is unsheltered from wind and by creating soil ridges or other barriers, sediment transport by wind will be reduced.

Where conditions and opportunities permit, install practices that prevent edge-of-field sediment loss.

- ❒ **Contour farming (330)**: Farming sloping land in such a way that preparing land, planting, and cultivating are done on the contour. This includes following established grades of terraces or diversions.
- ❒ **Field windbreak (392):** Establishment of trees in or adjacent to a field as a barrier to wind.
- ❒ **Grassed waterway (412):** A natural or constructed channel that is shaped or graded to required dimensions and established in suitable vegetation for the stable conveyance of runoff.
- ❒ **Contour stripcropping (585)**: Growing crops in a systematic arrangement of strips or bands on the contour to reduce water erosion. The crops are arranged so that a strip of grass or close-growing crop is alternated with a strip of clean-tilled crop or fallow or a strip of grass is alternated with a close-growing crop (Figure 4c-3).
- ❒ **Herbaceous Wind Barriers (442A)**: Herbaceous vegetation established in rows or narrow strips across the prevailing wind direction.
- ❒ **Field stripcropping (586)**: Growing crops in a systematic arrangement of strips or bands across the general slope (not on the contour) to reduce water erosion. The crops are arranged so that a strip of grass or a close-growing crop is alternated with a clean-tilled crop or fallow.
- ❒ **Terrace (600)**: An earthen embankment, a channel, or combination ridge and channel constructed across the slope (Figures 4c-4 and 4c-5).
- ❒ **Contour Buffer Strips (332)**: Narrow strips of permanent, herbaceous vegetative cover established across the slope and alternated down the slope with parallel, wider cropped strips.

Practices to Trap Sediment Below the Field or Critical Area

Trap sediment before it reaches riparian areas.

Practices are also typically needed to trap sediment leaving the field before it reaches a wetland or riparian area. Deposition of sediment is achieved by practices that slow water velocity or increase infiltration.

- ❒ **Sediment basins (350):** Basins constructed to collect and store debris or sediment.
- ❒ **Field border (386):** A strip of perennial vegetation established at the edge of a field by planting or by converting it from trees to herbaceous vegetation or shrubs.
- ❒ **Filter strip (393):** A strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater.
- ❒ **Water and sediment control basin (638)**: An earthen embankment or a combination ridge and channel generally constructed across the slope and minor watercourses to form a sediment trap and water detention basin.

Figure 4c-3. Stripcropping and rotations (USDA-ARS, 1987).

Contour strip cropping systems can involve up to 10 strips in a field. A strip cropping system could involve the following:

Corn (either for grain and/or silage)

Soybeans

1st year Meadow

Established Meadow (2-4 years)

Oats

Grassed waterway or diversion

Tillage systems may include two kinds in the same year such as chisel plowing for the soybean crop and moldboard plowing for the oats.

See the following figure showing typical patterns of stripcropping.

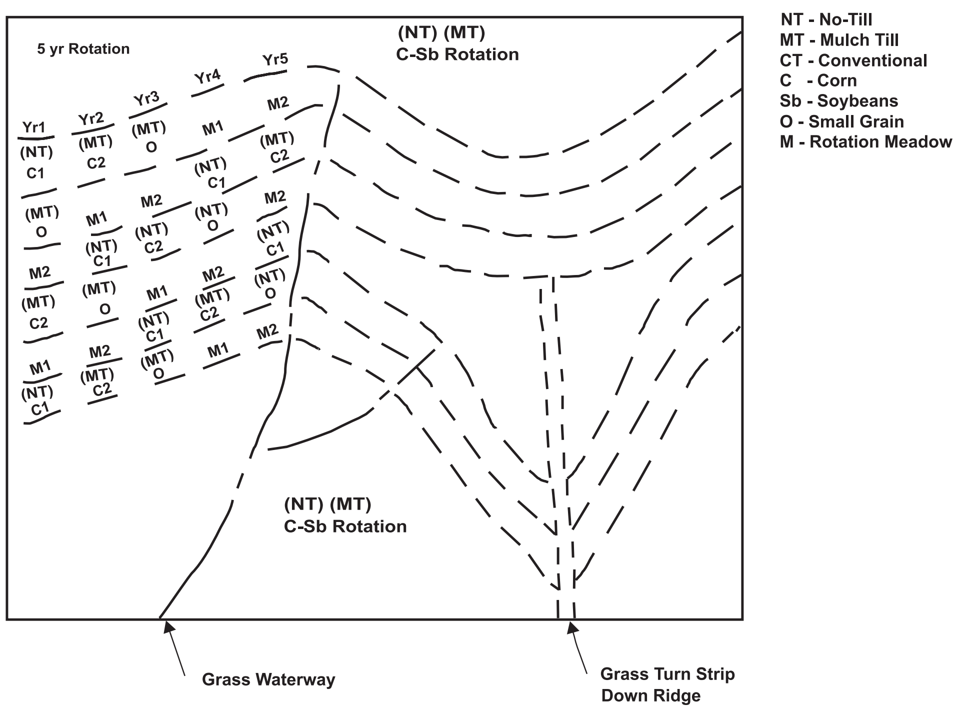


Figure 4c-4. Gradient terraces with tile outlets (USDA-SCS, 1984).

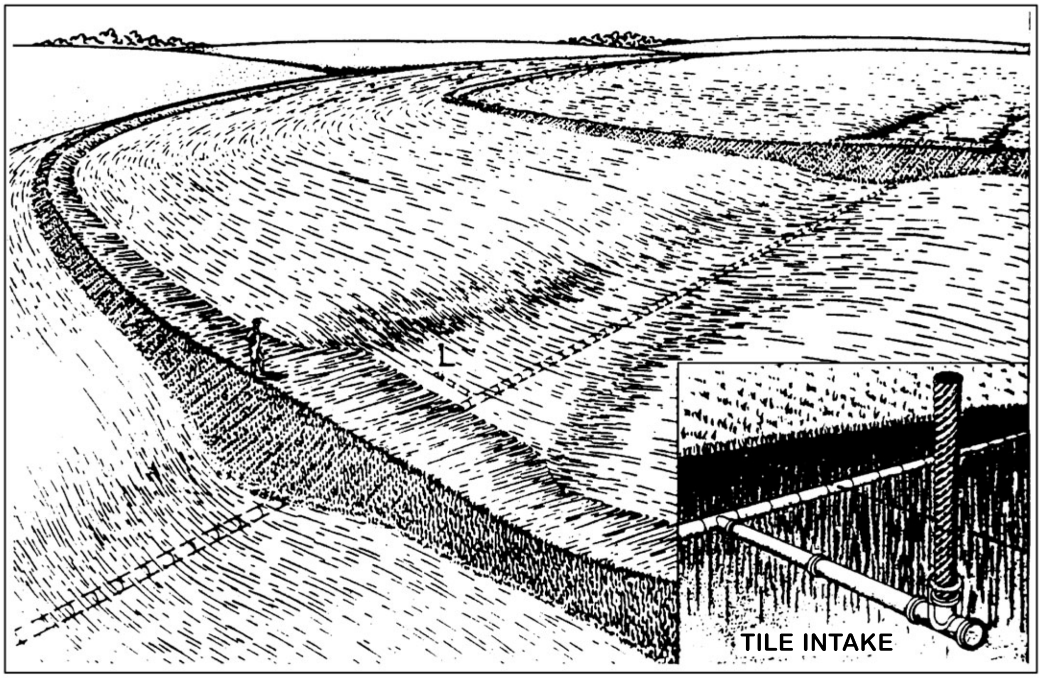


Figure 4c-5. Gradient terraces with waterway outlet (USDA-SCS, 1984).

Healthy Wetland and Riparian Areas Help Reduce Sediment Transport and Delivery

Riparian area practices can serve to repair damaged stream corridors. Assessment and remediation of runoff and sedimentation problems enhances riparian area restoration.

Properly functioning natural wetlands and riparian areas can significantly reduce nonpoint source pollution by intercepting surface runoff and subsurface flow and by settling, filtering, or storing sediment and associated pollutants. Wetlands and riparian areas typically occur as natural buffers between uplands and adjacent water bodies. Loss of these systems allows a more direct contribution of nonpoint source pollutants to receiving waters; degraded wetlands and riparian areas may even become pollutant sources. Thus, natural wetlands and riparian areas should be protected and should not be used as designated erosion control practices. Their nonpoint source control functions are most effective as part of an integrated land management system focusing on nutrient, sediment, and erosion control practices applied to upland areas.

Management measures for protection of the full range of functions for wetlands and riparian areas are discussed in *Nonpoint Source Pollution Guidance for Wetlands, Riparian Areas, and Vegetated Treatment Systems* (EPA, 2001 draft). Protection of wetlands and riparian areas should allow for both nonpoint source pollution control and maintenance of other benefits of these natural aquatic systems, e.g. wildlife habitat. **The Management Measure for Protection of Wetlands and Riparian Areas** states:

> Protect from adverse effects wetlands and riparian areas that are serving a significant NPS abatement function and maintain this function while protecting other existing functions of these wetlands and riparian areas as measured by characteristics such as vegetative composition and cover, hydrology of surface water and ground water, geochemistry of the substrate, and species composition.

Examples of implementation practices for protecting wetlands and riparian areas include:

> Identify existing functions of those wetlands and riparian areas with significant NPS control potential when implementing NPS management practices. Do not alter wetlands or riparian areas to improve their water quality functions at the expense of their other functions.
>
> Use appropriate preliminary treatment practices such as vegetated treatment systems or detention or retention basins to prevent adverse impacts to wetland functions that affect NPS pollutant abatement from hydrologic changes, sedimentation, or contaminants.

Practices specifically designed to repair or protect wetlands and streambanks from erosion include:

- ❒ **Wildlife wetland habitat management (644**): Creating, maintaining, or enhancing wetland habitat for desired wildlife species.
- ❒ **Grade stabilization structure (410):** A structure used to control the grade and head cutting in natural or artificial channels.
- ❒ **Streambank and Shoreline Protection (580):** Using vegetation or structures to stabilize and protect banks of streams, lakes, estuaries, or excavated channels against scour and erosion.

- ❐ **Stream Channel Stabilization (584):** Stabilizing the channel of a stream with suitable structures.
- ❐ **Use exclusion (472):** Excluding animals, people, or vehicles from an area, primarily by means of fencing.
- ❐ **Riparian forest buffer/herbaceous cover (391A/390):** Establishing an area of trees, shrubs, grasses, or forbs adjacent to and up-gradient from water bodies.
- ❐ **Control of streambank erosion** on agricultural land requires techniques different from those used to treat upland sheet and rill erosion. The force of flowing water in a river or stream is a very important process causing streambank erosion. Protection of the slope faces on channel banks, especially those already undergoing active erosion, from the force of flowing water is the key control principle. Techniques may be divided into two general categories: bioengineering (vegetative) and structural. Vegetative methods are generally preferred, unless structural methods are more cost-effective.

  Soil bioengineering uses live or dead plant materials, in combination with natural and synthetic support materials, for slope stability, erosion reduction, and vegetative establishment. It should be noted that soil bioengineering measures depending on growth of living vegetation also require livestock exclusion to protect the growing plants from grazing and trampling.

Specific bioengineering practices include:

- ***Live staking***: insertion and tamping of live, rootable vegetative cuttings into the ground to create a living root mat that stabilizes the soil.
- ***Live fascines and brushlayering***: placement of bundles of branch cuttings (usually of willow) in shallow trenches or benches on bare streambanks to rapidly establish protective vegetation.
- ***Tree/shrub planting***: planting of rooted cuttings and tree or shrub seedlings on shaped streambanks and in the riparian zone.
- ***Trench packing***: filling of a gully with woody brush to provide a barrier to retard water flow and accumulate sediment.
- ***Brushrolls, brushmattresses, brush boxes***: bundles of brush of varying configurations staked against the base of an eroding streambank as a barrier to slow water flow and to settle and accumulate sediment.

Structural practices can protect streambank soils from the erosive force of streamflow, help retain eroding soil, or influence the direction or velocity of streamflow with durable nonliving materials. When using hardened structures like those below, care must be taken to avoid causing additional problems within the stream channel (e.g., channelization, incision):

- ***Riprap***: rock dumped or placed along a sloped streambank to armor the bank against the force of flowing water.
- ***Revetments***: structures such as timber cribbing backfilled with gravel, anchored trees, gabions, or bulkheads applied to the streambank to hold back eroding material as well as to protect from flowing water.

- Streamflow deflectors: sills, bars, or groins of logs, rock, or concrete projecting out from the bank into the stream to redirect the streamflow away from an eroding bank.

For further information on controlling streambank erosion, refer to Chapter 6: "Management Measures for Hydromodification: Channelization and Channel Modification, Dams, and Streambank and Shoreline Erosion," in *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*, EPA 840-B-92-002, 1993. *Stream Corridor Restoration: Principles, Processes, and Practices,* from the Federal Interagency Stream Restoration Working Group (ISBN-0-934213-59-3), (FISRWG, 1998), also contains valuable information on streambank erosion, as well as restoration.

Practice Effectiveness

The available information shows that erosion and sediment control practices in-field can be used to greatly reduce the quantity of eroding soil on agricultural land, and that edge-of-field practices can effectively reduce sediment transport. The benefits of this management measure include preservation of productive agricultural soils and significant reductions in the mass of sediment and associated pollutants (e.g., phosphorus, some pesticides) entering water bodies.

Although some sites are challenging, detailed local information combined with sound erosion control knowledge and experience should result in an effective system plan for erosion and sediment control.

The effectiveness of sediment control practices depends on several factors, including:

- ❒ The contaminant (e.g. sediment, phosphorus) to be controlled;
- ❒ The nature of the soil particles to be controlled;
- ❒ The types of practices or controls being considered;
- ❒ Site-specific conditions (e.g. crop rotation, topography, tillage, harvesting method); and
- ❒ Operation and maintenance.

Management practices or systems of practices must be designed for site-specific conditions to achieve desired effectiveness levels. Management practice systems include combinations of practices that provide source control of the contaminant(s) as well as control or reductions in edge-of-field losses and delivery to receiving waters. Table 4c-1 provides a gross estimate of practice effectiveness (i.e., "average" changes in runoff and pollutant loads due to the addition of the practice(s) at sites where erosion control practices are generally lacking) as reported in research literature. Even within relatively small watersheds, extreme spatial and temporal variations are common. Because of this variation, the actual effectiveness of practices at a specific site may differ considerably from the gross estimates given in Table 4c-1.

Table 4c-1. Relative Gross Effectivenessa of Sediment[b] Control Measures Pennsylvania State University, 1992b).

Practice Category[c]	Runoff Volume	Total[d] Phosphorus (% reduction)	Total[d] Nitrogen (% reduction)	Sediment (% reduction)
Reduced Tillage Systems[e]	reduced	45	55	75
Diversion Systems[f]	reduced	30	10	35
Terrace Systems[g]	reduced	70	20	85
Filter Strips[h]	reduced	75	70	65

a Actual effectiveness depends on site-specific conditions. Values are not cumulative between practice categories.

b Includes data where land application of manure has occurred.

c Each category includes several specific types of practices.

d Total phosphorus includes total and dissolved phosphorus; total nitrogen includes surface-delivered organic-N, ammonia-N, and nitrate-N.

e Includes practices such as conservation tillage, no-till, and crop residue use.

f Includes practices such as grassed waterways and grade stabilization structures.

g Includes several types of terraces with safe outlet structures where appropriate.

h Includes all practices that reduce contaminant losses using vegetative control methods.

Conservation tillage is now promoted widely by a large number of groups and organizations because it is both profitable and effective in controlling erosion. For example, researchers at Louisiana State University have shown that the use of no-till with or without a cover crop (2-6 tons of soil loss per acre per year) is much more effective at controlling erosion on cotton fields than is use of conventional tillage with or without a cover crop (13-16 tons per acre per year) (Zeneca, 1994). It is reported that the top three reasons soybean farmers adopt no-till are reduced soil erosion, increased profit potential, and time and labor savings (Alesii, 1998). The percentage of soybeans planted in no-till has increased from 1992 to 1997 at an average annual rate of 11.6 percent, ranging from 4 percent (Minnesota) to 25 percent (North Dakota) in the Upper Midwest (CTIC, 1997). According to some of the leading authorities on conservation tillage, the economic and environmental benefits of farming with conversation tillage are simply too numerous to ignore (CTIC, ca. 1997). CTIC reported that, on average, no-till resulted in 93 percent less erosion and 69 percent less water runoff than moldboard plowing.

Factors in the Selection of Management Practices

Site conditions, cost, and maintenance requirements are considered for practice selection. Local demonstrations are also needed to refine practices and encourage adoption.

Two fundamental options exist to minimize water and wind erosion from agricultural land and the delivery of sediment to receiving waters: (1) Controlling soil loss from fields or streambanks by reducing detachment and transport of sediment, and (2) Encouraging deposition of eroded sediment to prevent delivery to surface waters. Different management strategies are employed with the different options. Preventing initial soil loss (option “(1)”) is generally the most desirable option because it not only minimizes the delivery of sediment to receiving waters but also provides an agronomic benefit by preserving soil resources. Option “(2)” minimizes the delivery of sediment to receiving waters, but does not necessarily provide the agronomic benefits of upland erosion control. In addition, practices encouraging sediment deposition require maintenance to retain their effectiveness over time. In some cases, for example, management or economic constraints may prevent full installation of all practices needed to adequately reduce field soil loss, and additional practices to prevent delivery of eroded sediment may be needed. In other cases, even if field soil loss can be reduced to "T" level, additional practices may be needed to prevent delivery of sediment to critical or sensitive water bodies. Using one or both of these options, planners have the flexibility to address erosion and sediment problems in a manner that best reflects State, local, and land owner/operator needs and preferences.

Management practices for a given site should not result in undue economic impact on the operator. Many of the practices that could be used to implement this measure may already be encouraged or required by Federal, State, or local programs (e.g., filter strips or field borders along streams) or may otherwise be in use on agricultural fields. By building upon existing erosion and sediment control efforts, the time, effort, and cost of implementing this measure will be reduced.

It should be noted that basic erosion control measures will not always provide adequate control of nutrients, pesticides, or other sediment-attached pollutants. Erosion control practices tend to be most effective on larger particles, which tend to carry a lower proportion of adsorbed pollutants than do finer particles like clays. Many erosion control practices or structures may not effectively control the majority of pollutants that are attached to fine soil particles. If pollutants attached to soil particles are the primary concern, practices specifically designed to control fine sediments should be applied.

Conversely, some nutrient or irrigation management practices may contribute to erosion control, even though their primary purpose is not erosion control. Waste utilization, for example, may help reduce soil erodibility by both water and wind through improvements in soil organic matter content. Improved irrigation water management may help reduce wind erosion potential by maintaining adequate soil moisture during critical periods.

Continued performance of this measure will be ensured through supporting maintenance operations where appropriate. Although some practices are designed to be effective and withstand a design storm, they may suffer damage when larger storms occur. It is expected that damage will be repaired after such storms and that practices will be inspected periodically. To ensure that practices selected to implement this measure will continue to function as designed and installed, some operational functions and maintenance will be necessary over the life of the practices.

Most structural practices for erosion and sediment control are designed to operate without human intervention. Management practices such as conservation tillage, however, do require some attention each time they are used. Field operations should be conducted with practices like contouring or terraces in mind to ensure that the practices or structures are not damaged or destroyed by the operations. For example, non-selective herbicides should not be applied to areas of permanent vegetative cover that are used as part of erosion control practices, such as waterways and filter strips.

Structural practices such as diversions, grassed waterways, and filter strips may require grading, shaping, and reseeding. Trees and brush should not be allowed to grow on berms, dams, or other structural embankments. Cleaning of sediment retention basins will be needed to maintain their original design capacity and trapping efficiency.

Filter strips and field borders must be maintained to prevent channelization of flow and the resulting short-circuiting of filtering mechanisms. Reseeding of filter strips may be required on a frequent basis. Periodic removal of vegetative growth will help keep filter strips actively growing and remove nutrients and other potential pollutants that have been taken up by the plants or attached to the vegetative growth. Grazing and other livestock activities should be managed to avoid damage to vegetation cover, especially near streams.

Finally, conditions sometimes occur when serious wind erosion is imminent or has just begun, and immediate action is needed to protect soil and crops. Several emergency techniques can lessen or slow wind erosion. Emergency measures are not as effective as long-term planned erosion control; they are last resort options and should not be relied on for primary erosion control or continued use. The following emergency control methods can reduce damage from anticipated wind erosion (Smith et al., 1991).

- ❒ Emergency tillage to produce surface roughness, ridges, and clods
- ❒ Addition of crop residue
- ❒ Application of manure
- ❒ Irrigation to increase soil moisture
- ❒ Temporary, artificial wind barriers
- ❒ Soil additives or spray-on adhesives

Choice of specific methods depends on severity of erosion, soil type, crop type and growth stage, and equipment available.

Reliable and current information on cost of initial investment, along with annualized cost throughout practice life, helps planners and farmers make sound decisions.

Cost and Savings of Practices

Costs

Both national and selected State costs for a number of common erosion control practices are presented in Table 4c-2. The variability in costs for practices can be accounted for primarily through differences in site-specific applications and costs, differences in the reporting units used, and differences in the interpretation of reporting units.

The cost estimates for control of erosion and sediment transport from agricultural lands in Table 4c-3 are based on experiences in the Chesapeake Bay Program.

Savings

It is important to note that for some practices, such as conservation tillage, the net costs often approach zero and in some cases can be negative because of the savings in labor and energy. In fact, it is reported that cotton growers can lower their cost per acre by $24.32 due to lower fixed costs associated with conservation tillage (Zeneca, 1994).

Table 4c-2. Representative costs of selected erosion control practices.

Practice	Unit	Range of Capital Costs[1]	References
Diversions	ft	1.97 - 5.51	Sanders et al., 1991 Smolen and Humenik, 1989
Terraces	ft a.s.[2]	3.32 - 14.79 24.15 - 66.77	Smolen and Humenik, 1989 Russell and Christiansen, 1984
Waterways	ft ac a.e.[3]	5.88 - 8.87 113 - 4257 1250 - 2174	Sanders et al., 1991 Barbarika, 1987; NCAES, 1982; Smolen and Humenik, 1989 Russell and Christiansen, 1984
Permanent Vegetative Cover	ac	69 - 270	Barbarika, 1987; Russell and Christiansen, 1984; Sanders et al., 1991; Smolen and Humenik, 1989
Conservation Tillage	ac	9.50 - 63.35	NCAES, 1982; Russell and Christiansen, 1984; Smolen and Humenik, 1989

1 Reported costs inflated to 1998 dollars by the ratio of indices of prices paid by farmers for all production items, 1991=100.
2 acre served
3 acre established

[Note: 1991 dollars from CZARA were adjusted by +15%, based on ratio of 1998 Prices Paid by Farmers/1991 Prices Paid by Farmers, according to USDA National Agricultural Statistics Service, *http://www.usda.gov/nass/sources.htm*, 28 September, 1998]

Table 4c-3. Annualized cost estimates and life spans for selected management practices from Chesapeake Bay Installations[a] (Camacho, 1991).

Practice	Practice Life Span (Years)	Median Annual Costs[b] (EAC[c])($/acre/yr)
Nutrient Management	3	2.40
Strip-cropping	5	11.60
Terraces	10	84.53
Diversions	10	52.09
Sediment Retention Water Control Structures	10	89.22
Grassed Filter Strips	5	7.31
Cover Crops	1	10.00
Permanent Vegetative Cover on Critical Areas	5	70.70
Conservation Tillage[d]	1	17.34
Reforestation of Crop and Pasture[d]	10	46.66
Grassed Waterways[e]	10	1.00/LF/yr
Animal Waste System[f]	10	3.76/ton/yr

a Median costs (1990 dollars) obtained from the Chesapeake Bay Program Office (CBPO) BMP tracking data base and Chesapeake Bay Agreement Juristictions' unit data cost. Costs per acre are for acres benefited by the practice.
b Annualized BMP total cost including O&M, planning, and technical assistance costs.
c EAC = Equivalent annual cost: annualized total; costs for the life span. Interest rate = 10%.
d Government incentive costs.
e Annualized unit cost per linear foot of constructed waterway.
f Units for animal waste are given as $/ton of manure treated.