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SECTION 1: SUMMARY AND SCOPE

1.1 INTRODUCTION

EPA published a final action withdrawing proposed effluent guidelines for storm water discharges associated with construction activities in March of 2004. This document presents technical information to support the Agency's decision and compliments "Economic Analysis for Final Action for Effluent Guidelines and Standards for the Construction and Development Category," EPA-821-B-04-002.

A summary of the information contained in the sections of this document is as follows:

- Section 2 presents a summary of the legal authority for effluent guidelines and the existing EPA storm water program.
- Section 3 summarizes the data collection activities and the analytical tools and processes followed to support the final action.
- Section 4 summarizes the characteristics of the construction and development industry, including major indicators of industry size and annual construction activity.
- Section 5 presents information and data on erosion and sediment control (ESC) best management practices (BMPs) used by the construction and development industry, including applicability, costs, and efficiencies of various technologies..
- Section 6 presents a description of the regulatory options considered by EPA for the final action.
- Section 7 presents EPA's methodology for estimating the costs of the options considered.
- Section 8 summarizes the approach used by EPA to estimate the pollutant loads, load reductions and environmental benefits of the options considered.

SECTION 2: BACKGROUND

2.1 LEGAL AUTHORITY

The Environmental Protection Agency (EPA) establishes Effluent Limitation Guidelines under the authority of Sections 301, 304, 306, 308, 402, and 501 of the Clean Water Act (CWA) (the Federal Water Pollution Control Act), 33 United States Code (U.S.C.) 1311, 1314, 1316, 1318, 1342, and 1361.

2.2 CLEAN WATER ACT

Congress adopted the Clean Water Act (CWA) to "restore and maintain the chemical, physical, and biological integrity of the nation's waters" (Section 101(a), 33 U.S.C. 1251(a)). To achieve this goal, the CWA prohibits the discharge of pollutants into navigable waters except in compliance with the statute. CWA sec. 402 requires "point source" discharges to obtain a permit under the National Pollutant Discharge Elimination System (NPDES). These permits are issued by EPA regional offices or authorized State agencies.

Following enactment of the Federal Water Pollution Control Amendments of 1972 (Pub.L. 92-500, October 18, 1972), EPA and the States issued NPDES permits to thousands of dischargers, both industrial (e.g. manufacturing, energy and mining facilities) and municipal (sewage treatment plants). As required under Title III of the Act, EPA promulgated effluent limitation guidelines and standards for many industrial categories, and these requirements are incorporated into the permits.

The Water Quality Act of 1987 (Pub.L. 100-4, February 4, 1987) amended the CWA. The NPDES program was expanded by defining municipal and industrial storm water discharges as point sources. Industrial storm water dischargers, municipal separate storm sewer systems and other storm water dischargers designated by EPA must obtain NPDES permits pursuant to Section 402(p) (33 U.S.C. 1342(p)).

2.2.1 BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE

In guidelines for a point source category, EPA may define Best Practicable Control Technology (BPT) effluent limits for conventional, toxic,[1] and non-conventional pollutants. In specifying BPT, EPA looks at a number of factors. EPA first considers the cost of achieving effluent reductions in relation to the effluent reduction benefits. The Agency also considers the age of the equipment and facilities, the processes employed and any required process changes, engineering aspects of the

[1] In the initial stages of EPA CWA regulation, EPA efforts emphasized the achievement of BPT limitations for control of the "classical" pollutants (e.g., TSS, pH, BOD_5). However, nothing on the face of the statute explicitly restricted BPT limitation to such pollutants. Following passage of the Clean Water Act of 1977 (Pub.L. 95-217, December 27, 1977) with its requirement for point sources to achieve best available technology limitations to control discharges of toxic pollutants, EPA shifted its focus to developing BAT limitations for the listed priority toxic pollutants.

control technologies, non-water quality environmental impacts (including energy requirements), and such other factors as the Agency deems appropriate (CWA sec. 304(b)(1)(B)). Traditionally, EPA establishes BPT effluent limitations based on the average of the best performance of facilities within the category of various ages, sizes, processes or other common characteristics. Where existing performance is uniformly inadequate, EPA may require higher levels of control than currently in place in a category if the Agency determines that the technology can be practically applied. See "A Legislative History of the Federal Water Pollution Control Act Amendments of 1972," U.S. Senate Committee of Public Works, Serial No. 93-1, January 1973, p. 1468.

In addition, the Act requires a cost-reasonableness assessment for BPT limitations. In determining the BPT limits, EPA considers the total cost of treatment technologies in relation to the effluent reduction benefits achieved. This inquiry does not limit EPA's broad discretion to adopt BPT limitations that are achievable with available technology unless the required additional reductions are "wholly out of proportion to the costs of achieving such marginal level of reduction." See Legislative History, op. cit., p. 170. Moreover, the inquiry does not require the Agency to quantify benefits in monetary terms. See, for example, American Iron and Steel Institute v. EPA, 526 F. 2d 1027 (3rd Cir., 1975).

In balancing costs against the benefits of effluent reduction, EPA considers the volume and nature of expected discharges after application of BPT, the general environmental effects of pollutants, and the cost and economic impacts of the required level of pollution control. In past effluent limitation guidelines and standards, BPT cost-reasonableness removal figures have ranged from $0.21 to $33.71 per pound removed in year 2000 dollars. In developing guidelines, the Act does not require consideration of water quality problems attributable to particular point sources, or water quality improvements in particular bodies of water. See Weyerhaeuser Company v. Costle, 590 F. 2d 1011 (D.C. Cir. 1978).

2.2.2 BEST CONVENTIONAL POLLUTANT CONTROL TECHNOLOGY

The 1977 amendments to the CWA required EPA to identify effluent reduction levels for conventional pollutants associated with Best Conventional Pollutant Control Technology (BCT) for discharges from existing point sources. BCT is not an additional limitation, but replaces Best Available Technology (BAT) for control of conventional pollutants. In addition to other factors specified in sec. 304(b)(4)(B), the CWA requires that EPA establish BCT limitations after consideration of a two- part "cost-reasonableness" test. EPA explained its methodology for the development of BCT limitations in July 1986 (51 FR 24974).

Section 304(a)(4) designates the following as conventional pollutants: biochemical oxygen demand (BOD_5), total suspended solids (TSS), fecal coliform, pH, and any additional pollutants defined by the Administrator as conventional. The Administrator designated oil and grease as an additional conventional pollutant on July 30, 1979 (44 FR 44501). A primary pollutant of concern at construction sites, sediment, is commonly measured as TSS.

2.2.3 BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE

In general, Best Available Technology (BAT) effluent guidelines (CWA sec. 304(b)(2)) represent the best existing economically achievable performance of direct discharging plants in the subcategory or category. The factors considered in assessing BAT include the cost of achieving BAT effluent reductions, the age of equipment and facilities involved, the processes employed, engineering aspects of the control technology, potential process changes, non-water quality environmental impacts (including energy requirements), and such factors as the Administrator deems appropriate. The Agency retains considerable discretion in assigning the weight to be accorded to these factors. An additional statutory factor considered in setting BAT is "economic achievability." Generally, EPA determines the economic achievability on the basis of the total cost to the subcategory and the overall effect of the rule on the industry's financial health. The Agency may base BAT limitations upon effluent reductions attainable through changes in a facility's processes and operations. As with BPT, where existing performance is uniformly inadequate, EPA may base BAT upon technology transferred from a different subcategory or from another category. In addition, the Agency may base BAT upon manufacturing process changes or internal controls, even when these technologies are not common industry practice.

2.2.4 NEW SOURCE PERFORMANCE STANDARDS

New Source Performance Standards (NSPS) reflect effluent reductions that are achievable based on the best available demonstrated control technology. New facilities have the opportunity to install the best and most efficient production processes and wastewater treatment technologies. As a result, NSPS should represent the greatest degree of effluent reduction attainable through the application of the best available demonstrated control technology for all pollutants (i.e., conventional, non-conventional, and priority pollutants). In establishing NSPS, CWA sec. 306 directs EPA to take into consideration the cost of achieving the effluent reduction and any non-water quality environmental impacts and energy requirements.

2.2.5 PRETREATMENT STANDARDS FOR EXISTING SOURCES AND PRETREATMENT STANDARDS FOR NEW SOURCES

The CWA also defines standards for indirect discharges, i.e. discharges into publicly owned treatment works (POTWs). These are Pretreatment Standards for Existing Sources (PSES) and Pretreatment Standards for New Sources (PSNS) under sec. 307(b).

2.2.6 EFFLUENT GUIDELINES SCHEDULE

Clean Water Act section 304(m) requires EPA to publish a plan every two years that consists of three elements. First, under sec. 304(m)(1)(A), EPA is required to establish a schedule for the annual review and revision of existing effluent guidelines in accordance with sec. 304(b). Section 304(b) applies to ELGs for direct dischargers and requires EPA to revise such regulations as appropriate. Second, under sec. 304(m)(1)(B), EPA must identify categories of sources discharging toxic or nonconventional pollutants for which EPA has not published BAT ELGs under sec.

304(b)(2) or new source performance standards under sec. 306. Finally, under sec. 304(m)(1)(C), EPA must establish a schedule for the promulgation of BAT and NSPS for the categories identified under subparagraph (B) not later than three years after being identified in the 304(m) plan. Section 304(m) does not apply to pretreatment standards for indirect dischargers, which EPA promulgates pursuant to sec. 307(b) and 307(c) of the Act.

On October 30, 1989, Natural Resources Defense Council, Inc. (NRDC), and Public Citizen, Inc., filed an action against EPA in which they alleged, among other things, that EPA had failed to comply with sec. 304(m). Plaintiffs and EPA agreed to a settlement of that action in a consent decree entered on January 31, 1992. (Natural Resources Defense Council et al v. Whitman, D.D.C. Civil Action No. 89-2980). The consent decree, which has been modified several times, established a schedule by which EPA is to propose and take final action for eleven point source categories identified by name in the decree and for eight other point source categories identified only as new or revised rules, numbered 5 through 12. EPA selected the Construction and Development (C&D) category as the subject for new or revised rule #10. The decree, as modified, calls for the Administrator to sign a proposed ELG for the C&D category no later than May 15, 2002, and to take final action on that proposal no later than March 31, 2004. A settlement agreement between the parties, signed on June 28, 2000, requires that EPA develop regulatory options applicable to discharges from construction, development and redevelopment, covering site sizes included in the Phase I and Phase II NPDES storm water rules (i.e. one acre or greater). EPA is required to develop options including numeric effluent limitations for sedimentation and turbidity; control of construction site pollutants other than sedimentation and turbidity (e.g. discarded building materials, concrete truck washout, trash); BMPs for controlling post-construction runoff; BMPs for construction sites; and requirements to design storm water controls to maintain pre-development runoff conditions where practicable. The June 2002 proposal contained discussion of these issues and the public docket contains further information. The settlement also requires EPA to issue guidance to MS4s and other permittees on maintenance of post-construction BMPs identified in the proposed ELGs. Since EPA's proposal or final action did not contain requirements for post-construction BMPs, this guidance is no longer necessary and therefore was not fully developed. However, a draft of the maintenance guidance that was prepared while EPA was considering including options for post-construction BMPs is contained in the public docket.

2.2.7 NPDES PHASE I AND II STORM WATER RULES

The National Pollutant Discharge Elimination System (NPDES) is a permit system established under the CWA to enforce effluent limitations. Operators of construction activities, which include clearing, grading and excavation are required to apply for permit coverage under the NPDES Phase I and II storm water rules. Under the Phase I rule (promulgated in 1990), construction sites of 5 or more acres must be covered by either a general or an individual permit. General permits covering the Phase I sites have been issued by EPA regional offices and state water quality agencies. Permittees are required to develop storm water pollution prevention plans that include descriptions of BMPs employed, although actual BMP selection and design are at the discretion of permittees (in conformance with applicable state or local requirements).

Construction sites between 1 and 5 acres in size are subject to the NPDES Phase II storm water rule (promulgated in 1999). The construction activities covered under Phase II are termed small construction activities and exclude routine maintenance that is performed to maintain the original line and grade, hydraulic capacity, or original purpose of the facility. Under the Phase II program, NPDES permit requirements for construction activities are similar to the Phase I requirements because they will be covered under similar general permits. EPA issued a new general permit that covers all sizes of construction sites subject to the NPDES rules on July 1, 2003.

2.3 POLLUTION PREVENTION ACT OF 1990

The Pollution Prevention Act of 1990 (PPA) (42 U.S.C. 13101 et seq., Pub. L. 101-508, November 5, 1990) makes pollution prevention the national policy of the United States. The PPA identifies an environmental management hierarchy in which pollution "should be prevented or reduced whenever feasible; pollution that cannot be prevented should be recycled in an environmentally safe manner, whenever feasible; pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and disposal or release into the environment should be employed only as a last resort..." (42 U.S.C. 13103). In short, preventing pollution before it is created is preferable to trying to manage, treat or dispose of it after it is created. According to the PPA, source reduction reduces the generation and release of hazardous substances, pollutants, wastes, contaminants or residuals at the source, usually within a process. The term source reduction "...includes equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control. The term 'source reduction' does not include any practice which alters the physical, chemical, or biological characteristics or the volume of a hazardous substance, pollutant, or contaminant through a process or activity which itself is not integral to or necessary for the production of a product or the providing of a service." In effect, source reduction means reducing the amount of a pollutant that enters a waste stream or that is otherwise released into the environment prior to out-of-process recycling, treatment, or disposal.

Although the PPA does not explicitly address storm water discharges or discharges from construction sites, the principles of the PPA are implicit in many of the practices used to reduce pollutant discharges from construction sites. These include controls that minimize the potential for erosion such as proper phasing of construction, retention of on-site vegetation and stabilization of disturbed areas as soon as practicable. These controls and practices are described in Section 5 of this document.

2.4 STATE REGULATIONS

States and municipalities have been regulating discharges of runoff from the construction and land development industry to varying degrees for some time. A compilation of state construction general permits and regulations was prepared to help establish the baseline for national and regional levels of control. Data were collected by reviewing state construction general permits, web sites, summary references, state erosion and sediment control and/or storm water management guidance

manuals. The state regulatory data are summarized in Section 3 and 7 of this document and the complete data sheets are included in Appendix D.

SECTION 3: DATA COLLECTION

3.1 INTRODUCTION

EPA gathered and evaluated technical and economic data from various sources in support of this final action. EPA used existing data sources to profile the industry with respect to general industry description, industry trends, environmental impacts, and erosion and sediment control best management practices (BMPs) and costs. This section details the data sources used in the development of the final action.

3.2 LITERATURE SEARCH

A literature search was performed to obtain information on various BMPs that pertain to the construction and land development industry. Journal articles and professional conference proceedings were used to summarize the most recent BMP effectiveness data, design and installation criteria, applicability, advantages, limitations, and cost.

3.3 COMPILATION OF STATE CONTROL STRATEGIES, CRITERIA, AND STANDARDS

A compilation of existing State programs for the control of construction site storm water was prepared. The data were collected by reviewing State construction general permits, web sites, summary references, and State regulations and erosion and sediment control design and guidance manuals. A summary of criteria and standards for construction site erosion and sediment control that are implemented by States as of September 2003 are presented in Table 3-1. More information on this analysis can be found in Section 7.2 and State-level data sheets are contained in Appendix D.

Table 3-1. State Requirements for Construction Site Erosion and Sediment Control

Element	Number of States with Equivalent Requirement
Initiate soil stabilization with 14 days after construction activity has ceased	27
Install sediment basins that provide storage for the 2-year, 24-hour storm or 3,600 cubic feet per acre for drainage areas with 10 or more disturbed acres at one time	30
Install smaller sediment basins and/or sediment traps for drainage areas serving less than 10 acres	22
Remove sediment from sediment traps or sedimentation ponds when the design capacity has been reduced by 50 percent	25
Conduct inspections at least every 7 calendar days or at least every 14 calendar days and within 24 hours of the end of a storm event of 0.5 inches or greater	41

3.4 OTHER DATA SOURCES

3.4.1 PHASE II STORM WATER RULE ECONOMIC ANALYSIS

The *Economic Analysis of the Final Phase II Storm Water Rule* (USEPA, 1999) estimated Phase II Storm Water Rule compliance costs for two major categories of pollutant controls for construction sites: erosion and sediment control BMPs and post-construction storm water management controls. Total costs for implementing the Phase II Rule encompass expenditures for installation of erosion and sediment control technologies, labor requirements for submitting a Notice of Intent (NOI) to be covered by a general permit, a Notification to Municipalities, a Storm Water Pollution Prevention Plan (SWPPP), and maintenance costs. Costs were derived on a per-site basis and then aggregated to the State and national level based on the number of the building permits issued. As described in the Economic Analysis Report for the Phase II Rule, census data were used to project the annual number of construction permits by Standard Industrial Classification (SIC) Code and construction permit data from 14 municipalities were used to categorize construction activities by site size.

EPA used several data sources collected for the Phase II economic analysis in this rulemaking, including construction permit data collected in 14 municipalities and estimates of BMP installations on small construction sites.

3.4.2 USDA NATIONAL RESOURCES INVENTORY

The National Resources Inventory (NRI) (USDA, 2000) is a statistically based survey that has been designed and implemented using scientific principles to assess conditions and trends of soil, water, and related resources on non-Federal lands in the United States. The NRI is conducted every 5 years by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS), in cooperation with the Iowa State University Statistical Laboratory. The inventory provides scientifically valid, timely, and relevant information that is used to formulate effective agricultural and environmental policies and legislation, implement resource conservation programs, and enhance the public's understanding of natural resources and environmental conditions.

The NRI is a compilation of natural resource information on non-Federal land in the United States–nearly 75 percent of the country's land base. The inventory captures data on land cover and use, soil erosion, prime farmland, wetlands, habitat diversity, selected conservation practices, and related resource attributes at more than 800,000 scientifically selected sample sites. The NRI can be accessed at http://www.nrcs.usda.gov/technical/NRI/.

EPA used the NRI data in support of several analyses. First, NRI data was used to determine the amount of annual construction acreage in each state, which served as a basis for calculating state-level compliance costs of the options considered. NRI data was also used to estimate the amount of construction activity occurring in each of the watersheds in the U.S. based on the Hydrologic Unit Code (HUC) cataloging system. HUC-level data was used to estimate the number of construction sites and the associated loads occurring in each HUC and to link these loads to stream reaches for modeling of water quality improvements and benefits estimates using EPA's National Water Pollution Control Assessment Model (NWPCAM).

3.4.3 CENSUS OF CONSTRUCTION

The census of construction was used as a data source in a number of analyses including determining the amount of construction activity by sector (single-family residential, multi-family residential, commercial and industrial) and in EPA's analysis of financial impacts of the options considered. Additional information on these analyses can be found in the document "Economic Analysis for Final Action for Effluent Guidelines and Standards for the Construction and Development Category," EPA-821-B-04-002.

3.4.4 SOILS DATABASES, REVISED UNIVERSAL SOIL LOSS EQUATION AND SEDCAD

EPA utilized data from the USDA State Soil Geographic STATSGO database (USDA, 1995) to determine county-level soil textural information in support of the loadings estimates and BMP removals estimates. EPA utilized the Revised Universal Soil Loss Equation (RUSLE) in combination with the soils data to determine soil erosion rates from model construction sites in different areas of the county. In order to evaluate BMP removal efficiencies and to calculate

national loadings reductions of the options considered, EPA used the SEDCAD (Warner, 1998) model to evaluate removals under various control strategies.

3.5 REFERENCES

USEPA. 1999. *Economic Analysis of the Final Phase II Storm Water Rule*. U.S. Environmental Protection Agency, Office of Wastewater Management. Washington D.C.

USDA. 1995. State Soil Geographic (STATSGO) Database, Miscellaneous Publication 1492, Revised 1994.

USDA. 2000. *1997 National Resources Inventory*. U.S. Department of Agriculture, National Resources Conservation Service, Washington, DC.

Warner, R.C. and P.J. Schwab. 1998. SEDCAD 4 for Windows 95 & NT-Design Manual and User's Guide. Civil Software Design, Ames, IA.

SECTION 4: INDUSTRY PROFILE

4.1 INTRODUCTION

The construction sector is among the largest and most important sectors in the national economy. The construction industry is divided into three major subsectors: general building contractors, heavy construction contractors, and special trade contractors. General contractors build residential, industrial, commercial, and other buildings. Heavy construction contractors build sewers, roads, highways, bridges, and tunnels. Special trade contractors typically provide carpentry, painting, plumbing, and electrical services. Additional information. including detailed descriptions of industry size and revenues, can be found in the document "Economic Analysis for Final Action for Effluent Guidelines and Standards for the Construction and Development Category," EPA-821-B-04-002.

4.2 INDUSTRY PRACTICES AND TRENDS

4.2.1 OVERVIEW OF CONSTRUCTION LAND-DISTURBING ACTIVITIES

Constructing a building or facility involves a variety of activities, including the use of equipment that alters the site's environmental conditions. These changes include vegetation and top soil removal, regrading, and drainage pattern alteration. The following provides a brief description of typical land-disturbing activities at construction sites and the types of equipment employed.

Construction Site Preparation. Construction activities generally begin with the planning and engineering of the site and site preparation. During this stage, mobile offices, which are usually housed in trailers, are established on the construction site. The construction company uses these temporary structures to handle vital activities such as preparing and submitting applicable permits, hiring employees and subcontractors, and ensuring that proper environmental requirements are met. The entire construction yard is delineated with erosion and sediment controls installed and security measures established. The latter includes installing fences and signs to warn against trespassing and to mark dangerous areas. After the site is secured, equipment is brought to the site (and is stored there throughout the construction period).

Clearing, Excavating, and Grading. Construction on any size parcel of land almost always calls for a remodeling of the earth (Lynch and Hack,1984). Therefore, actual site construction begins with site clearing and grading. Organic material—in particular, roots—cannot support the weight of buildings and must be removed from the top layer of ground. (Some developers stockpile the organic material for use during the landscaping phase of construction rather than paying for it to be hauled from the site.) Construction contractors must ensure that earthwork activities meet local, state, and federal regulations for soil and erosion control, runoff, and other environmental controls. The size of the site, extent of water present, soil types, topography, and weather determine the kinds of equipment used in site clearing and grading (Peurifoy and Oberlender, 1989). Material that will not be used on the site must be hauled away by tractor-pulled wagons, dump trucks, or articulated trucks (Peurifoy and Oberlender, 1989).

Equipment used for lifting excavated and cleared materials include aerial-work platforms, forwarders, cranes, rough-terrain forklifts, and truck-mounted cranes. In addition, track loaders are used for digging and dumping earth (Caterpillar, 2000; Construction Equipment On-Line, 1996-1998; Lynch and Hack, 1984; and Peurifoy and Oberlender, 1989).

Excavation and grading are performed by several different types of machines. These tasks can also be done by hand, but this is generally more expensive (Lynch and Hack, 1984). When grading a site, builders typically ensure that new grades are as close to the original as possible, to avoid erosion and storm water runoff (Lynch and Hack, 1984). Proper grading also ensures a flat surface for development and drains water away from constructed buildings.

Excavation and grading equipment includes backhoes, bulldozers (including the versatile tracked bulldozer), loaders, directional drilling rigs, hydraulic excavators, motor graders, scrapers, skid-steer loaders, soil stabilizers, tool carriers, trenchers, wheel loaders, and pipeliners. Equipment selection depends on functions to be performed and specific site conditions (Caterpillar, 2000; Construction Equipment On-Line, 1996-1998; Lynch and Hack, 1984; and Peurifoy and Oberlender, 1989). Therefore, multiple types of equipment are used throughout the clearing and grading process.

Self-transporting trenching machines, wheel-type trenching machines, and ladder-type trenching machines are also used during site excavation. Self-transporting trenching machines are used to create shallow trenches, such as for underground wire and cables. This type of machine has a bulldozer blade attached to the front, is highly maneuverable, and can be used to dig narrow, shallow trenches. Wheel-type trenching machines also dig narrow trenches, most often for water mains and gas and oil pipelines. Ladder-type trenching machines are used to dig deep trenches, such as for sewer pipes. These machines might have a boom mounted at the rear. Along the boom are cutter teeth and buckets that are attached to chains. As the machine moves, it digs dirt and moves it to the sides of the newly formed trench (Peurifoy and Oberlender, 1989).

Power shovels can also be used for excavating soils. They are used on all classes of earth that have not been loosened. For solid rock, prior loosening is required. As materials are excavated, they are immediately loaded onto trucks or tractor-pulled wagons and hauled from the site (Peurifoy and Oberlender, 1989). Hydraulic excavators, with either a front or a back shovel, are also used to dig into the earth and to load a hauling vehicle. There are several categories of hydraulic excavators, including backhoes, back shovels, hoes, and pull shovels. Hydraulic excavators are one of the most widely used types of excavating equipment because of their ease of use and their ability to remove the earth that caves as it is moved. They are effective excavating machines, and they are easy to use in terms of loading some a hauling vehicle (Peurifoy and Oberlender, 1989).

Draglines, used to dig ditches or build levees, can transport soil within casting limits, thus eliminating the need for hauling equipment (Peurifoy and Oberlender, 1989). Draglines have a bucket that hangs from a cable. The bucket is brought through the dirt and toward the operator (Lynch and Hack, 1984). Draglines can be used on both wet and dry ground and can dig earth out of pits that contain water (Peurifoy and Oberlender, 1989). They are most useful for making large

cuts and channels below the level of the machine as well as for making valleys, mounds, slopes, and banks (Lynch and Hack, 1984). Draglines have a lower output than power shovels, and do not excavate rock as well as power shovels (Peurifoy and Oberlender, 1989).

Draglines can be converted to clamshells by replacing the dragline bucket with a clamshell bucket. A clamshell is typically used for handling sand, gravel, crushed stone, sandy loam, and other loose materials; it is not efficient in handling compacted earth, clay, or other dense materials. A clamshell is lowered into a material, and the bucket closes on the material. It is then raised over a hauling vehicle and the materials are deposited (Peurifoy and Oberlender, 1989).

Scrapers, either self-powered or drawn by tractors, dig and compact materials by taking up earth from its underside with toothed scoops and loading it into hauling vehicles. Scrapers are useful in removing earth and weak or broken rock, and for excavating hills and rock faces. Some scrapers are designed for long hauls; others with good traction are used on steep slopes (Lynch and Hack, 1984).

A crawler tractor, which pulls a rubber-tired self-loading scraper, is often used for short-haul distances. The crawler tractor uses a drawbar pull to load the scraper. It has good traction and can operate on muddy roads. It is, however, a slower vehicle and thus is more appropriate for shorter hauls.

Wheel-type tractor-pulled scrapers, which come in two- and four-wheel tractors, are used for longer hauling distances. Unlike the crawler tractor-pulled scrapers, the wheel-type tractor-pulled scrapers do not maintain good traction. Under such conditions, a helper tractor, such as a bulldozer, might be used (Peurifoy and Oberlender, 1989).

All of these machines shape and compact the earth, a crucial site preparation step. In addition, earthwork activities might require that fill be brought in. In such cases, the fill must be spread in uniform, thick layers and compacted to a specified density with an optimum moisture content. Graders and bulldozers are the most common earth-spreading machines. Machines that compact include tractor-pulled sheep's foot rollers, smooth-wheel rollers, pneumatic rollers, and vibrating rollers, among other equipment (Peurifoy and Oberlender, 1989). Rollers and scarifiers are used either to compact or to break up the ground (Lynch and Hack, 1984).

To remove rock, it must first be loosened and broken up–usually through drilling or blasting. Drilling equipment includes jackhammers, wagon drills, drifters, churn rills, and rotary drills; each is designed to work on a specific size and type of rock. Dynamite and other explosives are used to loosen rock (Peurifoy and Oberlender, 1989).

Once materials have been excavated and removed and the ground cleared and graded, the site is ready for construction.

4.2.2 CONSTRUCTION SITE SIZE CATEGORIES AND ESTIMATES OF AMOUNT OF DISTURBED LAND

The regulatory options evaluated apply to construction sites of all types (i.e., residential, commercial, and industrial) of more than 5 acres of disturbed land. Because the costs of best management practices (BMPs) for erosion and sediment control are largely driven by site size, EPA must estimate the distribution of construction sites by size category, land use type, and geographic region to estimate the total cost of the options. In addition, estimating distribution of sites by type allows EPA to estimate the cost to each construction sector.

The method used to estimate the number of construction sites by size category–and therefore the total area disturbed–is based on a number of data sources, including U.S. Census data and data collected during the Phase II Storm Water rulemaking.

4.2.2.1 National Estimates of Disturbed Acreage

EPA used the U.S. Department of Agriculture's (USDA's) 1997 National Resources Inventory (NRI) to estimate the level of new U.S. development each year. NRI is designed to track changes in land cover and land use over time. The inventory, conducted every five years, covers all non-federal lands in the U.S. (which constitutes 75 percent of the total land area in the U.S.). The program captures land use data from approximately 800,000 statistically selected locations. From 1992 to 1997, an average of 2.2 million acres per year were converted from non-developed to developed status. Table 4-1 shows the allocation of this converted land area by type of land or land cover. Table 4-2 shows the national allocation of developed acres by state.

Table 4-1. Acres Converted from Undeveloped to Developed State, 1992-1997

Type of Land	Acres Converted to Development[a] 1992-1997 (thousands) Annual Average	Percent Contribution by Type of Land
Cropland	574.8	26.6%
Conservation Reserve Program land	1.5	0.1%
Pastureland	391.2	17.4%
Rangeland	245.9	11.0%
Forest land	939.0	41.9%
Other rural area	89.1	4.0%
Water areas and federal land	1.8	0.1%
Total [b]	**2,243.4**	**100.0%**

[a] NRI defines *developed land* as a combination of the following land cover/use categories *large urban and built-up areas*, *small built-up areas*, and *rural transportation land*. These are defined as follows:
Large urban and built-up areas. A land cover/use category composed of developed tracts of at least 10 acres—meeting the definition of urban and built-up areas.
Small built-up areas. A land cover/use category consisting of developed land units of 0.25 to 10 acres, which meet the definition of urban and built-up areas.
Rural transportation land. A land cover/use category which consists of all highways, roads, railroads and associated right-of-ways outside urban and built-up areas; also includes private roads to farmsteads or ranch headquarters, logging roads, and other private roads (field lanes are not included).
Urban and built up areas are in turn defined as:
Urban and built-up areas. A land cover/use category consisting of residential, industrial, commercial, and institutional land; construction sites; public administrative sites; railroad yards; cemeteries; airports; golf courses; sanitary landfills; sewage treatment plants; water control structures and spillways; other land used for such purposes; small parks (less than 10 acres) within urban and built-up areas; and highways, railroads , and other transportation facilities if they are surrounded by urban areas. Also included are tracts of less than 10 acres that do not meet the above definition but are completely surrounded by urban and built-up land. Two size categories are recognized in the NRI: areas of 0.25 acre to 10 acres, and areas of at least 10 acres.
[b] Excludes Alaska
Source: USDA, 2000.

Table 4-2. State Rankings by Rate of Non-Federal Land Developed, 1992 - 1997*

Ranking	State	Average Annual Conversion Rate (acres)	Ranking	State	Average Annual Conversion Rate (acres)
1	Texas	178,700	26	West Virginia	35,360
2	Georgia	170,380	27	Oklahoma	35,340
3	Florida	165,040	28	Arkansas	33,780
4	California	110,680	29	Louisiana	26,720
5	Pennsylvania	109,020	30	Arizona	22,760
6	North Carolina	101,320	31	Colorado	22,500
7	Tennessee	80,380	32	Puerto Rico	22,480
8	Ohio	72,960	33	Maine	22,220
9	Michigan	72,820	34	Oregon	20,780
10	South Carolina	72,400	35	Kansas	19,300
11	Virginia	68,700	36	Idaho	18,380
12	New York	63,520	37	Utah	16,260
13	Alabama	63,060	38	Montana	15,260
14	Illinois	49,300	39	Iowa	13,820
15	Washington	48,160	40	New Hampshire	12,520
16	Kentucky	47,420	41	South Dakota	11,560
17	Minnesota	46,360	42	Nebraska	11,020
18	Missouri	44,840	43	Connecticut	7,880
19	New Mexico	43,440	44	Wyoming	6,880
20	New Jersey	42,720	45	North Dakota	6,560
21	Massachusetts	42,360	46	Nevada	5,340
22	Mississippi	41,280	47	Delaware	4,620
23	Indiana	39,060	48	Vermont	2,300
24	Wisconsin	37,640	49	Hawaii	1,360
25	Maryland	35,520	50	Rhode Island	1,320

* Excludes Alaska

It is important to note that the 2001 NRI data was becoming available as EPA was finishing its analyses. However, since the national total of acres developed annually (2.2 million acres) was the same for both the 1997 and 2001 NRI datasets, EPA elected not to update its evaluation to reflect the 2001 values.

4.2.2.2 Distribution of Acreage by Project Type

To allocate the NRI acreage among the various segments of the industry, EPA has estimated the distribution of acres developed by type of project in the following way. First, EPA multiplied the number of building permits issued annually by estimates of the average site size for each project type. Thus for single-family residential construction, EPA multiplied the number of new single-family home building permits by the average lot size for new single-family construction. Estimates for other types of construction were based on extrapolations from the U.S. Census permit data and EPA estimates of average project size. Second, EPA adjusted the estimates of acres converted to reconcile any differences between the total number of acres accounted for using this approach and the total acres developed as estimated in the NRI.

Single-family Residential

Census data indicate that in recent years the number of new single-family housing units authorized has averaged just over 1.0 million units per year (see Table 4-3). The average lot size for new single-family housing units is 13,553 square feet, or 0.31 acres (1 acre = 43,560 square feet). Using the average lot size (see Table 4-4), however, will underestimate the total acreage converted for single-family residential projects because it does not include common areas of developments not counted as part of an owner's lot–for example, streets, sidewalks, parking areas, storm water management structures, and open spaces.

Table 4-3. New Single-Family and Multifamily Housing Units Authorized, 1995-1997

Year	All Housing Units	Single-Family Housing Units	Multifamily Housing Units
1995	1,332,549	997,268	335,281
1996	1,425,616	1,069,472	356,144
1997	1,441,136	1,062,396	378,740
1995-1997 avg	**1,399,767**	**1,043,045**	**356,722**

Source: BOC, 2000b. Series C40 New Privately Owned Housing Units Authorized

Table 4-4. Average and Median Lot Size for New Single-Family Housing Units Sold, 1995-1997

Year	Average Lot Size (Square Feet)	Median Lot Size (Square Feet)
1995	13,665	9,375
1996	13,705	9,100
1997	13,290	9,000
1995-1997 avg	**13,553**	**9,158**

Source: BOC, 2000a. Series C25 Characteristics of New Housing

To account for these differences, EPA examined data obtained from a survey of municipalities conducted in support of the Phase II Storm Water rule (EPA 1999). This survey identified 14 communities that consistently collected project type and size data as part of their construction permitting programs.[2] EPA's review of permitting data from these communities covered 855 single-family developments encompassing 18,134 housing units. The combined area of these developments was 11,460 acres. This means that each housing unit accounted for 0.63 acres (11,460 acres ÷ 18,134 units = 0.63 acres per unit). This estimate, essentially double the average lot size, appears to more than account for the common areas and undeveloped areas in a typical single-family residential development. For this reason, EPA averaged the Census estimate of the national average lot size (0.31 acres) and the Phase II estimate of 0.63 acres per unit to arrive at an estimate of 0.47 acres per unit. This number was multiplied by the average number of single-family housing units authorized by building permit, 1.04 million, to arrive at an estimate of 490,231 acres (see Table 4-7).

Multifamily Residential

For residential construction other than single-family housing, EPA divided the average number of units authorized during 1995-1997 (356,722, from Table 4-3) by the average number of units per new multifamily building. The average number of units per building was obtained by examining the distribution of units by unit size class in Census data (BOC 2000b). EPA estimated the number of buildings in each size class by dividing the number of units in each class by the average number of units. The total number of units was then divided into the estimated number of buildings to arrive at an average number of 10.8 units across all building size classes.

EPA next examined data on the average site size for multifamily residential developments. The Center for Watershed Protection reports survey results showing that an average building footprint

[2] The communities were: Austin, TX; Baltimore County, MD; Cary, NC; Ft. Collins, CO; Lacey, WA; Loudoun County, VA; New Britain, CT; Olympia, WA; Prince George's County, MD; Raleigh, NC; South Bend, IN; Tallahassee, FL; Tuscon, AZ; and Waukesha, WI.

occupies 15.6 percent of the total site (CWP 2001). EPA assumed that the average-sized multifamily building (10.8 units) would have two floors and that each unit would occupy the national average of 1,095 square feet (NAHB 2002). The total square footage accounted for by living space is thus 11,826 square feet. Multiplying by a factor of 1.2 to account for common areas and other non-living space (utility rooms, hallways, stairways), and dividing by 2 to reflect the assumption of a 2-story structure, EPA obtained a typical building footprint of 7,096 square feet (11,826 x 1.2 ÷ 2 = 7,096). Combining this with the CWP estimate of the building footprint share of total site size (15.6 percent), the average site size was estimated to be 45,487 square feet (7,096 ÷ 0.156 = 45,487), or just over 1 acre (1.04 acres).

EPA compared the average site size obtained using this approach with data from the 14 community survey referenced above under the Phase II Storm Water rule. That study's review of permitting data identified 286 multifamily developments covering a total of 3,476 acres. The average site size, 12.1 acres, is considerably higher than that calculated above. EPA has no indication that the permits reviewed in these communities are for projects of a larger-than- average size. Therefore, for purposes of this analysis, EPA has taken the midpoint of the estimates, 6.5 acres, as the average size of multifamily projects. This number was multiplied by the average number of multifamily housing developments authorized by building permit, 35,672, to arrive at an estimate of 231,868 acres (see Table 4-7).

Nonresidential Construction

EPA lacked current data on the number of nonresidential construction and development projects authorized annually because the Census Bureau ceased to collect data on the number of permits issued for such projects in 1995. EPA used regression analysis to forecast the number of nonresidential building permits issued in 1997, based on the historical relationship between residential and nonresidential construction activity. Using this approach, EPA estimates that a total of 426,024 nonresidential permits were issued in 1997. These represent a variety of project types, including commercial and industrial, institutional, recreational, as well as nonresidential, nonbuilding projects such as parks and road or highway projects.

EPA first combined a number of project types into a larger "commercial" category, which included hotels and motels and retail and office projects, as well as religious, public works, and educational projects.[3] EPA's reasoning for including the latter categories under the commercial category is based on engineering judgment that erosion and sediment control practices would be similar across each project type. The total estimated number of commercial permits in 1997 was 254,566 (59.7 percent of the nonresidential total). (EPA calculated an estimate for the industrial category, which totaled 12,140 permits (2.8 percent), separately.) The residual 159,318 permits (37.4 percent), are nonbuilding, nonresidential projects that include parks, bridges, roads, and highways. EPA accounts for these projects in the steps described below.

[3] The commercial category included: hotels/motels, amusement, religious, parking garages, service stations, hospitals, offices, public works, educational, stores, and other nonresidential buildings.

For the industrial and commercial categories, EPA reviewed the project size data collected from the 14-community Phase II rule survey referenced earlier (EPA, 1999). This study identified 817 commercial sites occupying 5,514 acres and 115 industrial sites occupying 689 acres. The average site sizes are 6.7 and 6.0 acres, respectively.

EPA also reviewed estimates from CWP (2001) on the average percent of commercial and industrial sites taken up by the building footprint. These percentages, 19.1 and 19.6 respectively, were multiplied across the model project site sizes of 0.5, 3, 7.5, 25, 70, and 200 acres to estimate building size on each site, assuming single-story buildings in each case. These estimates are shown in Table 4-5.

Table 4-5. Average Building Square Footage

Project Size (Acres)	Commercial	Industrial
0.5	4,160	4,269
3	24,960	25,666
7.5	62,400	64,164
25	207,999	213,880
70	582,397	598,863
200	1,663,992	1,711,037

Estimates were obtained by multiplying the site size in square feet by the percentage of the site estimated to be occupied by the building footprint, based on data from CWP (2001).

As seen in the table, the average building size corresponding to the 6- to 7- acre sites estimated from the 14-community study are in the 60,000 square feet range. EPA next examined R.S. Means' *Building Construction Cost Data* (2000), which provides cost data for "typical" commercial and industrial buildings. As part of the cost data, R.S. Means identifies the typical range of building sizes based on a database of actual projects. Table 4-6 shows the typical size and size range for a variety of building types that would fall into either the commercial or industrial category. While some of the building types correspond with the estimated average of 60,000 square feet, these appear high for other categories, such as low-rise office and supermarkets, warehouses, and elementary schools. EPA believes generally that there are more small projects than large ones. As a result, EPA inferred that this approach would suggest an average building size of 25,000 square feet, which implies an average site size of 3 acres, based on Table 4-5.

To reconcile the estimates obtained from the two approaches, EPA has taken the midpoint of the estimates. For commercial development, EPA assumes an average site size of 4.85 acres (the average of 6.7 and 3.0 acres) and for industrial development EPA assumes an average site size of 4.5 acres (the average of 6.0 and 3.0 acres).

Table 4-6. Typical Building Sizes and Size Ranges by Type of Building

Building Category/Type	Typical Size (Gross Square Feet)	Typical Range (Gross Square Feet)	
		Low	High
Commercial - Supermarkets	20,000	12,000	30,000
Commercial - Department Store	90,000	44,000	122,000
Commercial - Low-Rise Office	8,600	4,700	19,000
Commercial - Mid-Rise Office	52,000	31,300	83,100
Commercial - Elementary[a]	41,000	24,500	55,000
Industrial - Warehouse	25,000	8,000	72,000

[a] For the purpose of this analysis EPA combined a number of building types, including educational, under the commercial category.
Source: R.S. Means, 2000.

The resulting average project sizes were then multiplied by the estimated number of commercial and industrial permits to obtain an estimate of the total acreage developed for these project categories. Table 4-7 shows the results of this "bottom-up" approach to estimating the number of acres of land developed. The overall estimate of the amount of land developed is 2.01 million acres per year. Residential single-family development accounts for 24.4 percent of the total, multifamily development for 11.5 percent, commercial for 61.4 percent, and industrial for 2.7 percent.

Table 4-7. National Estimates of Land Area Developed Per Year, Based on Building Permit Data

Type of Construction		Permits		Average Site Size[a]	Acres Disturbed	
		Number	Pct. of Total		Number	Pct. of total
Residential	Single-family	1,043,045	77.5%	0.47	490,231	24.4%
	Multifamily	35,672	2.7%	6.5	231,868	11.5%
Nonresidential	Commercial[b]	254,566	18.9%	4.9	1,234,645	61.4%
	Industrial	12,140	0.9%	4.5	54,630	2.7%
Total		**1,345,423**	**100.0%**	**--**	**2,011,374**	**100.0%**

[a] For single-family residential, this is the average of the average lot size for new construction in 1999 (BOC, 2000b) and the average obtained in EPA (1999). For all other categories, the site sizes are EPA assumptions based on representative project profiles contained in R.S. Means (2000) and the 14-community survey conducted in support of the Phase II NPDES storm water rule (EPA, 1999).
[b] A number of project types were grouped together to form the "commercial" category, including: hotels/motels, amusement, religious, parking garages, service stations, hospitals, offices, public works, educational, stores, other nonresidential buildings.

This estimate of 2.01 million acres of annual developed land (Table 4-7) is close to the estimate of 2.2 million acres obtained from NRI. For the purpose of developing national compliance costs of the options and calculating loadings reductions, EPA has allocated the entire NRI developed acreage (excluding Puerto Rico and Hawaii) into the four land use categories according to the percentages shown in the final column of Table 4-7. This revised estimate is shown in Table 4-8.

Table 4-8. National Estimates of Land Area Developed Per Year, Based on National Resources Inventory Totals

Type of Construction		Developed Area Based on Permits Data		Developed Acres Based on NRI Data [b]
		Acres[a]	Pct. of Total	
Residential	Single-family	490,231	24.4%	540,800
	Multifamily	231,868	11.5%	253,358
Nonresidential	Commercial [c]	1,234,645	61.4%	1,366,387
	Industrial	54,630	2.7%	59,009
Total		**2,011,374**	**100.0%**	**2,219,553**

[a] From Table 4-7.
[b] This column distributes the total acreage estimated in NRI to be converted on an annual basis according to the distribution by type of development estimated through analysis of permits data. See also Tables 4-2 through 4-6.
[c] A number of project types were grouped together to form the "commercial" category, including: hotels/motels, amusement, religious, parking garages, service stations, hospitals, offices, public works, educational, stores, other nonresidential buildings.

4.2.2.3 Distribution of Developed Acreage by Project Size

For each of the four land use categories in Table 4-8, EPA developed procedures to allocate developed acre estimates into six site size categories: 0.5, 3, 7.5, 25, 70 and 200 acres. EPA evaluated the survey data collected from 14 municipalities in support of the Phase II storm water rule. This survey identified 14 communities that consistently collect project type and size data as part of their construction permitting programs. From this data set, EPA was able to determine the percentage of projects and developed acreage for each of the six site size groups and four land use categories. Table 4-9 shows the distribution of the 14 community survey data by project size for each of the four land use categories (single family residential, multi-family residential, commercial and industrial). The percentages shown in the "Percent Acres by Size" column of Table 4-9 for each land use type were used to assign total estimated developed acres to site sizes for each of the four land use categories, based on the total developed NRI acreage by category shown in the last column of Table 4-8. The result of this allocation is shown in Table 4-10. The totals differ slightly as fractional sites were rounded to whole numbers. EPA further subdivided developed acreage to a state-level based on the state-specific developed acreage estimates contained in the NRI data and shown in Table 4-2. This distribution to a state-level was necessary for the costing analysis, since costs were calculated on a state-level basis to account for the existing state programs in place. Sites were further subdivided to a watershed level (based in Hydrologic Unit Codes, or "HUCs) for the loadings analysis. At both of these steps, fractional sites were again rounded to whole numbers. As a result, the state and HUC totals of sites and developed acreage do not sum to the national totals. However, the variation is minor.

Table 4-9. Distribution of 14 Community Survey Permits by Site Size

Site Size (Acres)	No. of Permits	Acres by Size	Pct. Acres by Size	Site Size (Acres)	No. of Permits	Acres by Size	Pct. Acres by Size
Single-Family Residential				***Commercial***			
0.5	266	133	1.2%	0.5	266	133	2.5%
3	228	684	6.0%	3	356	1,068	19.8%
7.5	138	1,035	9.1%	7.5	86	645	12.0%
25	175	4,375	38.6%	25	91	2,275	42.3%
70	30	2,100	18.5%	70	16	1,260	23.4%
200	15	3,000	26.5%	200	0	0	0.0%
Total	852	11,327	100.0%	Total	815	5,381	100.0%
Multifamily Residential				***Industrial***			
0.5	43	22	0.6%	0.5	39	20	2.9%
3	100	300	8.7%	3	55	165	24.6%
7.5	61	458	13.3%	7.5	10	75	11.2%
25	71	1,775	51.4%	25	8	200	29.9%
70	10	700	20.3%	70	3	210	31.4%
200	1	200	5.8%	200	0	0	0.0%
Total	286	3,455	100.0%	Total	115	670	100.0%
Total							
0.5	614	307	1.5%				
3	739	2,217	10.6%				
7.5	295	2,213	10.6%				
25	345	8,625	41.4%				
70	59	4,270	20.5%				
200	16	3,200	15.4%				
Total	2,068	20,832	100.0%				

Based on permitting data from the following municipalities or counties: Austin, TX; Baltimore County, MD; Cary, NC; Ft. Collins, CO; Lacey, WA; Loudoun County, VA; New Britain, CT; Olympia, WA; Prince George's County, MD; Raleigh, NC; South Bend, IN; Tallahassee, FL; Tuscon, AZ; and Waukesha, WI.
Assumes sites less than 1 acre are represented by an average of 0.5 acres.
Source: USEPA, 1999

Table 4-10. Distribution of National Construction by Site Size and Development Type

Site Size (Acres)	No. of Permits	Acres by Size	Pct. Acres by Size	Site Size (Acres)	No. of Permits	Acres by Size	Pct. Acres by Size
Single-Family Residential				***Commercial***			
0.5	12,753	6,377	1.2%	0.5	67,590	33,795	2.5%
3	10,932	32,796	6.1%	3	90,458	271,374	19.9%
7.5	6,611	49,582	9.2%	7.5	21,845	163,838	12.0%
25	8,387	209,675	38.8%	25	23,116	577,900	42.3%
70	1,431	100,170	18.5%	70	4,564	319,480	23.4%
200	711	142,200	26.3%	200	0	0	0.0%
Total	40,825	540,800	100.0%	Total	207,573	1,366,387	100.0%
Multifamily Residential				***Industrial***			
0.5	3,178	1,589	0.6%	0.5	3,491	1,746	3.0%
3	7,408	22,224	8.8%	3	4,931	14,793	25.1%
7.5	4,514	33,855	13.4%	7.5	888	6,660	11.3%
25	5,258	131,450	51.9%	25	710	17,750	30.1%
70	732	51,240	20.2%	70	258	18,060	30.6%
200	65	13,000	5.1%	200	0	0	0.0%
Total	21,155	253,358	100.0%	Total	10,278	59,009	100.0%
Total							
0.5	87,012	43,507	2.0%				
3	113,729	341,187	15.4%				
7.5	33,858	253,935	11.4%				
25	37,471	936,775	42.2%				
70	6,985	488,950	22.0%				
200	776	155,200	7.0%				
Total	279,831	2,219,554	100.0%				

Based on permitting data from the following municipalities or counties: Austin, TX; Baltimore County, MD; Cary, NC; Ft. Collins, CO; Lacey, WA; Loudoun County, VA; New Britain, CT; Olympia, WA; Prince George's County, MD; Raleigh, NC; South Bend, IN; Tallahassee, FL; Tuscon, AZ; and Waukesha, WI.
Assumes sites less than 1 acre are represented by an average of 0.5 acres.
Source: USEPA, 1999

4.2.2.4 State-Level Estimation of Developed Acreage and Sites

Based on the state-level estimates of the amount of construction acreage occurring annually, the number of national construction sites by land use in Table 4-9 was distributed to the state level. Table E-1 in Appendix E indicates the number of construction sites by site size and land use for each state.

4.2.2.5 Estimates of Number of Sites and Acreage Covered by Regulatory Options

Based on the information in Table 4-9 and 4-10, EPA was able to estimate the amount of acreage covered under the various regulatory options considered. This information is illustrated in Table 4-11. It is important to note, however, that these estimates include all national construction acreage occurring annually in the U.S. The actual number of sites that would be required to implement controls in response to the Option 4 is actually much lower than for Options 1 and 2, since in many states the existing requirements are equivalent to or more stringent than the requirements contained in this option. For Options 1 and 2, however, since no states currently have equivalent inspection and certification requirements the number of sites and acreage incurring costs are the same as the entire universe of sites that would have been subject to the guidelines under these options. Table 4-12 contains EPA's estimates of the number of sites and acreage that are actually expected to incur costs as a result of the regulatory options considered. This table integrates the results of the state equivalency analysis presented in Section 7 with the state-level estimates of construction sites by site size and land use presented in Table E-1 in Appendix E.

Table 4-11. National Construction Acreage Subject to Effluent Guidelines Requirements

Type of Construction	Option 1		Options 2 and 4	
	Acres	Number of Construction Sites	Acres	Number of Construction Sites
Single-family Residential	534,424	28,072	501,628	17,140
Multi-family Residential	251,769	17,977	229,545	10,569
Commercial	1,332,592	139,983	1,061,218	49,525
Industrial	57,263	6,787	42,470	1,856
Total	2,176,047	192,819	1,834,860	79,090
Percent of National Total	98.0 %	68.9 %	82.7 %	28.3 %

Table 4-12. Acreage Incurring Costs Under Options Considered

Type of Construction	Option 1		Option 2		Option 4	
	Acres	Number of Sites	Acres	Number of Sites	Acres	Number of Sites
Single-family Residential	534,424	28,072	501,628	17,140	324,478	11,087
Multi-family Residential	251,769	17,977	229,545	10,569	148,481	6,837
Commercial	1,332,592	139,983	1,061,218	49,525	686,450	32,035
Industrial	57,263	6,787	42,470	1,856	27,472	1,201
Total	2,176,047	192,819	1,834,860	79,090	1,186,881	51,159
Percent of National Total	98.0 %	68.9 %	82.7 %	28.3 %	53.5 %	18.3%

4.3 REFERENCES

BOC. 2000a. *1997 Economic Census-Construction Sector Special Study: Housing Start Statistics, a Profile of the Homebuilding Industry*. Issued July 2000. U.S. Bureau of the Census, Washington, DC.

BOC. 2000b. *New Privately Owned Housing Units Authorized by Building Permits in Permit-issuing Places, Annual Data.* U.S. Bureau of the Census, Washington, DC.

Caterpillar. 2000. Caterpillar, Inc. <www.cat.com>

Construction Equipment On-line. 2000. Reed Business Information, U.S., <www.coneq.com>

CWP. 2001. *Impervious Cover and Land Use in the Chesapeake Bay Watershed*. Ellicott City, MD: Center for Watershed Protection, January. Additional data table, "Chesapeake bay watershed impervious cover results by land use polygon," received via a facsimile from Tetra Tech, Inc., September 20, 2001.

Lynch, Kevin and Hack, Gary. 1984. *Site Planning (3rd ed.)*. Cambridge, MA: MIT Press.

NAHB. 2002. *Characteristics of New Multifamily Buildings 1987-1999*. National Association of Home Builders. <http://www.nahb.com/multifamily/characteristics.htm>. Accessed May 29, 2001.

Peurifoy, Robert L. and Oberlender, Garold D. (1989). *Estimating Construction Costs (4th ed.)*. New York: McGraw Hill Book Company.

R.S. Means. 2000. *Building Construction Cost Data 58th Annual Edition*. R.S. Means Co., Kingston, Massachusetts.

USDA. 2000. *1997 National Resources Inventory*. U.S. Department of Agriculture, National Resources Conservation Service, Washington, DC. <www.nrcs.usda.gov/technical/NRI/>.

USEPA. 1999. *Economic Analysis of the Final Phase II Storm Water Rule*. U.S. Environmental Protection Agency, Office of Wastewater Management. Washington, DC.

SECTION 5: TECHNOLOGY ASSESSMENT

This technology assessment of available data sources is intended to determine the depth and breadth of effectiveness data for various erosion and sediment controls, and to identify the amount and quality of data available to describe the performance of all currently used and innovative construction site runoff control practices, the ability of each practice to effectively control impacts due to runoff, and the design criteria or standards currently used to size each practice to ensure effective control of runoff.

5.1 CONSTRUCTION EROSION AND SEDIMENT CONTROLS

5.1.1 INTRODUCTION

This assessment addresses the erosion and sediment control BMPs for the construction phase of development. Prior to initiating this aspect of the work, EPA reviewed the findings of information sources and literature assessments to identify the appropriate definition of "performance" or the various definitions or "levels" of performance that are considered in evaluating and defining the levels of performance for these BMPs. A scientific-based approach to describe the performance of erosion and sediment control BMPs was devised similar to the approach developed by Barfield and Clar (1985) in the evaluation of the Maryland Erosion and Sediment Control Standards, as well as the one recently developed in the American Society of Civil Engineers BMP Database (ASCE, 1999). The approach used in this assessment has been designed to provide the information needed to address several important issues, including whether to use a design-based approach, or an effluent-based concentration, or a loading approach in reporting on the current status of the technology. This sub-section identifies the following:

- The amount and quantity of data available to describe the performance of all currently used and innovative runoff control practices.
- The ability of each practice to effectively control impacts due to runoff.
- The design criteria or standards currently used to size each practice to ensure effective control of runoff.

Before a detailed evaluation of the BMPs can be provided, some background information is necessary. Sub-section 5.2 describes the procedure for assessing the technology. Sub-section 5.3 provides a historical background on the subject. Next, sub-section 5.4 presents a discussion of goals, control strategies, criteria, and standards in general, and sub-section 5.5 provides a detailed description and discussion of each BMP.

In the discussion of BMPs in sub-section 5.5, the major focus will be on sediment. This does not imply that there are no other impacts; however, construction BMPs have focused on erosion and sediment control rather than on other impacts.

In the assessment of BMPs, considerable attention is focused on whether to use a design-based approach, an effluent-based concentration, or a loading approach in reporting on the current status of the technology. Attention is also given to the recent emphasis in the literature on the use of an integrated approach to evaluate impacts to the receiving waters and downstream areas.

5.1.2 PROCEDURE FOR TECHNOLOGY ASSESSMENT

5.1.2.1 Identification of Performance Goals

In assessing the literature, particular consideration was given to definitions of performance of BMPs and how they addressed the range of receiving water impacts identified. It is important to point out that the overarching performance goal of all the BMPs is to minimize the impact of construction site runoff on receiving waters and downstream areas.

Control strategies that have been identified for construction BMPs can be divided into three categories.

Strategy 1. Control Based on Design Standards—Control at this level is based on standard designs that may include such things as volume requirements for reservoirs, detention time, and trapping efficiency that do not directly limit an allowable discharge to receiving waters or limit a downstream impact.

Strategy 2. Control Based on Effluent Standards—Control at this level is based on limiting the quantity of one or more substances such as peak discharge, runoff volume, TSS, and settleable solids. This directly addresses effluent but does not directly address downstream impacts.

Strategy 3. Control Based on an Integrated Approach—Control at this level uses an integrated approach (Snodgrass et al., 1998), including biological, chemical, and physical criteria, to define BMP performance. A combination of water quality, biohabitat, and geomorphic criteria is used to evaluate whether a receiving stream meets the targeted goal of fishable and swimmable, or the extent of departure from this goal.

The majority of BMPs address Strategies 1 or 2. Although Strategy 3 is being discussed in the literature, it has not been adopted in practice. There is an analog in the surface mining industry, where a cumulative hydrologic impact analysis on a watershed basis is required by the U.S. Surface Mining and Reclamation Act of 1977 (PL95-87). When moving from Strategy 2 to Strategy 3, a number of other parameters are added to the performance criteria in Strategy 2, including (1) stream buffer retention and thermal impacts considerations, (2) volume control considerations such as these presented in the Low Impact Development concept approach, which are added to the peak discharge and ground water recharge criteria to achieve maintenance of hydrologic function at a site-specific level, and (3) geomorphic criteria as described by Lane (1955), Leopold et al. (1964), Rosgen (1996), and others.

An important point must be made about controlling sediment. From a practical standpoint, a reasonably sized structure should not necessarily be expected to meet an effluent TSS standard unless the TSS specified in the standard is set at a very high value or unless some form of chemical treatment is used to enhance flocculation. The settling velocity for primary clay particles is in the range of feet per month for all but the largest particles. Since these size particles are frequently encountered in large percentages in sediment from construction sites, the expected trapping efficiencies will not approach 100 percent, nor will the effluent TSS be in the range of 100 mg/L or lower (Haan et al., 1994).

5.1.2.2 Goals, Environmental Impact Areas, And Assessment Scales

For the purposes of this report, impact areas are divided into three categories: local area, receiving water, and downstream areas.

Local Area. This is the area between the construction site and the receiving stream. Typically, these areas have ephemeral streams with low baseflows and highly variable flow rates. In these areas, flows fluctuate widely, with geomorphology and habitat being very susceptible to changes in hydrologic regime (Klaine, 2000). In some developments, there would essentially be no local area, and flows would exit directly into receiving waters.

Receiving Waters. This is the point at which flows enter a well-defined stream. Depending on the local geology, flows may primarily be ephemeral, there may be a well-established baseflow, or there may be intermediate flow. The degree to which flows, sediment, and chemicals impact receiving waters depends largely on the type of receiving water. For example, if the receiving waters have a low baseflow and highly variable flow rates, the habitat and geomorphology will be very sensitive to significant changes in the hydrologic regime. However, if the receiving waters have a high baseflow, the sensitivity to changes in flow rate will be much less and the primary problems will likely be chemical in nature. Thus, it is important to address impacts on a site-specific basis.

Downstream Areas. A definition of the downstream area can be somewhat nebulous. (A definition of the aerial extent of "downstream areas" is something that needs to be developed in follow-up studies.) However, consideration of this area is important. For example, use of peak discharge criteria may directly control the local area impacts and impacts to the point at which flow enters the receiving waters. If the watershed being considered is combined with other downstream watersheds and all use peak discharge control without controlling runoff volume, there can be an increase in flooding due to superposition of long duration peak flows exiting the numerous reservoirs (Smiley and Haan, 1976). This increased discharge can negatively impact channel geomorphology, habitat, and riparian areas.

Another important issue related to construction is the fraction of the watershed under construction at any one time. One argument about the relative importance of the construction phase versus the post-construction phase is that the construction phase is short-lived and the impact may be reversible after the site has stabilized. While this argument may have some validity on the local

area, it is invalid when considering the downstream areas. On a larger watershed under development, major construction may occur in the watershed for a long time, with a potential long-term major cumulative impact. When considering the entire watershed, it may be desirable to limit the area under construction at any one time to prevent exceeding some threshold that would result in an irreversible impact. This indicates the need to conduct a cumulative impact analysis on a river basin scale to evaluate the potential for such an impact to occur.

When considering area impacts, the following comments can be made about the strategies listed above.

Strategy 1. No guarantees can be made that impacts would be controlled at any level unless the design standards are highly conservative. This would result in overdesign for most situations so that the standard would be adequate for all situations.

Strategy 2. This strategy should ensure control at the local level. Downstream, the impacts may be positive or negative as a result of the control. Examples include the control of peak discharge only in storm water runoff. Control of peak discharge on all construction areas at the local level can result in increased peak discharge downstream (Smiley and Haan, 1976). These increases result from detaining increased volumes of runoff resulting from urbanization and releasing them at the predisturbed peak rate over a long period of time.

Strategy 3. This approach should ensure control in both the local area and downstream areas.

Scale is very important to BMP effectiveness analyses. A given BMP may be quite effective in controlling impacts nearby but have a significant negative impact when applied over a large area. In the final analysis, effectiveness should be evaluated at multiple scales before a decision is made. This will require both local- and watershed-level analyses.

5.1.2.3 Qualitative Versus Quantitative Assessment

In the assessments, impacts may be addressed on a qualitative or a quantitative basis. The difference can be explained in the following manner, using water temperature as an example. It is well known that turbidity impacts the depth of penetration of solar energy into a waterbody; hence, turbidity impacts temperature. When evaluating the impact of standards on water temperature, it is obvious that a TSS standard directly addresses water temperature because of the impact of TSS on turbidity. Thus, a qualitative analysis would simply state that TSS standards may impact water temperature, but give no degree to which the standard does impact temperature. A quantitative analysis, however, would define the degree to which a given TSS standard increased or decreased the impact of TSS on temperature.

5.1.3 REVIEW OF HISTORICAL APPROACHES TO EROSION AND SEDIMENT CONTROL

Most early sediment control was related to agriculture and was installed as a way to maintain our natural resource base. On-site control was the primary emphasis, attempting to prevent erosion rather than trap sediment. Strategies were developed to minimize exposure of bare soil to the erosive power of rainfall and runoff, using aboveground cover management, residue management, strip cropping, and terracing to limit the length of overland flow. Impacts to receiving streams and downstream areas had not yet been identified as an issue. In the 1960s, concern began to be expressed about the quantities of sediment in streams and reservoirs, and sediment was first identified as a pollutant. Initially, the major focus of sediment control was on the surface mining industry, with the passage of the Clean Water Act and then the Surface Mining, Reclamation, and Control Act (SMRCA) (PL 95-87). The first approach taken to sediment control was a design standard, requiring a sediment detention basin with a 24-hour detention time; TSS standards of 35 mg/L average and 70 mg/L peak were also promulgated, but were not typically enforced. The U.S. Environmental Protection Agency (USEPA) later evaluated the TSS standard and moved to a settleable solids standard of 0.5 mL/L, based on a modeling effort that showed that it was not possible to trap fine sediments, but that a 0.5 mL/L settleable solids standard could be met with a reasonably sized sediment basin (Ettinger and Lichty, 1979).

In the late 1960s and early 1970s, sediment in streams and waterways originating from urban construction sites became an issue, which was then addressed in the Clean Water Act. EPA developed a list of BMPs and standards for their construction (USEPA, 1971). In general, these standards were adopted from those of other agencies and were not based on studies related to urban runoff.

In 1987, the Clean Water Act was amended to include storm water discharges from urban areas. The Phase I NPDES Storm Water regulations were published in 1990, requiring all municipalities with Municipal Separate Storm Sewer Systems (MS4) serving populations greater than 100,000, construction sites 5 acres and larger, and certain industrial sites to obtain a permit. The permit required the development of a storm water pollution prevention plan (SWPPP) that typically included a storm water and sediment control plan. In 1999, the Phase II NPDES storm water regulations were published, extending permit coverage to construction sites of 1 acre or larger and municipalities with populations greater than 50,000 (or populations greater than 10,000 where population density is more than 1,000 people per square mile). The regulations allow use of general permits in lieu of individual site or facility permits. The degree of oversight of construction varies widely among the states.

In the last two decades, increased concern at the local level has been focused on sediment pollution of streams and waterways, particularly originating from construction, while less concern has been focused on the impacts of increased construction on storm water and chemical production. Much of this government concern originated from the Phase I and Phase II NPDES storm water regulations. A number of states and their local agencies have developed standards and BMPs for sediment control, most of which do not have a scientific basis, but were adopted from other agencies. Some

states, however, did conduct studies that gave their standards some scientific basis. For example, Maryland evaluated its BMP standards in the 1980s by using modeling techniques, and the state changed its sediment basin standards to account for the impacts of surface area on the trapping efficiency in sediment ponds. Based on typical soils in the region and modeling studies, the state adopted a surface area to peak discharge ratio of 0.01 cubic feet per second (cfs) per acre as a criterion (Barfield and Clar, 1985; McBurnie et al., 1990). Maryland was thus the first state to use a design criterion that was related to the overflow rate. Other states also used some of Maryland's results (Smolen et al., 1988).

Recent efforts have moved closer to an effluent standard approach. South Carolina conducted a detailed analysis and published regulations that required a trapping efficiency or settleable solids standard (SCDHEC, 1995). In addition, results from a detailed model were used to develop simplified design aids (Hayes and Barfield, 1995; Holbrook et al., 1998). Some municipalities are following suit to develop scientifically based standards of their own. For example, in 1998 Louisville, Kentucky, (Hayes et al., 2001) developed standards and design aids for storm water and sediment control, following the example of South Carolina.

There are no analogous examples in which the integrated approach to storm water and sediment control have been used on construction sites. The closest analog is the Cumulative Hydrologic Impact Analysis (CHIA) required in surface mining by the SMRCA. SMRCA requires each applicant for a surface mining permit to conduct a hydrologic impact analysis. Subsequently, the regulatory authority is required to conduct a CHIA for the entire watershed. It should be pointed out that although a CHIA is required, it is seldom undertaken on a scale that is useful.

Many of the advances in sediment control have been based on the capability to predict, *a priori*, the ability of a given design to meet a standard. For example, when the settleable solids standard was developed for surface mining, most regulatory authorities adopted it with the requirement that permit applicants would demonstrate through the use of widely accepted computer models that the proposed design would meet the settleable solids standard.

Most of the early work in modeling sediment production stemmed from efforts in the 1950s to develop a soil loss equation that would apply to the entire nation and allow evaluation of alternative erosion control practices. This led to the relationship known as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965) and its subsequent derivative, the Revised USLE (RUSLE) (Renard et al., 1994). These efforts focus on erosion control; thus, the relationships do not predict sediment yield. A flurry of efforts in the late 1970s and early 1980s lead to the development of sediment yield relationships such as the Modified USLE (MUSLE) (Williams, No Date), the CREAMS model (Knisel, 1980), SEDCAD (Warner, 1998), and SEDIMOT II (Wilson et al., 1982) and its derivatives. The MUSLE and CREAMS models did not include methods to evaluate the impact of sediment trapping structures, but SEDIMOT II contained relationships developed at the University of Kentucky to predict the impact of reservoirs (Ward et al., 1977; Wilson and Barfield, 1984), check dams (Hirschi, 1981), and vegetative filter strips (Hayes et al., 1984). The MUSLE and , SEDCAD and SEDIMOT II models were based on single storms, while the CREAMS model

was based on continuous simulation modeling. Details on these models can be found in Haan et al. (1994).

More recently, modeling has improved, resulting in several new relationships. The WEPP watershed model is one example of a continuous simulation approach. It includes computational procedures for a wide variety of sediment control structures (Lindley et al., 1998). Another example of a single storm-based model is SEDIMOT III (Barfield et al., 1996), which modifies the earlier SEDIMOT II model to include channel erosion routines and a wide variety of sediment control techniques. A significant drawback in the SEDIMOT III and WEPP models is that they do not have a good technique for predicting the impact of filter fence, which is the most common technique used today for sediment control. The authors of SEDCAD have attempted to provide algorithms to represent (silt) filter fence removals, although work remains prior to global acceptance in the literature.

Concerns for changes in geomorphology resulting from flow alterations have resulted in several modeling approaches. Early efforts were focused on what is known as the regime theory, in which changes in channel property are linked, qualitatively, to changes in flow. Examples include models of Lane (1955) and Schumm (1977). In addition, some statistically based models were developed, but they are not universally applicable (Blench, 1970; Simons and Albertson, 1960). More recently, models have been developed using physically based concepts to predict changes in geomorphology as related to changes in flow. The models of Chang (1988) are good examples. It is possible to predict, to a limited extent, the change in channel properties as impacted by changes in flow.

The impact of changes in flow and geomorphology on habitat is one major area where information is lacking. Although this deficiency can be addressed in a qualitative manner, it is not possible to predict quantitatively how a given change in geomorphology will impact habitat. Additional information is needed to develop a strategy based on the integrated assessment approach.

5.1.4 GOALS, CONTROL STRATEGIES, CRITERIA, AND STANDARDS

5.1.4.1 Goals, Control Strategies, Criteria, And Standards: How They Relate

The relationship between goals, control strategies, criteria, and standards can sometimes be confusing. For the purpose of the discussion of construction BMPs, the following definitions will be used.

Goal. The overarching objective of having a storm water, sediment, and pollution control program is known as the goal. It is what the program is trying to achieve. All BMPs should relate to that goal. As stated earlier, the goal of this program is to minimize the impact of construction on receiving water and downstream areas. The impacts of concern are identified in the Environmental Assessment.

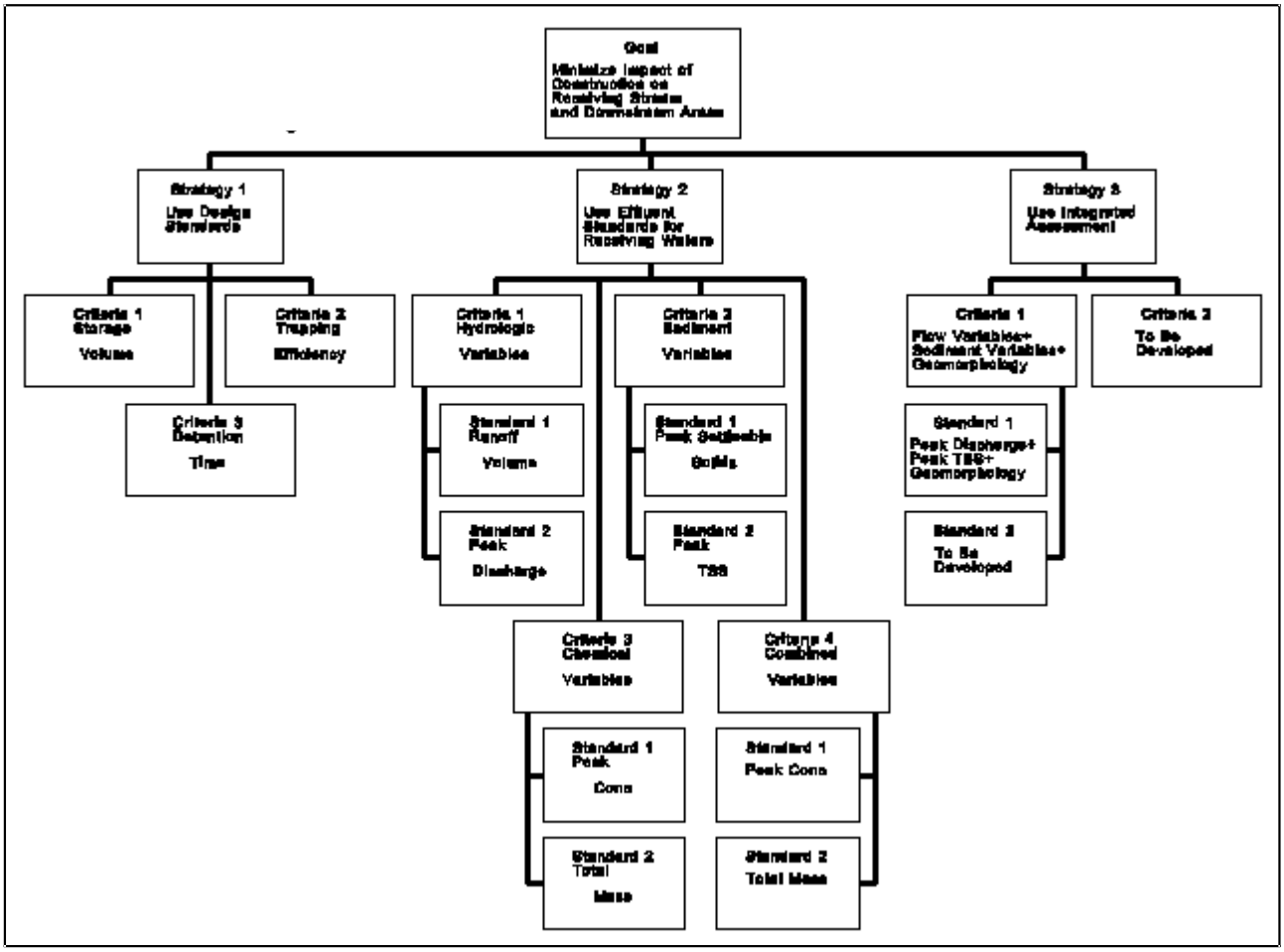
Control Strategies. The methods by which the regulatory agency tries to achieve the goal are called control strategies.

Criteria. The particular variables that are targeted by a given strategy are known as the criteria. For example, if the strategy is to control impacts by limiting the discharge of sediment to the receiving waters, then sediment becomes the criterion.

Standard. The specific variable chosen for the criteria and its numeric value is referred to as the standard. For example, if the control strategy is to limit sediment discharge to the receiving waters, the criterion is sediment, and the particular limiting variable and numeric value chosen is a peak settleable solids concentration of 0.5 mg/L, then the standard would be a peak settleable solids concentration of 0.5 mg/L.

The relationship among goals, control strategies, criteria, and standards is shown graphically in Figure 5-1.

Figure 5-1. Flow Diagram Showing Relationship Among Goals, Strategies, Criteria and Standards



5.1.4.2 Levels of Performance or "How Well Do The Strategies Work?"

Table 5-1 provides a description on the level of performance for the three strategies discussed in sub-section 5.2.1.

Table 5-1. Description of Levels of Performance of Three Control Strategies

Level	Description of Performance
0	No consideration of impact.
1	Performance defined by a design standard. No guarantee that the design will control the impact to a desired level on the specific watershed. Example: reservoir volume standard for runoff control.
2	Effluent standard based on controlling a single entity entering receiving waters. Control of the single parameter will not guarantee that the desired protection will occur for receiving waters or downstream impact. Example: controlling peak storm water discharge or peak TSS.
3	Effluent standard based on controlling two or more entities entering receiving waters, but not all entities causing environmental impact. Example: controlling peak discharge and sediment, but not storage volume or runoff volume.
4	Effluent standards for all entities entering receiving waters and causing environmental impact. Even controlling all quantities entering receiving waters will not guarantee that there are no undesired downstream impacts. Example: Controlling runoff rate, runoff volume, peak discharge, and TSS in receiving streams does not guarantee that there will be no undesirable biological impacts.
5	Control based on integrated evaluation of impacts on receiving stream and downstream.

5.1.4.3 Strategies, Criteria, Standards, And Enforcement

The effectiveness of a given strategy, criterion, or standard is directly related to the ability of an enforcement agency to enforce the rules. Thus, a given standard may theoretically provide excellent protection to the environment, but be so difficult to enforce that it is less effective than a less stringent standard that is enforceable. In general, the difficulty in enforcement increases as the level of desired performance increases. An estimate of relative difficulty in enforcement is given in Table 5-2 for the various levels of performance from Table 5-1. For example, it is easier to enforce the design standard, since enforcement is based entirely on reviewing plans and inspection of the site to ensure that the plans are put into action properly.

Important issues related to enforcement include the following:

- *A priori* demonstration by the best computational technology that the proposed design can meet the standard.
- As-built inspections to verify that the installed practices match the approved plan.
- Self-monitoring of effluent in the case of effluent standards, with spot checks by the regulatory authority to make sure that evaluations are being done properly.
- Evaluation of downstream impacts.
- Clearly defined rules for monitoring the effectiveness of a practice.

Table 5-2. Descriptions of Levels of Difficulty in Enforcement

Level of Performance from Table 5-1	Difficulty in Enforcing (Relative)	Description of Difficulty
0	0	Nothing to enforce.
1	1	Enforcement consists of reviewing plans and ensuring proper installation and maintenance.
2	2	Enforcement requires some monitoring and typically requires a preconstruction review of plans and submission of calculations showing that the standard can be met.
3	2.5	Same as above except multiple variables.
4	2.5	Same as above.
5	5	Enforcement requires some *a priori* demonstration of the expected flow and concentration changes and their impact on receiving waters and downstream variables. In addition, routine monitoring of downstream variables such as geomorphology, aquatic life, aesthetics, and riparian zones would be required.

***A Priori* Demonstration of Performance.** *A priori* demonstration that a given design can meet the standard is very important. Experience with the surface mining industry indicates that a sediment control plan is no better than its design. In other words, if the best computational technology indicates that the design will not meet the standard, then field monitoring of the BMP is not likely to show that the standards are being achieved. Thus, it will be important to have scientifically based and verified computational technologies to predict the performance of BMPs relative to meeting a specified standard.

In recognition of this need EPA funded the development of the National Stormwater BMP Database project by the Urban Water Resources Research Council of the American Society of Civil Engineers (ASCE, 1999) to establish the state of the art of BMP performance with respect to pollutant removal and peak discharge control (Level of performance 3, see Table 5-1). The database can be found at: http://www.bmpdatabase.org/. The ASCE project team prepared a report that contains several different methods for evaluating BMP efficiency data. This report presents statistically based approaches that involve conducting a statistical analysis to characterize inflow and outflow event mean concentrations (EMCs), and then evaluates whether or not there is a statistically significant difference between the two. The application of this approach in evaluating the data contained in the database has led the study team to conclude that evaluating effluent quality is a good indicator of performance of BMPs with respect to pollutant removal. Although the database currently is designed to address only permanent stormwater management practices, the methodologies could easily be adapted to the evaluation of erosion and sediment controls.

As-built Inspections. Another important issue related to enforcement is as-built inspections of installed practices. Although the rules may call for certification by an appropriately licensed professional, it is important that the regulatory authority conduct routine inspections to ensure that the licensed professionals are doing their job properly.

Monitoring. Finally, there are issues related to self-monitoring versus monitoring conducted by the regulatory authority. The use of effluent standards would require some type of monitoring to ensure that performance meets the standards. However, storm water and sediment control structures that control flows are highly variable and temporally stochastic. This means that it is not possible to plan ahead when the monitoring will occur. It will be necessary to have trained professionals to conduct the monitoring.

A monitoring methodology for BMPs should meet three criteria: (1) provide scientifically based numbers to evaluate effectiveness, (2) be executable and sufficiently simple to allow the use of trained technicians who would reasonably be available to do the monitoring, and (3) be adequate to ensure that the desired standards are met without excessive sampling or analysis. The first criterion could be met by providing clear documentation on the monitoring methodology that specifies times, frequency, and location of sampling relative to storms, as well as clearly articulated protocols for handling samples. The second criteria can be met by being sure that the techniques proposed have actually been field-applied by technicians in the monitoring business. The third criterion can be evaluated by an error analysis that determines the expected accuracy of measurement as a function of number and frequency of sampling.

Several possible criteria or standards have special measurement problems that should be mentioned. These include criteria or standards based on trapping efficiency, and/or effluent TSS and settleable solids (average or peak). The issues associated with these criteria are discussed below.

Trapping Efficiency. Literature citations frequently include studies that attempt to measure trapping efficiency by sampling one or more inflow and outflow concentrations (Barrett et al.,

1995). While this simplicity seems attractive, it is a grossly erroneous measure of trapping efficiency. A correct definition of trapping efficiency is given in Equation 1:

Equation 1: $$TE = (M_i - M_o) / M_i$$

where: M_i is inflow total mass
M_o is outflow total mass
M_i is given by integrating the product of inflow concentration and inflow rate over the duration of a hydrograph

or

Equation 2: $$M_i = \int_0^{t_D} C_i \, q_i \, dt$$

where: C_i is inflow concentration
q_i is inflow flow rate
t is time
t_D is the duration of the storm

Outflow total mass M_o is calculated by substituting the subscript o for i in Equation 2. Thus, to monitor trapping efficiency correctly, it is necessary to measure both flow and concentration as a function of time over the duration of both inflow and outflow. Such measurement is quite difficult and time-consuming, requiring many samples.

Statistical Evaluation of Inflow/Outflow Data (mean, median, standard deviation, coefficient of variance). To measure average or peak TSS, it is necessary to measure TSS in the effluent over the duration of the outflow hydrograph as well as the flow rate. This requires that multiple samples be taken and that the samples be centered around the peak discharge. The ACSE database data analysis document has the ability, depending upon the number of samples collected, to show a difference between various samples. Again, this is time-consuming and difficult since the timing of an event and the timing of the peak discharge are not known *a priori*. The average concentration is a weighted concentration, using flow rate as a weighting function.

5.1.5 CONTROL TECHNIQUES, BMP SYSTEMS

5.1.5.1 Erosion Control and Prevention

5.1.5.1.1 Planning, Staging, Scheduling

General Description

A construction sequence schedule is a specified work schedule that coordinates the timing of land-disturbing activities and the installation of erosion and sediment control measures. The goal of a construction sequence schedule is to reduce on-site erosion and off-site sedimentation by performing land-disturbing activities and installing erosion and sediment control practices in accordance with a planned schedule (Smolen et al., 1988).

Construction site phasing involves disturbing only part of a site at a time to prevent erosion from dormant parts (Claytor, 1997). Grading activities and construction are completed and soils are effectively stabilized on one part of the site before grading and construction commence at another part. This differs from the more traditional practice of construction site sequencing, in which construction occurs at only one part of the site at the time, but site grading and other site-disturbing activities typically occur simultaneously, leaving portions of the disturbed site vulnerable to erosion. Construction site phasing must be incorporated into the overall site plan early on. Elements to consider when phasing construction activities include the following (Claytor, 1997):

- Managing runoff separately in each phase.
- Determining whether water and sewer connections and extensions can be accommodated.
- Determining the fate of already completed downhill phases.
- Providing separate construction and residential accesses to prevent conflicts between residents living in completed stages of the site and construction equipment working on later stages (USEPA, 2000).

Applicability

Construction sequencing can be used to plan earthwork and erosion and sediment control activities at sites where land disturbances might affect water quality in a receiving waterbody.

Design and Installation Criteria

Construction sequencing schedules should, at a minimum, include the following (NCDNR, 1988; MDE, 1994):

- The erosion and sediment control practices that are to be installed

- The principal development activities
- The measures that should be installed before other activities are started
- The compatibility with the general contract construction schedule

Table 5-3 summarizes other important scheduling considerations in addition to those listed above.

Table 5-3. Scheduling Considerations for Construction Activities

Construction Activity	Schedule Consideration
Construction survey stakeout	Prior to initiating any construction activity a construction survey stakeout should be conducted. The stakeout should identify the limits of disturbance and location of control structures, especially perimeter controls.
Pre-construction meeting between owner, contractor, and regulatory agency	This meeting should take place before any construction activity begins at the site. The survey stakeout is reviewed, especially the limits of disturbance and location of controls.
Construction access—entrance to site, construction routes, areas designated for equipment parking	This is the first land-disturbing activity. As soon as construction takes place, any bare areas should be stabilized with gravel and temporary vegetation.
Clearing and grading required for the installation of controls	In conjunction with the construction access, the clearing and grading required for the installation of E&S controls should take place.
Sediment traps and barriers—basin traps, silt fences, outlet protection	After the construction site has been accessed, principal basins should be installed, with the addition of more traps and barriers as needed during grading.
Runoff control—diversions, perimeter dikes, water bars, outlet protection	Install key practices after the installation of principal sediment traps and before land grading. Additional runoff control measures may be installed during grading.
Runoff conveyance system—stabilize streambanks, storm drains, channels, inlet and outlet protection, slope drains	If necessary, stabilize streambanks as soon as possible, and install the principal runoff conveyance system with runoff control measures. The remainder of the systems may be installed after grading.
Land clearing and grading—site preparation (cutting, filling, and grading; sediment traps; barriers; diversions; drains; surface roughening)	Implement major clearing and grading after installation of principal sediment and key runoff control measures, and install additional control measures as grading continues. Clear borrow and disposal areas as needed, and mark trees and buffer areas for preservation.
Surface stabilization—temporary and permanent seeding, mulching, sodding, riprap	Immediately apply temporary or permanent stabilizing measures to any disturbed areas where work has been either completed or delayed.
Building construction—buildings, utilities, paving	During construction, install any erosion and sediment control measures that are needed.
Landscaping and final stabilization—adding topsoil, trees, and shrubs; permanent seeding; mulching; sodding; riprap	This is the last construction phase. Stabilize all open areas, including borrow and spoil areas, and remove and stabilize all temporary control measures.

Effectiveness

Construction sequencing can be an effective tool for erosion and sediment control because it ensures that management practices are installed where necessary and when appropriate. A comparison of sediment loss from a typical development and from a comparable phased project showed a 42 percent reduction in sediment export in the phased project (Claytor, 1997).

Limitations

Weather and other unpredictable variables may affect construction sequence schedules. The proposed schedule and a protocol for making changes resulting from unforseen problems should be plainly stated in an applicable erosion and sediment control plan.

Maintenance

The construction sequence should be followed throughout the project, and the written erosion and sediment control plan should be modified before any changes in construction activities are executed. The plan can be updated if a site inspection indicates the need for additional erosion and sediment control as determined by contractors, engineers, or developers.

Cost

Construction sequencing is a low-cost BMP because it requires a limited amount of a contractor's time to provide a written plan for the coordination of construction activities and management practices. Additional time might be needed to update the sequencing plan if the current plan is not providing sufficient erosion and sediment control.

Although little research has been done to assess the costs of phasing versus conventional construction costs, it is known that it will be to implement successful phasing for a larger project (Claytor, 1997).

5.1.5.1.2 Vegetative Stabilization

Vegetation can be used during construction to stabilize and protect soil exposed to the erosive forces of water, as well as post-construction to provide a filtration mechanism for storm water pollutants. The following discussion refers to vegetative stabilization as a construction BMP that stabilizes and protects soil from erosion.

General Description

Vegetative stabilization measures employ plant material to protect soil exposed to the erosive forces of water and wind. Selected vegetation can reduce erosion by more than 90 percent (Fifield, 1999). Natural plant communities that are adapted to the site provide a self-maintaining cover that is less

expensive than structural alternatives. Plants provide erosion protection to vulnerable surfaces by the following (Heyer, No Date):

- Protecting soil surface from the impact of raindrops.
- Holding soil particles in place.
- Maintaining the soil's capacity to absorb water.
- Using living root systems to hold soil in place, increasing overall bank stability.
- Directing flow velocity away from the streambank.
- Acting as a buffer against abrasive transported materials.
- Causing sediment deposition, which reduces sediment load and reestablishes the streambank.

The designer should be aware of and respond to local conditions that may influence the development of vegetative stabilization measures. As with any planting design, climate, maintenance practices, the availability of plant material (including native species), and many other factors will influence such considerations as plant or seed mix selection, installation methods, and project scheduling.

Slope Stabilization. On slopes, the goal of vegetative stabilization is not only to reduce surface erosion but also to prevent slope failure. Vegetation should provide dense coverage to protect soils from the direct impact of precipitation and help intercept runoff. A variety of plants should be used to provide root systems that are distributed throughout all levels of the soil, increasing slope shear strength and giving plants a greater ability to remove soil moisture. Uniform mats of shallow rooting plants should be avoided because, while such plants may increase runoff infiltration, they cannot remove soil moisture beyond the surface level, leaving slopes potentially saturated and prone to slippage. Shallow, interlocking root systems may also increase the size of a soil slippage by holding together and pulling down a larger area of slope after a small section has given way. Large trees that have become unstable may also pull down slopes and should be removed. Using plants with low water requirements can reduce the potential for soil saturation from irrigation.

Swale Stabilization. On swales, the goal of vegetative stabilization is to prevent erosion within the swale, where runoff is concentrated and flows at higher velocities. If natural stream channels are involved, vegetation with deep root systems should be preserved, or if absent, planted above the channel to help maintain the channel banks. More information is provided in the subsequent section dealing with grass-lined swales.

Surface Stabilization. On large, flat areas, the goal of vegetative stabilization is to reduce the loss of surface soil from sheet erosion. Vegetation should provide complete coverage to reduce the force of precipitation, which can shift soil particles to seal openings in the soil, reducing infiltration and

increasing runoff. Vegetation should also provide many stem penetrations to slow runoff and increase infiltration. Deep rooting plants are less critical for erosion control in flat areas than on slopes because soils are not subject to the same forces that may cause slippage on a slope. However, trees and shrubs can increase infiltration, lessening the buildup of runoff, and transpire large volumes of water, reducing soil saturation.

In areas susceptible to wind erosion, the goal of vegetative stabilization is to establish direct protection of the soil. Vegetation should provide dense and continuous surface cover. Binding the soil deeply is generally not a requirement. The ideal vegetation for this purpose is grass, which forms a mat of protection. In areas where the vegetation is developed, the grass generally has high maintenance requirements. In less developed, open areas, unmown grass, including perennial native species, can be used to provide protection. Trees and shrubs also can provide protection from the wind.

Shoreline Stabilization. In lakes and ponds, the goal of vegetative stabilization is to prevent erosion of the shoreline. Wetland plants anchor the bottom of the lake or pond adjacent to the shore and help dissipate the erosive energy of waves. An important consideration in planting along shorelines is the need to establish favorable conditions for plant establishment and growth. These include the proper grading of side slopes and the control of upland erosion to prevent the buildup of silt and associated pollutants in the water. Designers should maintain awareness of regulatory requirements that may influence vegetation projects in a wetland environment (USAF, 1998).

Vegetation used for shoreline stabilization work should be native material selected on the basis of strength, resiliency, vigor, and ability to withstand periodic inundation. Woody vegetation with short, dense, flexible tops and large root systems works well. Other important factors include rapid initial growth, ability to reproduce, and resistance to disease and insects.

According to Heyer (No Date), most streambank stabilization plantings have used various willows, including black willow (*Salix nigra*), sandbar willow (*S. interior*), meadow willow (*S. petiolaris*), heartleaf willow (*S. rigida*), and Ward willow (*S. caroliniana*). The size used depends on the severity of the erosion and the type of bank to be stabilized. Whatever the size, it is important to use dormant cuttings and to remove all lateral branches. Most tree revetment projects used either eastern red cedar (*Juniperus virginiana*) or hardwoods such as northern pin oak (*Quercus ellipsoidalis*). Important suggestions include the following:

- Choose trees with many limbs and branches to trap as much sediment as possible.
- Select decay-resistant trees.
- Use recently cut trees—dead trees are more brittle and likely to break apart.
- The tree size-diameter of the tree crown should be about two-thirds of the height of the eroding bank.

- Cut off any trunk without limbs.
- Place the tree revetments overlapping, butt end pointing upstream.
- Begin and end revetments at stable points along the bank.
- Choose an anchoring system according to the bank material to be stabilized and the weight of the object to be anchored.

Vegetative measures for streambank stabilization offer an alternative to structural measures and are becoming well known as bioengineering techniques for streambanks. Utilizing vegetative material for streambank stabilization could be the first step in the reestablishment of the riparian forest, which is essential for long-term stability of the streamside and floodplain areas. Each site must be evaluated separately as to the feasibility of using natural material (Heyer, No Date).

Vegetative streambank stabilization, with the goal to protect streambanks from the erosive forces of flowing water, is generally applicable where bankfull flow velocity does not exceed 6 ft/sec and soils are erosion resistant (Smolen, 1988). Table 5-4 includes general guidelines for maximum allowable velocities in streams to be protected by vegetation.

Table 5-4. Conditions Where Vegetative Streambank Stabilization Is Acceptable

Frequency of Bankfull Flow	Maximum Allowable Velocity for Highly Erodible Soil	Maximum Allowable Velocity for Erosion-Resistant Soil
> 4 times/yr	4 ft/sec	5 ft/sec
1 to 4 times/yr	5 ft/sec	6 ft/sec
< 1 time/yr	6 ft/sec	6 ft/sec

Source: Smolen, 1988.

Temporary Vegetative Stabilization. Temporary vegetative cover such as rapidly growing annuals and legumes can be used to establish a temporary vegetative cover. Such covers are recommended for areas that (Fifield, 1999):

- Will not be brought to final grade within 30 days or are likely to be redisturbed.
- Require seeding of cut and fill slopes under construction.
- Require stabilization of soil storage areas and stockpiles.
- Require stabilization of temporary dikes, dams, and sediment containment systems.
- Require development of cover or nursery crops to assist with establishing perennial grasses.

Examples of temporary vegetation include wheat, oats, barley, millet, and sudan grass. Temporary seeding may not be effective in arid or semi-arid regions where seasonal lack of moisture prevents

germination. It may be necessary to use a mixture of warm and cool season grasses to ensure germination. Mulching and geotextiles can be used to help provide temporary stabilization with vegetation, particularly in situations where establishing cover may be difficult.

Permanent Vegetative Stabilization. Permanent vegetative cover such as a perennial grass or a legume cover can be used to establish a permanent vegetative cover. Permanent vegetation is recommended for (Fifield, 1999):

- Final graded or cleared areas where permanent vegetative cover is needed to stabilize the soil
- Slopes designated to be treated with erosion control blankets
- Grass-lined channels or waterways designed to be protected with channel liners

The following sub-sections discuss the various types or means of providing vegetative stabilization.

5.1.5.1.2.1 Grass-lined Channels

General Description

Grass-lined channels, or swales, convey storm water runoff through a stable conduit. Vegetation lining the channel reduces the flow velocity of concentrated runoff. Grassed channels are usually not designed to control peak runoff loads by themselves and are often used in combination with other BMPs such as subsurface drains and riprap stabilization.

Applicability

Grassed channels should be used in areas where erosion-resistant conveyances are needed, such as in areas with highly erodible soils and slopes of less than 5 percent. They should be installed only where space is available for a relatively large cross-section. Grassed channels have a limited ability to control runoff from large storms and should not be used in areas where velocity exceeds 5 feet per second unless they are on erosion-resistant soils with dense groundcover at the soil surface.

Design and Installation Criteria

Because of their ease of construction and low cost, vegetation-lined waterways are frequently used for diversion and collection ditches. USDA's Soil Conservation Service's (SCS) *Engineering Field Manual* (1979) recommends the maximum permissible velocities for individual site conditions shown in Table 5-5.

Table 5-5. Maximum Permissible Velocities for Individual Site Conditions for Grass Swales

Site Location	Velocity
Areas where only a sparse cover can be established or maintained because of shale, soils, or climate	3.00 ft/sec (0.91 m/sec)
If the vegetation is to be established by seeding	3.00 to 4.00 ft/sec (0.91 to 1.22 m/sec)
Areas where a dense, vigorous sod is obtained quickly or where the runoff can be diverted out of the waterway while the vegetation is being established	4.00 to 5.00 ft/sec (1.22 to 1.52 m/sec)

Source: USDA, 1979

Grassed waterways typically begin eroding in the invert of the channel if the velocity exceeds the sheer strength of the vegetation soil interface. Once the erosion process has started, it will continue until an erosion-resistant layer is encountered. If erosion of a channel bottom is occurring, rock or stone should be placed in the eroded area or the design should be changed (UNEP, 1994).

Grassed waterways on construction land must be able to carry peak runoff events from snowmelt and rainstorms (in some areas limited to up to 1 cubic meter of water per second). The size of the waterway depends on the size of the area to be drained. A typical grassed waterway cross-section is parabolic with a nearly flat-bottom, a bottom width of 3 m, and channel depth of at least 30 cm. Side slopes usually rise about 1 m for every 10 m horizontal distance but may be as steep as a 1 m rise for every 2 m of horizontal distance. The waterway should follow the natural drainage path if possible (Vanderwel and Abday, 1998). The design should be site-specific and be derived using well-established procedures.

Lined channels are a means of carrying water to lower elevations along steep parts of a waterway. Those portions of the waterway are precisely shaped and carefully lined with heavy-duty erosion control matting (a geotextile product). The lining is covered with a layer of soil and seeded to grass. The resulting channel is highly resistant to erosion. Lined channels are appropriate for waterways that only carry water occasionally and have slopes of up to 10 percent. Companies that sell geotextile products provide detailed information on installation of their products (Vanderwel and Abday, 1998). The design should be site-specific and be derived using well-established procedures. No standard procedure is available for evaluating the effectiveness of geotextile liners for pollutant removal.

Grass-lined channels should be sited in accordance with the natural drainage system and should not cross ridges. The channel design should not have sharp curves or significant changes in slope. The channel should not receive direct sedimentation from disturbed areas and should be sited only on the perimeter of a construction site to convey relatively clean storm water runoff. They should be separated from disturbed areas by a vegetated buffer or other BMP to reduce sediment loads.

Although exact design criteria should be based on local conditions, basic design recommendations for grassed channels include the following:

- Construction and vegetation of the channel should occur before grading and paving activities begin.
- Design velocities should be less than 5 ft/sec.
- Geotextiles can be used to stabilize vegetation until it is fully established.
- Covering the bare soil with sod or geotextiles can provide reinforced storm water conveyance immediately.
- Triangular-shaped channels should be used with low velocities and small quantities of runoff; parabolic grass channels are used for larger flows and where space is available; trapezoidal channels are used with large flows of low velocity (low gradient).
- Outlet stabilization structures might be needed if the runoff volume or velocity has the potential to exceed the capacity of the receiving area.
- Channels should be designed to convey runoff from a 10-year storm without erosion.
- The sides of the channel should be sloped less than 3:1, with V-shaped channels along roads sloped 6:1 or less for safety.
- All trees, bushes, stumps, and other debris should be removed during construction.

Effectiveness

Grass-lined channels can effectively transport storm water from construction areas if they are designed for expected flow volumes and velocities and if they do not receive sediment directly from disturbed areas. The primary function is to carry the flow at a higher velocity without eroding or overtopping the channel.

Limitations

Grassed channels, if improperly installed, can alter the natural flow of surface water and have adverse impacts on downstream waters. Additionally, if the design capacity is exceeded by a large storm event, the vegetation might not be sufficient to prevent erosion and the channel might be destroyed. Clogging with sediment and debris reduces the effectiveness of grass-lined channels for storm water conveyance.

Maintenance

Maintenance requirements for grass channels are relatively minimal. During the vegetation establishment period, the channels should be inspected after every rainfall. Other maintenance activities that should be carried out after vegetation is established are mowing, litter removal, and spot vegetation replacement. The most important objective in the maintenance of grassed channels is the maintaining of a dense and vigorous growth of turf. Periodic cleaning of vegetation and soil buildup in curb cuts is required so that water flow into the channel is unobstructed. During the growing season, channel grass should be cut no shorter than the level of design flow, and the cuttings should be removed promptly.

Cost

Costs of grassed channels range according to depth, with a 1.5-foot-deep, 10-foot-wide grassed channel estimated to cost between $6,395 and $17,075 per trench, while a 3.0-foot-deep, 21-foot-wide grassed channel is estimated at $12,909 to $33,404 per trench (SWRPC, 1991).

As an alternative cost approximation, grassed channel construction costs can be developed using unit cost values. Shallow trenching (1 to 4 feet deep) with a backhoe in areas not requiring dewatering can be performed for $4 to $5 per cubic yard of removed material (R. S. Means, 2000). Assuming no disposal costs (i.e., excavated material is placed on either side of the trench), only the cost of fine grading, soil treatment, and grassing (approximately $2 per square yard of earth surface area) should be added to the trenching cost to approximate the total construction cost. Site-specific hydrologic analysis of the construction site is necessary to estimate the channel conveyance requirement, however, it is not unusual to have flows on the order of 2 to 4 cfs per acre served. For channel velocities between 1 and 3 feet per second, the resulting range in the channel cross-section area can be as low as 0.67 square foot per acre drained to as high as 4 square feet per acre. If the average channel flow depth is 1 foot, then the low estimate for grassed channel installation is $0.27 per square foot of channel bottom per acre served per foot of channel length. The high estimate is $1.63 per square foot of channel bottom per acre served per foot of channel length.

5.1.5.1.2.2 Seeding

General Description

Permanent seeding, is used to control runoff and erosion on disturbed areas by establishing perennial vegetative cover from seed. It is used to reduce erosion, decrease sediment yields from disturbed areas, and provide permanent stabilization. This practice is both economical and adaptable to different site conditions, and it allows selection of the most appropriate plant materials. Seeding is a best management practice that is particularly susceptible to local conditions such as the climatic conditions, physical and chemical characteristics of the soil, topography, and time of year.

Applicability

Permanent seeding is well-suited in areas where permanent, long-lived vegetative cover is the most practical or most effective method of stabilizing the soil. Permanent seeding can be used on roughly graded areas that will not be regraded for at least a year. Vegetation controls erosion by protecting bare soil surfaces from displacement by raindrop impacts and by reducing the velocity and quantity of overland flow. The advantages of seeding over other means of establishing plants include lower initial costs and labor inputs.

Design and Installation Criteria

Areas to be stabilized with permanent vegetation must be seeded or planted 1 to 4 months after the final grade is achieved unless temporary stabilization measures are in place. Successful plant establishment can be maximized with proper planning; consideration of soil characteristics; selection of plant materials that are suitable for the site; adequate seedbed preparation, liming, and fertilization; timely planting; and regular maintenance. Climate, soils, and topography are major factors that dictate the suitability of plants for a particular site. The soil on a disturbed site might require amendments to provide sufficient nutrients for seed germination and seedling growth. The surface soil must be loose enough for water infiltration and root penetration. Soil pH should be between 6.0 and 6.5 and can be increased with liming if soils are too acidic. Seeds can be protected with mulch to retain moisture, regulate soil temperatures, and prevent erosion during seedling establishment.

Seedbed preparation is critical in established vegetation. Spraying seeds on a scraped slope will generally not provide satisfactory results. Typical seedbed preparation will begin with a soil test to determine the amount of lime or fertilizer that should be added. In addition, tillage should be performed that will break up clods so that seed contact can be established. When the seed is applied, it should be covered and lightly compacted. A natural or synthetic mulch is recommended to provide surface stabilization until the vegetation is established. In addition to providing surface stabilization, the mulch will also retard evaporation and encourage rapid growth. A suitable tack to hold the mulch may be necessary if the mulch is not otherwise anchored. Mulch as an erosion control practice is covered in a subsequent sub-section.

Depending on the amount of use permanently seeded areas receive, they can be considered high- or low-maintenance areas. High-maintenance areas are mowed frequently, limed and fertilized regularly, and either (1) receive intense use (for example, athletic fields) or (2) require maintenance to an aesthetic standard (for example, home lawns). Grasses used for high-maintenance areas are long-lived perennials that form a tight sod and are fine-leaved. High-maintenance vegetative cover is used for homes, industrial parks, schools, churches, and recreational areas.

Low-maintenance areas are mowed infrequently or not at all and do not receive lime or fertilizer on a regular basis. Plants must be able to persist with minimal maintenance over long periods of time. Grass and legume mixtures are favored for these sites because legumes fix nitrogen from the

atmosphere. Sites suitable for low-maintenance vegetation include steep slopes, streambanks or channel banks, some commercial properties, and "utility" turf areas such as road banks.

Effectiveness

Seeding that results in a successful stand of grass has been shown to remove between 50 and 100 percent of total suspended solids from storm water runoff, with an average removal of 90 percent (USEPA, 1993).

Limitations

The effectiveness of permanent seeding can be limited because of the high erosion potential during establishment, the need to reseed areas that fail to establish, limited seeding times depending on the season, and the need for stable soil temperature and soil moisture content during germination and early growth. Permanent seeding does not immediately stabilize soils—temporary erosion and sediment control measures should be in place to prevent off-site transport of pollutants from disturbed areas. Use of mulches and/or geotextiles may improve the likelihood of successfully establishing vegetation.

Maintenance

Grasses should emerge within 4 to 28 days and legumes within 5 to 28 days after seeding. A successful stand should exhibit the following:

- Vigorous dark green or bluish green seedlings—not yellow
- Uniform density, with nurse plants, legumes, and grasses well intermixed
- Green leaves—perennials remaining throughout the summer, at least at the plant bases

Seeded areas should be inspected for failure, and necessary repairs and reseeding should be made as soon as possible. If a stand has inadequate cover, the choice of plant materials and quantities of lime and fertilizer should be reevaluated. Depending on the condition of the stand, areas can be repaired by overseeding or reseeding after complete seedbed preparation. If the timing is bad, an annual grass seed can be overseeded to temporarily thicken the stand until a suitable time for seeding perennials. Consider seeding temporary, annual species if the season is not appropriate for permanent seeding. If vegetation fails to grow, the soil should be tested to determine whether low pH or nutrient imbalances are responsible. Local NRCS or county extension agents can also be contacted for seeding and soil testing recommendations.

On a typical disturbed site, full plant establishment usually requires refertilization in the second growing season. Soil tests should be used to determine whether more fertilizer needs to be added. Do not fertilize cool season grasses in late May through July. Grass that looks yellow may be

nitrogen deficient. Nitrogen fertilizer should not be used if the stand contains more than 20 percent legumes.

Cost

Seeding costs range from $200 to $1,000 per acre and average $400 per acre. Maintenance costs range from 15 to 25 percent of initial costs and average 20 percent (USEPA, 1993). R. S. Means (2000) indicates the cost of mechanical seeding to be approximately $900 per acre, and demonstrates that the coverage cost varies with the seed type, seeding approach and scale (total acreage to be seeded). For example, hydro or water-based seeding for grass is estimated to be $700 per acre, but seeding of "field" grass species is only $540 per acre (Costs include materials, labor, and equipment, with profit and overhead). If surface preparation is required, then the installation costs increase. R. S. Means suggests the cost of fine grading, soil treatment, and grassing is approximately $2 per square yard.

5.1.5.1.2.3 Sodding

General Description

Sodding is a permanent erosion control practice that involves laying a continuous cover of grass sod on exposed soils. In addition to stabilizing soils, sodding can reduce the velocity of storm water runoff. Sodding can provide immediate vegetative cover for critical areas and stabilize areas that cannot be vegetated by seed. It can also stabilize channels or swales that convey concentrated flows and reduce flow velocities. While sodding is not as dependent as seeding on local conditions, it does depend on soil and climatic conditions to be successful. Watering immediately after installation and occasionally until establishment is generally beneficial.

Applicability

Sodding is appropriate for any graded or cleared area that might erode, requiring immediate vegetative cover. Locations particularly well-suited to sod stabilization are:

- Waterways and channels carrying intermittent flow
- Areas around drop inlets that require stabilization
- Residential or commercial lawns and golf courses where prompt use and aesthetics are important
- Steeply sloped areas

Design and Installation Criteria

Sodding eliminates the need for seeding and mulching and produces more reliable results with less maintenance. Sod can be laid during times of the year when seeded grasses can fail. The sod must be watered frequently within the first few weeks of installation. Some seedbed preparation is recommended, including smoothing to provide contact between the sod and the soil surface and soil testing to determine liming and fertilizer application rates. Since sod provides instantaneous cover, mulches are not typically recommended, but anchoring may be appropriate on steep slopes.

The type of sod selected should be composed of plants adapted to site conditions. Sod composition should reflect environmental conditions as well as the function of the area where the sod will be laid. The sod should be of known genetic origin and be free of noxious weeds, diseases, and insects. The sod should be machine cut at a uniform soil thickness of 15 to 25 mm at the time of establishment (this does not include top growth or thatch). Soil preparation and addition of lime and fertilizer may be needed—soils should be tested to determine whether amendments are needed. Sod should be laid in strips perpendicular to the direction of water flow and staggered in a brick-like pattern. The corners and middle of each strip should be stapled firmly. Jute or plastic netting may be pegged over the sod for further protection against washout during establishment.

Areas to be sodded should be cleared of trash, debris, roots, branches, stones, and clods larger than 2 inches in diameter. Sod should be harvested, delivered, and installed within a period of 36 hours. Sod not transplanted within this period should be inspected and approved prior to its installation.

Limitations

Compared to seed, sod is more expensive and more difficult to obtain, transport, and store. Care must be taken to prepare the soil and provide adequate moisture before, during, and after installation to ensure successful establishment. If sod is laid on poorly prepared soil or unsuitable surface, the grass will die quickly because it is unable to root. Sod that is not adequately irrigated after installation may cause root dieback because grass does not root rapidly and is subject to drying.

Effectiveness

Sod has been shown to remove between 98 and 99 percent of total suspended solids in runoff (USEPA, 1993). It is therefore a highly effective management practice for erosion and sediment control.

Maintenance

Watering is very important to maintain adequate moisture in the root zone and to prevent dormancy, especially within the first few weeks of installation, until it is fully rooted. Mowing should not result in the removal of more than one-third of the shoot. Grass height should be maintained to be 2–3 inches long. After the first growing season, sod might require fertilization or liming.

Permanent, fine turf areas require yearly fertilization. Warm-season grass should be fertilized in late spring to early summer, and cool-season grass in late winter and again in early fall.

Cost

Average installation costs of sod average $0.20 per square foot and range from $0.10 to $1.10 per square foot; maintenance costs are approximately 5 percent of installation costs (USEPA, 1993). R. S. Means (2000) indicates the sodding ranges between $250 and $750 per 1000 square feet for 1" deep bluegrass sod on level ground, depending on the size of the area treated (unit costs value are for orders over 8,000 square feet and less than 1000 square feet, respectively). Bent grass sod values range between $350 and $500 per 1,000 square feet; again the lower value is more likely for most construction sites because it is for large area applications. (Costs include materials, labor, and equipment, with profit and overhead).

5.1.5.1.2.4 Mulching

General Description

Mulching is a temporary erosion control practice in which materials such as grass, hay, wood chips, wood fibers, straw, or gravel are placed on exposed or recently planted soil surfaces. Mulching is highly recommended as a stabilization method and is most effective when anchored in place until vegetation is well established. In addition to stabilizing soils, mulching can reduce the velocity of storm water runoff. When used in combination with seeding or planting, mulching can aid plant growth by holding seeds, fertilizers, and topsoil in place; by preventing birds from eating seeds; by retaining moisture; and by insulating plant roots against extreme temperatures.

Mulch mattings are materials such as jute or other wood fibers that are formed into sheets and are more stable than loose mulch. They can also be easily unrolled during the installation process and are particularly useful in steeper areas or in channels. Netting can be used to stabilize soils while plants are growing, although netting does not retain moisture or insulate against extreme temperatures. Mulch binders consist of asphalt or synthetic materials that are sometimes used instead of netting to bind loose mulches, but these have been found to have limited usefulness.

Applicability

Mulching is often used in areas where temporary seeding cannot be used because of environmental constraints. Mulching can provide immediate, effective, and inexpensive erosion control. On steep slopes and critical areas such as waterways, mulch matting is used with netting or anchoring to hold it in place. Mulches can be used on seeded and planted areas where slopes are steeper than 2:1 or where sensitive seedlings require insulation from extreme temperatures.

Design and Installation Criteria

When possible, organic mulches should be used for erosion control and plant material establishment. Suggested materials include loose straw, netting, wood cellulose, or agricultural silage. All materials should be free of seed, and loose hay or straw should be anchored by applying tackifier, stapling netting over the top, or crimping with a mulch crimping tool. Materials that are heavy enough to stay in place do not need anchoring (for example, gravel). Steepness of the slope will also affect the extent of anchoring the mulch. Other examples include hydraulic mulch products with 100 percent post-consumer paper content, yard trimming composts, and wood mulch from recycled stumps and tree parts. Inorganic mulches such as pea gravel or crushed granite can be used in unvegetated areas.

Mulches may or may not require a binder, netting, or tacking. All straw and loose materials must have a binder to hold them in place. Mulch materials that float away during storms can clog drainage ways and lead to flooding. The extent of binding depends on the type of mulch applied. Effective use of netting and matting material requires firm, continuous contact between the materials and the soil. If there is no contact, the material will not hold the soil and erosion will occur underneath the material. Grading is not necessary before mulching.

There must be adequate coverage, or erosion, washout, and poor plant establishment will result. If an appropriate tacking agent is not applied, or if it is applied in an insufficient amount, mulch will not withstand wind and runoff. The channel grade and liner must be appropriate for the amount of runoff, or the channel bottom will erode. Also, hydromulch should be applied in spring, summer, or fall to prevent deterioration of the mulch before plants can become established. Table 5-6 presents guidelines for installing mulches, but local conditions may warrant additional requirements.

Table 5-6. Typical Mulching Materials and Application Rates

Material	Rate per Acre	Requirements	Notes
Organic Mulches			
Straw	1-2 tons	Dry, unchopped, unweathered; avoid weeds.	Spread by hand or machine; must be tacked or tied down.
Wood fiber or wood cellulose	0.5-1 ton		Use with hydroseeder; may be used to tack straw. Do not use in hot, dry weather.
Wood chips	5-6 tons	Air dry. Add fertilizer N, 12 lb/ton.	Apply with blower, chip handler, or by hand. Not for fine turf areas.
Bark	35 yd^3	Air dry, shredded or hammermilled, or chips.	Apply with mulch blower, chip handler, or by hand. Do not use asphalt tack.
Nets and Mats			
Jute net	Cover area	Heavy, uniform; woven of single jute yarn. Used with organic mulch.	Withstands water flow.
Excelsior (wood fiber) mat	Cover area		
Fiberglass roving	0.5-1 ton	Continuous fibers of drawn glass bound together with a non-toxic agent.	Apply with compressed air ejector. Tack with emulsified asphalt at a rate of 25-35 gal/1,000 ft^2.

Effectiveness

Mulching effectiveness varies with the type of mulch used and local conditions such as rainfall and runoff amounts. Percent soil loss reduction for different mulches ranges from 53 to 99.8 percent and associated water velocity reductions range from 24 to 78 percent (Harding, 1990). Table 5-7 shows soil loss and water velocity reductions for different mulch treatments.

Table 5-7. Measured Reductions in Soil Loss for Different Mulch Treatments

Mulch characteristics	Soil loss reduction (%)	Water velocity reduction (%) relative to bare soil
100% wheat straw/top net	97.5	73
100% wheat straw/two nets	98.6	56
70% wheat straw/30% coconut fiber	98.7	71
70% wheat straw/30% coconut fiber	99.5	78
100% coconut fiber	98.4	77
Nylon monofilament/two nets	99.8	74
Nylon monofilament/rigid/bonded	53.0	24
Vinyl monofilament/flexible/bonded	89.6	32
Curled wood fibers/top net	90.4	47
Curled wood fibers/two nets	93.5	59
Antiwash netting(jute)	91.8	59
Interwoven paper and thread	93.0	53
Uncrimped wheat straw–2,242 kg/ha	84.0	45
Uncrimped wheat straw–4,484 kg/ha	89.3	59

Source: Harding, 1990, as cited in USEPA, 1993.

Limitations

Mulching, matting, and netting might delay seed germination because the cover changes soil surface temperatures. The mulches themselves are subject to erosion and may be washed away in a large storm if not sufficiently anchored with netting or tacking. Maintenance is necessary to ensure that mulches provide effective erosion control.

Maintenance

Mulches must be anchored to resist wind displacement. Netting should be removed when protection is no longer needed and disposed of in a landfill or composted. Mulched areas should be inspected frequently to identify areas where mulch has loosened or been removed, especially after

rain storms. Such areas should be reseeded (if necessary) and the mulch cover replaced immediately. Mulch binders should be applied at rates recommended by the manufacturer. If washout, breakage, or erosion occurs, surfaces should be repaired, reseeded, and remulched, and new netting should be installed. Inspections should be continued until vegetation is firmly established.

Cost

The costs of seed and mulch average $1,500 per acre and range from $800 to $3,500 per acre (USEPA, 1993). R. S. Means (2000) estimates the cost of power mulching to be $22.50 per 1,000 square feet, for large volume applications. In addition, hydro- and mechanical seeding are approximately $700 to $900 per acre. Coverage cost varies with the seed type, seeding approach, and scale (total acreage to be seeded). For example, hydro or water-based seeding for grass is estimated to cost $700 per acre, but seeding of "field" grass species is only $540 per acre. (Costs include materials, labor, and equipment, with profit and overhead.) If surface preparation is required, then the installation costs increase. R. S. Means (2000) suggests the cost of fine grading, soil treatment, and grassing is approximately $2 per square yard of earth surface area.

5.1.5.1.2.5 Geotextiles

General Description

Geotextiles are porous fabrics also known as filter fabrics, road rugs, synthetic fabrics, construction fabrics, or simply fabrics. Geotextiles are manufactured by weaving or bonding fibers made from synthetic materials such as polypropylene, polyester, polyethylene, nylon, polyvinyl chloride, glass, and various mixtures of these materials. As a synthetic construction material, geotextiles are used for a variety of purposes such as separators, reinforcement, filtration and drainage, and erosion control (USEPA, 1992). Some geotextiles are made of biodegradable materials such as mulch matting and netting. Mulch mattings are jute or other wood fibers that have been formed into sheets and are more stable than normal mulch. Netting is typically made from jute, wood fiber, plastic, paper, or cotton and can be used to hold the mulching and matting to the ground. Netting can also be used alone to stabilize soils while the plants are growing; however, it does not retain moisture or temperature well.

Geotextiles can aid in plant growth by holding seeds, fertilizers, and topsoil in place. Fabrics are relatively inexpensive for certain applications—a wide variety of geotextiles exist to match the specific needs of the site.

Applicability

Geotextiles can be used for erosion control by using it alone. Geotextiles can be used as matting, which is used to stabilize the flow of channels or swales or to protect seedlings on recently planted slopes until they become established. Matting may be used on tidal or streambanks where moving

water is likely to wash out new plantings. They can also be used to protect exposed soils immediately and temporarily, such as when active piles of soil are left overnight.

Geotextiles are also used as separators. An example of such a use is geotextile as a separator between riprap and soil. This "sandwiching" prevents the soil from being eroded from beneath the riprap and maintaining the riprap's base.

Design and Installation Criteria

Many types of geotextiles are available. Therefore, the selected fabric should match its purpose. State or local requirements, design procedures, and any other applicable requirements should be considered. In the field, important concerns include regular inspections to determine whether cracks, tears, or breaches are present in the fabric and to identify when repairs should be made. Effective netting and matting require firm, continuous contact between the materials and the soil. If there is no contact, the material will not hold the soil and erosion will occur underneath the material.

Effectiveness

A geotextile's effectiveness depends upon the strength of the fabric and proper installation. For example, when protecting a cut slope with a geotextile, it is important to properly anchor the fabric using appropriate length and spacing of wire staples. This will ensure that it will not be undermined by a storm event.

Limitations

Geotextiles (primarily synthetic types) have the potential disadvantage of being sensitive to light and must be protected prior to installation. Some geotextiles might promote increased runoff and might blow away if not firmly anchored. Depending on the type of material used, geotextiles might need to be disposed of in a landfill, making them less desirable than vegetative stabilization. If the fabric is not properly selected, designed, or installed, the effectiveness may be reduced drastically.

Maintenance

Regular inspections should be made to determine whether cracks, tears, or breaches have formed in the fabric—it should be repaired or replaced immediately. It is necessary to maintain contact between the ground and the geotextile at all times.

Cost

Costs for geotextiles range from $0.50 to $10.00 per square yard depending on the type chosen (SWRPC, 1991). Geosynthetic turf reinforcement mattings (TRMs) are widely used for immediate erosion protection and long-term vegetative reinforcement, usually for steeply sloped areas or areas exposed to runoff flows. The Erosion Control Technology Council (a geotextile industry support

association) estimates TRMs cost approximately $7.00 per square yard (installed) for channel protection (ECTC, 2002a). Channel protection is one of the most demanding of installations (much more demanding than general coverage of denuded area). The ECTC (2002b) estimates the cost to install a simple soil blanket (or rolled erosion control product), seed, and fertilizer to be $1.00 per square yard.

5.1.5.1.2.6 Vegetated Buffer Strips

General Description

Vegetated buffers are areas of either natural or established vegetation that are maintained to protect the water quality of neighboring areas. Buffer zones reduce the velocity of storm water runoff, provide an area for the runoff to permeate the soil, allow ground water recharge, and act as filters to catch sediment. The reduction in velocity also helps to prevent soil erosion.

Applicability

Vegetated buffers can be used in any area that is able to support vegetation, but they are most effective and beneficial on floodplains, near wetlands, along streambanks, and on steep, unstable slopes. They are also effective in separating land use areas that are not compatible and in protecting wetlands or waterbodies by displacing activities that might be potential sources of nonpoint source pollution.

Design and Installation Criteria

To establish an effective vegetative buffer, the following guidelines should be followed:

- Soils should not be compacted.
- Slopes should be less than 5 percent.
- Buffer widths should be determined after careful consideration of slope, vegetation, soils, depth to impermeable layers, runoff sediment characteristics, type and quantity of storm water pollutants, and annual rainfall.
- Buffer widths should increase as slope increases.
- Zones of vegetation (native vegetation in particular), including grasses, deciduous and evergreen shrubs, and understory and overstory trees, should be intermixed.
- In areas where flows are concentrated and velocities are high, buffer zones should be combined with other structural or nonstructural BMPs as a pretreatment.

Vegetated strips have been studied extensively, with emphasis placed on their effectiveness in removing sediment and other pollutants. Vegetated strips are most appropriate at sites where sediment loads are relatively low, as high sediment loads will cause large quantities of deposition along the leading edge of the vegetation. This deposition will cause the flow to divert around the vegetation in a concentrated flow pattern, which will cause short-circuiting and greatly reduce removal efficiency. Variability in vegetation density and uniformity often causes similar problems. Removal efficiency depends on a combination of slope, length, and width of the filter; density of the vegetation; sediment characteristics, hydraulics of the flow; and infiltration. The interaction of these variables is complex and prevents the process from being reduced to a simple relationship except on a local basis. For site-specific local conditions, methods have been developed that allow trapping to be related to strip length and slope.

Effectiveness

Considerable data have been collected on the effectiveness of buffer strips for specific conditions. Numerous factors such as infiltration rate, flow depth, slope, dimensions of the buffer, density and type of vegetation, sediment size, and sediment density impact removal rates. Recent studies show that even short vegetative buffers can trap high percentages of sediment and certain chemicals. A significant concern is whether flow is allowed to concentrate, which will greatly reduce the travel time through the buffer and prevent the removal of pollutants.

Several researchers have measured greater than 90 percent reductions in sediment and nitrate concentrations; buffer/filter strips do a reasonably good job of removing phosphorus attached to sediment, but are relatively ineffective in removing dissolved phosphorus (Gillman, 1994). However, since the hydraulics of flow through buffer strips are not well defined and can vary considerably based on site conditions, it is difficult to consistently estimate the effectiveness of buffer strips.

Limitations

Vegetated buffers require plant growth before they can be effective, and land must be available on which to plant the vegetation. If land costs are very high, buffer zones might not be cost-effective. Although vegetated buffers help to protect water quality, they usually do not effectively mitigate concentrated storm water flows to neighboring or downstream wetlands.

Maintenance

Keeping the vegetation in vegetated buffers healthy requires routine maintenance, which (depending on species, soil types, and climatic conditions) can include weed and pest control, mowing, fertilizing, liming, irrigating, and pruning. Inspection and maintenance are most important when buffer areas are first installed. Once established, vegetated buffers do not require much maintenance beyond the routine procedures listed earlier and periodic inspections of the areas, especially after any heavy rainfall and at least once a year. Inspections should focus on encroachment, gully erosion, density of vegetation, evidence of concentrated flows through the

areas, and any damage from foot or vehicular traffic. If there are more than 6 inches of sediment in one place, it should be removed.

Cost

Conceptual cost estimates for grassed buffer strips can be made based on square footage using unit cost values. R. S. Means (2000) estimates the cost of fine grading, soil treatment, and grassing to be $2 per square yard. This cost estimate is based on application of traditional lawn seed. The cost for field seed is lower than lawn seed, reducing the coverage price. Where gently sloping areas just need to be grassed with acceptable species, the cost can be as low as $0.38 per square yard.

5.1.5.1.2.7 Erosion Control Matting

General Description

Erosion control mats can be either organic or made from a synthetic material. A wide variety of products exist to match the specific needs of the site. Organic mats are made from such materials as wood fiber, jute net, and coconut coir fiber. Unlike organic matter, synthetic mats are constructed from non-biodegradable materials and remain in place for many years. These organic mats are classified as Turf Reinforcement Mats (TRMs) and Erosion Control and Revegetation Mats (ECRMs) (USDOT, 1995).

Erosion control matting aids in plant growth by holding seeds, fertilizers, and topsoil in place. Matting can be used to stabilize the flow of channels or swales or to protect seedlings on recently planted slopes until they become established. Matting can be used on tidal or streambanks where moving water is likely to wash out new plantings. It can also be used to protect exposed soils immediately and temporarily, such as when active piles of soil are left overnight.

Applicability

Mulch mattings, netting, and filter fabrics are particularly useful in steep areas and drainage swales where loose seed is vulnerable to being washed away or failing to survive dry soil (UNEP, 1994). Erosion control mats can also be used to separate riprap and soil. This results in a “sandwiching” effect, maintaining the riprap’s base and preventing the soil beneath from being eroded.

Design and Installation Criteria

Matting is especially recommended for steep slopes and channels (UNEP, 1994).

Many types of erosion control mats are available. Therefore, the selected product should match its purpose. Effective netting and matting require firm, continuous contact between the materials and the soil. If there is no contact, the material will not hold the soil and erosion will occur underneath the material.

Wood fiber or curled wood mat consists of curled wood with fibers, 80 percent of which are 150 mm or longer, with a consistent thickness and even distribution of fiber over the entire mat. The top side of the mat is covered with a biodegradable plastic mesh. The mat is placed in the channel or on the slope parallel to the direction of flow and secured with staples and check slots. This is applied immediately after seeding operations (USDOT, 1995).

Jute net consists of jute yarn, approximately 5 mm in diameter, woven into a net with openings that are approximately 10 by 20 mm (or 0.40 to 0.79 inches). The jute net is loosely laid in the channel parallel to the direction of flow. The net is secured with staples and check slots at intervals along the channel. Placement of the jute net is done immediately after seeding operations (USDOT, 1995).

Coconut blankets are constructed of biodegradable coconut fibers that resist decay for 5 to 10 years to provide long, temporary erosion control protection. The materials are often encased in ultraviolet stabilized nets and sometimes have a composite, polypropylene structure to provide permanent turf reinforcement. These materials are best used for waterway stabilization and slopes that require longer periods to stabilize (USDOT, 1995).

Within the synthetic mat category are TRMs and ECRMs. *Turf reinforcement mats* are three-dimensional polymer nettings or monofilaments formed into a mat. They have sufficient thickness (>13 mm or 0.5 inch) and void space (>90 percent) to allow for soil filling and retention. The mat acts as a traditional mat to protect the seed and increase germination. As the turf establishes, the mat remains in place as part of the root structure. This gives the established turf a higher strength and resistance to erosion (USDOT, 1995).

Erosion control and revegetation mats are composed of continuous monofilaments bound by heat fusion or stitched between nettings. They are thinner than TRMs and do not have the void space to allow for filling of soil. They act as a permanent mulch and allow vegetation to grow through the mat (USDOT, 1995).

Effectiveness

The effectiveness of erosion control matting depends upon the strength of the material and proper installation. For example, when protecting a cut slope with an erosion control mat, it is important to anchor the mat properly. This will ensure that it will not be undermined by a storm event.

While erosion control blankets can be effective, their performance varies. Some general trends are that organic materials tend to be the most effective (Harding, 1990) and that thicker materials are typically superior (Fifield, 1992), but there are exceptions to both of these trends. Information about product testing of blankets is generally lacking. One notable exception is the Texas Department of Transportation, which publishes the findings of their testing program in the form of a list of acceptable and unacceptable materials for specific uses.

Limitations

Erosion control mats (primarily synthetic types) are sensitive to light and for this reason must be protected prior to installation. Some erosion control mats might cause an increase in runoff or blow away if not firmly anchored. Erosion control mats might need to be properly disposed of in a landfill, depending on the type of material. Effectiveness may be reduced if the fabric is not properly selected, designed, or installed.

Maintenance

Regular inspections are necessary to determine whether cracks, tears or breaches have formed in the fabric. Contact between the ground and erosion control mat should be maintained at all times and trapped sediment removed after each storm event.

Cost

Costs for erosion control mats range from $0.50 to $10.00 per square yard depending on the type chosen (SWRPC, 1991). Geosynthetic turf reinforcement mattings are widely used for immediate erosion protection and long-term vegetative reinforcement, usually for steeply sloped areas or areas exposed to runoff flows. The Erosion Control Technology Council (a geotextile industry support association) estimates that TRMs cost approximately $7.00 per square yard (installed) for channel protection (ECTC, 2002a). Channel protection is one of the most demanding of installations (much more demanding than general coverage of denuded area). The ECTC estimates the cost to install a simple soil blanket (or rolled erosion control product), seed, and fertilizer to be $1.00 per square yard (ECTC, 2002b).

5.1.5.1.2.8 Topsoiling

General Description

Topsoiling is the placement of a surface layer of soil enriched in organic matter over a prepared subsoil to provide a suitable soil medium for vegetative growth on areas with poor moisture, low nutrient levels, undesirable pH, and/or the presence of other materials that would inhibit the establishment of vegetation. Advantages of topsoil include its high organic matter content and friable consistency and its water-holding capacity and nutrient content. The texture and friability of topsoil are usually more conducive to seedling emergence and root growth. In addition to being a better growth medium, topsoil is often less erodible than subsoils, and the coarser texture of topsoil increases infiltration capacity and reduces runoff. During construction, topsoil is often removed from the project area and stockpiled. It is replaced on areas to be grassed or landscaped during the final stages of the project.

Applicability

Conditions where topsoiling applies include the following:

- Where a sufficient supply of quality topsoil is available.

- Where the subsoil or areas of existing surface soil present the following problems:
  - The structure, pH, or nutrient balance of the available soil cannot be amended by reasonable means to provide an adequate growth medium for the desired vegetation.
  - The soil is too shallow to provide adequate rooting depth or will not supply necessary moisture and nutrients for growth of desired vegetation.
  - The soil contains substances toxic to the desired vegetation.

- Where high quality turf or ornamental plants are desired.

- Where slopes are 2:1 or flatter.

Design and Installation Criteria

The topsoil should be uniformly distributed over the subsoil to a minimum compacted depth of 50 mm (2 inches) on slopes steeper than 3:1 and 100 mm (4 inches) on flatter slopes. Thicknesses of 100 to 150 mm is preferred for vegetation establishment via seeding. The topsoil should not be placed while in a frozen or muddy condition or when the subsoil is excessively wet, frozen, or in a condition that is detrimental to proper grading or seedbed preparation. The final surface should be prepared so that any irregularities are corrected and depressions and water pockets do not form. If the topsoil has been treated with soil sterilants, it should not be placed until the toxic substances have dissipated (USDOT, 1995). Table 5-8 summarizes the cubic yards of topsoil required for application to various depths.

Table 5-8. Cubic Yards of Topsoil Required for Application to Various Depths

Depth (inches)	Per 1,000 Sq Ft	Per Acre
1	3.1	134
2	6.2	268
3	9.3	403
4	12.4	536
5	15.5	670
6	18.6	804

Source: Smolen et al., 1988.

On slopes and areas that will not be mowed, the surface may be left rough after spreading topsoil. A disk may be used to promote bonding at the interface between the topsoil and subsoil (Smolen et al., 1988).

Effectiveness

No information is available describing the effectiveness of applying topsoil as a BMP.

Limitations

Limitations of applying topsoil can include to following:

- Topsoil spread when conditions are too wet, resulting in severe compaction.
- Topsoil mixed with too much unsuitable subsoil material, resulting in poor vegetation establishment.
- Topsoil contaminated with soil sterilants or chemicals, resulting in poor or no vegetation establishment.
- Topsoil not adequately incorporated or bonded with the subsoil, resulting in poor vegetation establishment and soil slippage on sloping areas.
- Topsoiled areas not protected, resulting in excessive erosion.

Maintenance

Newly topsoiled areas should be inspected frequently until the vegetation is established. Eroded or damaged areas should be repaired and revegetated.

Cost

Topsoiling costs are a function of the price of topsoil, the hauling distance, and the method of application. R. S. Means (2000) report unit cost values of $3 and $4 per square yard, for 4 and 6 inches of topsoil cover, respectively. This price is for furnishing and placing of topsoil, and includes materials, labor, and equipment, with profit and overhead.

5.1.5.2 Water Handling Practices

5.1.5.2.1 Earth Dike

General Description

An earth dike is a temporary or permanent ridge of soil designed to channel water to a desired location. Dikes are used to divert the flow of runoff by constructing a ridge of soil that intercepts and directs the runoff to the desired outlet or alternative management practice, such as a pond. This practice serves to reduce the length of a slope for erosion control and protect downslope areas. An earth dike can be used to prevent runoff from going over the top of a cut and eroding the slope, directing runoff away from a construction site or building; to divert clean water from a disturbed area; or to reduce a large drainage area into a more manageable size. Dikes should be stabilized with vegetation after construction (NAHB, No Date).

Applicability

Earth dikes are applicable to all areas; the size of the dike is correlated to the size of the drainage area (NAHB, No Date).

Design and Installation Criteria

The location of dikes should take into consideration outlet conditions, existing land use, topography, length of slope, soils, and development plans. The capacity of earth dikes and diversions should be suitable for the area that is being protected, including adequate freeboard, or extra depth that is added as a safety margin. For homes, schools, and industrial buildings, the recommended design frequency storm is 50 years and the freeboard is 0.5 feet (NAHB, No Date).

Earth dikes can be employed as a perimeter control. For small sites, a compacted 2-foot-tall dike is usually suitable, if hydroseeded. Larger dikes will actually divert runoff to another portion of the site, usually to a downstream sediment trap or basin. Therefore, the designer should ensure that they have the capacity for the 10-year storm event, and that the channel created behind the dike is properly stabilized to prevent erosion (Brown and Schueler, 1997). In addition, the downstream structure must be sized to handle the flow from the dike. Dikes should be designed using standard hydrologic and hydraulic calculations and certified by a professional hydrologist or engineer. Diversion dikes should be installed prior to the majority of the soil-disturbing activity. As soon as the dike form is completed, it should be machine compacted, fertilized, and either seeded and mulched or sodded. Excavated materials should be properly stockpiled for future use or disposed of properly. Dikes should have an outlet that functions with a minimum of erosion. Depending on site conditions and outlet structures, the runoff directed by dikes may need to be conveyed to a sediment-trapping device, such as a sediment basin or detention pond. As grades increase over 4 percent, geotextile material or sod may be required to control erosion. Slopes greater than 8 percent may require riprap. Dikes may be removed when stabilization of the drainage area and outlet are complete (NAHB, No Date). Dike design criteria must incorporate site-specific conditions, as dimensions depend on expected flows, soil types, and climatic conditions. All of these inputs vary tremendously over different sections of the country.

Effectiveness

No information has been found on the effectiveness of earth dikes used as BMPs, although terraces often have sediment removal rates of up to 90 percent.

Limitations

An erosion-resistant lining in the channel may be needed to prevent erosion in the channel caused by excessive grade. In addition, the channel should be deepened and the grade realigned if there is overtopping caused by sediment in the channel where the grade decreases or reverses. If overtopping occurs at low points in the ridge where the diversion crosses the shallow draw, the ridge should be reconstructed with a positive grade toward the outlet at all points. Finally, if there

is erosion at the outlet, an outlet stabilization structure should be installed; if sedimentation occurs at the diversion outlet, a temporary sediment trap should be installed.

Maintenance

An earth dike should be inspected for signs of erosion after every major rain event. Any repairs and/or revegetation should be completed promptly (NAHB, No Date). The following actions can be taken to properly maintain an earth dike:

- Remove debris and sediment from the channel immediately after the storm event.
- Repair the dike to its original height.
- Check outlets and make necessary repairs to prevent gully formation.
- Clean out sediment traps when they are 50 percent full.
- Once the work area has been stabilized, remove the diversion ridge, fill and compact the channel to blend with the surrounding area, and remove sediment traps, disposing of unstable sediment in a designated area.

Cost

The cost of an earth dike depends on the design and materials used. Small dikes can cost approximately $2.00 per linear foot, while larger dikes can cost approximately $2.00 per cubic yard. EPA states that an earth dike can cost approximately $4.50 per linear foot (NAHB, No Date).

An alternative means to estimate conceptual costs for earthen dikes is to use unit cost values and a rough estimate of the quantities needed. Shallow trenching (1 to 4 feet deep) with a backhoe in areas not requiring dewatering can be performed for $4 to $5 per cubic yard of removed material (R. S. Means, 2000). Based on this value, $2 per linear foot provides for 11 square feet of flow area and $4.50 per linear foot provides for 24 square feet of flow area. This suggests that the size of the dike is required prior to specifying a cost, which requires a site-specific hydrologic evaluation. Based on standards for Virginia, most small drainage areas (made up of 5 acre or less) require 18-inch tall diversion dikes with a 4.5-foot base. Assuming the excavation volume equals the volume of the dike, the resulting excavation volume is approximately 7 cubic feet per linear foot, which (conservatively) equates to $1.03 to $1.30 per linear foot for construction costs.

If the earthen dikes are to be permanent, then additional costs are incurred to vegetate the dike. R. S. Means (2000) estimates the cost of fine grading, soil treatment, and grassing is approximately $2 per square yard of earth surface area. This adds approximately $6 per linear foot of dike. Where gently sloping areas just need to be grassed with acceptable species, the cost can be as low as $0.38 per square yard.

5.1.5.2.2 Temporary Swale

General Description

The term swale (grassed channel, dry swale, wet swale, biofilter) refers to a series of vegetated, open channel management practices designed specifically to treat and attenuate storm water runoff for a specified water quality volume. As storm water runoff flows through these channels, it is treated by filtering through the vegetation in the channel, filtering through a subsoil matrix, and/or infiltrating into the underlying soils. Variations of the grassed swale include the grassed channel, dry swale, and wet swale. The specific design features and methods of treatment differ in each of these designs, but all are improvements on the traditional drainage ditch and incorporate modified geometry and other features for use of the swale as a treatment and conveyance practice.

Applicability

Grassed swales can be applied in most situations with some restrictions and are very well suited for treating highway or residential road runoff because they are linear practices. Perimeter dikes/swales should be limited to a drainage area of no more than 0.8 hectare and usually work best on gently sloping terrain. Perimeter dikes may not work well on moderate slopes, and they should never be established on slopes exceeding 20 percent (UNEP, 1994).

Regional Applicability. Grassed swales can be applied in most regions of the country. In arid and semi-arid climates, however, the value of these practices needs to be weighed against the water needed to irrigate them.

Ultra-Urban Areas. Ultra-urban areas are densely developed urban areas in which little pervious surface exists. Grassed swales are generally not well suited to ultra-urban areas because they require a relatively large area of pervious surface.

Storm Water Hot Spots. Storm water hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those commonly found in storm water. A typical example is a gas station or convenience store. With the exception of the dry swale design, hot spot runoff should not be directed toward grassed channels. These practices either infiltrate storm water or intersect the ground water, making use of the practices for hot spot runoff a threat to ground water quality.

Storm Water Retrofit. A storm water retrofit is a storm water management practice (usually structural), put into place after development has occurred, to improve water quality, protect downstream channels, reduce flooding, or meet other specific objectives. One retrofit opportunity using grassed swales modifies existing drainage ditches. Ditches have traditionally been designed to convey storm water away from roads as quickly as possible. In some cases, it may be possible to incorporate features to enhance pollutant removal or infiltration such as check dams (for example, small dams along the ditch that trap sediment, slow runoff, and reduce the longitudinal slope). Since grassed swales cannot treat a large area, using this practice to retrofit an entire watershed

would be expensive because of the number of practices needed to manage runoff from a significant amount of the watershed's land area.

Cold Water (Trout) Streams. Grassed channels are a good treatment option in watersheds that drain to cold water streams. These practices do not retain water for a long period of time and often induce infiltration. As a result, standing water will not typically be subjected to warming by the sun in these practices.

Design and Installation Criteria

Temporary swales should be designed using standard hydrologic and hydraulic calculations. Designs should be certified by a professional hydrologist, engineer, or other appropriate professional.

Perimeter dikes/swales should be established before any major soil-disturbing activity takes place. Dikes should be compacted with construction equipment to the design height plus 10 percent to allow for settlement. If they are to remain in place for longer than 10 days, they should be stabilized using vegetation, filter fabric, or other material. Diverted water should be directed to a sediment trap or other sediment treatment area (UNEP, 1994).

In addition to the broad applicability concerns described above, designers need to consider conditions at the site level. In addition, they need to incorporate design features to improve the longevity and performance of the practice while minimizing the maintenance burden.

Siting Considerations

In addition to considering the restrictions and adaptations of grassed swales to different regions and land uses, designers must ensure that this management practice is feasible at the site in question. Depending on the design option, grassed channels can be highly restricted practices based on site characteristics.

Drainage Area. Grassed swales generally should treat small drainage areas of less than 5 acres. If the practices are used to treat larger areas, the flows and volumes through the swale become too large to achieve storm water treatment through infiltration and filtration.

Slope. Grassed swales should be used on sites with relatively flat slopes (less than 4 percent). Runoff velocities within the channel become too high on steeper slopes. This can cause erosion and does not allow for infiltration or filtration in the swale.

Soils /Topography. Grassed swales can be used on most soils, with some restrictions on the most impermeable soils. In the dry swale, a fabricated soil bed replaces on-site soils to ensure that runoff is filtered as it travels through the soils of the swale.

Ground water. The depth to ground water depends on the type of swale used. In the dry swale and grassed channel options, designers should separate the bottom of the swale from the ground water by at least 2 feet to prevent a moist swale bottom or contamination of ground water. In the wet swale option, treatment is enhanced by a wet pool, which is maintained by intersecting the water table.

Design Considerations

Although the grass swale has different design variations, including the grassed channel, dry swale, and wet swale, some design considerations are common to all three. One similarity is their cross-sectional geometry. Swales should generally have a trapezoidal or parabolic cross-section with relatively flat side slopes (flatter than 3:1). Designing the channel with flat side slopes maximizes the wetted perimeter, which is the length along the edge of the swale's cross-section where runoff flowing through the swale is in contact with the vegetated sides and bottom of the swale. Increasing the wetted perimeter slows runoff velocities and provides more contact with vegetation to encourage filtering and infiltration. Another advantage to flat side slopes is that runoff entering the grassed swale from the side receives some pretreatment along the side slope. The flat bottom of all three should be between 2 and 8 feet wide. The minimum width ensures an adequate filtering surface for water quality treatment, and the maximum width prevents braiding (the formation of small channels within the swale bottom).

Another similarity among all three designs is the type of pretreatment needed. A small forebay should be used at the inflow area of the swale to trap incoming sediments. A pea gravel diaphragm (a small trench filled with river run gravel) should be used to pretreat runoff entering along the sides of the swale.

Two other features designed to enhance the treatment ability of grassed swales are a flat longitudinal slope (generally between 1 and 2 percent) and a dense vegetative cover in the channel. The flat slope helps to reduce the velocity of flow in the channel. Dense vegetation also helps reduce velocities, protect the channel from erosion, and act as a filter to treat storm water runoff. During construction, it is important to stabilize the channel before the turf has been established, either with a temporary grass cover or with the use of natural or synthetic erosion control products.

In addition to treating runoff for water quality, grassed swales need to convey larger storms safely. Typical designs allow the runoff from the 2-year storm to flow through the swale without causing erosion. Swales should also have the capacity to pass larger storms (typically a 10-year storm) safely.

The length of the swale necessary to infiltrate runoff can be calculated by using a mass balance of runoff and infiltration for a triangular-shaped cross-sectional area.

Design Variations

The following discussion identifies three different variations of open channel practices, including the grassed channel, the dry swale, and the wet swale.

Grassed Channel. (Discussed in more length in sub-section 5.5.1.2.1) Of the three grassed swale designs, grassed channels are the most similar to a conventional drainage ditch, with the major differences being flatter side slopes and longitudinal slopes and a slower design velocity for water quality treatment of small storm events. Of all of the grassed swale options, grassed channels are the least expensive, but they also provide the least reliable pollutant removal performance. The best application of a grassed channel is as pretreatment to other storm water treatment practices.

One major difference between the grassed channel and most of the other structural practices is the method used to size the practice. Most water quality practices for storm water management are sized by volume. This method sets the volume available in the practice equal to the water quality volume, or the volume of water to be treated in the practice. The grassed channel, on the other hand, is a flow rate-based design. Based on the peak flow from the water quality storm (this varies from region to region but a typical value is the 1-inch storm), the channel should be designed so that runoff takes, on average, 10 minutes to flow from the top to the bottom of the channel. A procedure for this design can be found in *Design of Storm Water Filtering Systems* (CWP, 1996).

Dry Swales. Dry swales are similar in design to bioretention areas. These practices incorporate a fabricated soil bed into their design. The existing soil is replaced with a sand/soil mix that meets minimum permeability requirements. An underdrain system is used under the soil bed. This system is a gravel layer that encases a perforated pipe. Storm water treated in the soil bed flows through the bottom into the underdrain, which conveys this treated storm water to the storm drain system. Dry swales are a relatively new design, but studies of swales with a native soil similar to the man-made soil bed of dry swales suggest high pollutant removal rates.

Wet Swales. Wet swales intersect the ground water and behave similarly to a linear wetland cell. This design variation incorporates a shallow permanent pool and wetland vegetation to provide storm water treatment. This design also has potentially high pollutant removal. One disadvantage of the wet swale is that its use in residential or commercial settings is unpopular because the shallow standing water in the swale is sometimes viewed as a potential nuisance by property owners.

Regional Variations

Cold Climates. In cold or snowy climates, swales may serve a dual purpose by acting as both a snow storage/treatment practice and a storm water management practice. This dual purpose is particularly relevant when swales are used to treat road runoff. If used for this purpose, swales should incorporate salt-tolerant vegetation, such as creeping bentgrass.

Arid Climates. In arid or semi-arid climates, swales should be designed with drought-tolerant vegetation, such as buffalo grass. As pointed out in the Applicability discussion, the value of vegetated practices for water quality needs to be weighed against the cost of water needed to maintain them in arid and semi-arid regions.

Effectiveness

Swales act to control peak discharges in two ways. First, the grass reduces runoff velocity, depending on the length and slope of the swale. Second, a portion of the storm water runoff volume passes through the swale and infiltrates into the soil. Table 5-9 summarizes grassed swale pollutant removal efficiencies.

Table 5-9. Grassed Swale Pollutant Removal Efficiency Data

Grassed Swale Removal Efficiencies							
Study	**TSS**	**TP**	**TN**	**NO_3**	**Metals**	**Bacteria**	**Type**
Goldberg, 1993	67.8	4.5	-	31.4	42–62	-100	Grassed channel
Seattle Metro and Washington Department of Ecology, 1992	60	45	-	-25	2–16	-25	Grassed channel
Seattle Metro and Washington Department of Ecology, 1992	83	29	-	-25	46–73	-25	Grassed channel
Wang et al., 1981	80	-	-	-	70–80	-	Dry swale
Dorman et al., 1989	98	18	-	45	37–81	-	Dry swale
Harper, 1988	87	83	84	80	88–90	-	Dry swale
Kercher, Landon, and Massarelli, 1983	99	99	99	99	99	-	Dry swale
Harper, 1988	81	17	40	52	37–69	-	Wet swale
Koon, 1995	67	39	-	9	-35 to 6	-	Wet swale
Occoquan Watershed Monitoring Lab, 1983	-100	-100	-100	-	-100	-	Drainage channel
Yousef et al., 1985	-	8	13	11	14–29	-	Drainage channel
Occoquan Watershed Monitoring Lab, 1983	-50	-9.1	-18.2	-	-100	-	Drainage channel
Yousef et al., 1985	-	-19.5	8	2	41–90	-	Drainage channel
Occoquan Watershed Monitoring Lab, 1983	31	-23	36.5	-	-100 to 33	-	Drainage channel
Welborn and Veenhuis, 1987	0	-25	-25	-25	0	-	Drainage channel
Yu, Barnes, and Gerde, 1993	68	60	-	-	74	-	Drainage channel
Dorman et al., 1989	65	41	-	11	14–55	-	Drainage channel
Pitt and McLean, 1986	0	-	0	-	0	0	Drainage channel
Oakland, 1983	33	-25	-	-	20–58	0	Drainage channel
Dorman et al., 1989	-85	12	-	-100	14–88	-	Drainage channel

Limitations

Common problems associated with swales include excessive erosion along unlined channels (usually because of excessive grade), erosion or sedimentation at the outlet point, or overtopping of the dike at low points (UNEP, 1994).

Additional limitations of the grass swale include the following:

- Grassed swales cannot treat a very large drainage area.

- Swales do not appear to be effective at reducing bacteria.
- Wet swales may become a nuisance because of mosquito breeding.
- If designed improperly (for example, improper slope), grassed channels will have very little pollutant removal.
- A thick vegetative cover is needed for these practices to function properly.

Maintenance

As with any BMP, swales must be maintained to continue to effectively remove pollutants. Maintenance may include occasional mowing, fertilizing, and liming. In addition, any areas that become damaged by erosion should be immediately repaired and replanted. The swales should be protected from concentrated flows and be checked periodically for downstream obstructions.

Cost

To produce a conceptual cost approximation, grassed channel construction costs can be developed using unit cost values. Shallow trenching (1 to 4 feet deep) with a backhoe in areas not requiring dewatering can be performed for $4 to $5 per cubic yard of removed material (R. S. Means, 2000). Assuming no disposal costs (i.e., excavated material is placed on either side of the trench), only the cost of fine grading, soil treatment, and grassing (approximately $2 per square yard) should be added to the trenching cost to approximate the total construction cost. Site-specific hydrologic analysis of the construction site is necessary to estimate the channel conveyance requirement and the desired retention time in the swale. It is not unusual to have flows on the order of 2 to 4 cfs per acre served.

For a design channel velocity of 1 foot per second, the resulting range in the channel cross-section area can be as low as 2 but as high as 4 square feet per acre drained. If the average channel flow depth is 1 foot, then the low estimate for grassed channel installation is $0.74 per square foot of channel bottom per acre served per foot of channel length. The high estimate is $1.48 per square foot of channel bottom per acre served per foot of channel length.

Table 5-10 summarizes additional costs of grass swales.

Table 5-10. Average Annual Operation and Maintenance Costs for a Grass Swale

Component	Estimated Unit Cost ($)	$ for Swale Size: 0.5 m Deep X 0.3 m Bottom Width X 3 m Top Width	$ for Swale Size: 1 m Deep X 1 m Bottom Width X 7 m Top Width	Comments
Mowing	0.89/100 m^2	145.0	241.0	Mow 2-3 times per year
General grass care	8.8/100 m^2	162.98	274.0	Grass maintenance area is (top width + 3 m) x length
Debris/litter removal	0.51/m^2	93.0	93.0	
Reseeding/ fertilization	0.35/m^2	5.9	10.37	Area revegetated is 1% of maintenance area per year
Inspection and general administration	0.74/m^2	231.0	231.0	Inspection once per year
TOTAL		638.0	850.0	

Source: Ellis, 1998.

5.1.5.2.3 Temporary Storm Drain Diversion

General Description

A temporary storm drain diversion is a pipe that reroutes an existing drainage system to discharge flow into a sediment trap or basin. This practice reduces the amount of sediment-laden runoff from construction sites that enters waterbodies without treatment. Temporary storm drain diversions can be used when a permanent storm water drainage system has not yet been installed. It should be recognized that diversion channels can also be installed but are not considered in the following discussion.

Applicability

A temporary storm drain diversion should be used to temporarily redirect discharge to a permanent outfall and should remain in place until the area draining to the storm sewer is no longer disturbed. Temporary storm drain diversions can also be combined with other structures and used as a sediment-trapping device when the completion of a permanent outfall has been delayed; alternatively, a sediment trap can be placed below a permanent outfall to remove sediment before the final flow discharge.

Design and Installation Criteria

Since the diversion is only temporary, the layout of piping and the overall impact of the diversion's installation on post-construction drainage patterns must be considered. Once construction is completed, the temporary diversion should be moved to restore the original system. The following activities should be done at this time:

- The storm drain should be flushed before the sediment trap is removed.
- The outfall should be stabilized.
- Graded areas should be restored.
- State or local requirements should be checked for more detailed requirements and an appropriate professional should certify that the design meets local hydrologic and hydraulic requirements.

Effectiveness

If installed properly to capture the bulk of runoff from a construction site, temporary storm drain diversions can be effective in reducing the discharge of sediment-laden, untreated water to waterbodies. When used in combination with other erosion and sediment control practices such as minimized clearing or vegetative and chemical stabilization, the level of pollution from a construction site can be substantially reduced or eliminated.

Limitations

Installation of a temporary storm drain diversion may result in the disturbance of existing storm drainage patterns. Care must be taken to ensure that the original system is properly restored once the temporary system is removed. The most common source of problems is excessive velocity at the outlet. Installation of an outlet stabilization structure is typically required and may be constructed of riprap, reinforced concrete, geotextile linings, or a combination.

Maintenance

Once installed, temporary storm drain diversions require very little maintenance. Frequent inspection and maintenance of temporary storm drain systems, especially after large storms, should ensure that pipe clogging does not occur and that runoff from the site is being successfully diverted. After removal of the temporary diversion, the permanent storm drain system should be carefully inspected to ensure that drainage patterns have not been altered by the temporary system.

Cost

Depending on the size of the construction site, a temporary storm drain diversion can be costly. Costs include those associated with materials needed to construct the diversion and sediment trap or basin (mainly piping, concrete, and gravel), and also labor costs for installation and removal of the system, all of which may involve excavation, regrading, and inspections. Based on the variety of conditions that can affect storm drain diversion designs, typical costs per installation are not presented here. However, site-specific cost estimates can be produced using unit cost values along with site-specific quantity estimates. R. S. Means (2000) indicates a range of pipe costs for surface placement, between $5.00 per linear foot for 4" diameter PVC piping, and $9.20 per linear foot for 10" diameter PVC piping. On construction sites, temporary inlets and outlets are usually formed by small rock-lined depressions. Assuming 4 cubic yards of crushed rock (1.5" mean diameter) per opening, an inlet and outlet combine to add approximately $200 per pipe installation, based on $25 per cubic yard of stone (R. S. Means, 2000).

5.1.5.2.4 Pipe Slope Drain

General Description

Pipe slope drains are used to reduce the risk of erosion on slopes by discharging runoff to stabilized areas. Consisting of a metal or plastic flexible pipe if temporary, or pipes or paved chutes if permanent, these drains carry surface runoff from the top to the bottom of a slope that has already been damaged by erosion or is at high risk for erosion. These drains are also used to drain saturated slopes that have the potential for soil slides.

Applicability

Temporary slope drains can be used on most disturbed slopes to eliminate gully erosion problems resulting from concentrated flows discharged at a diversion outlet. Slope drains should be used as a temporary measure for as long as the drainage area remains disturbed. They will need to be moved once construction is complete and a permanent storm drainage system is established. Appropriate restoration measures will then need to be taken, such as adjusting grades and flushing sediment from the pipe before it is removed (UNEP, 1994).

Design and Installation Criteria

Pipe slope drains can be placed directly on the ground or buried under the surface. The inlet should be located at the top of the slope and should be fitted with an apron, attached with a watertight connection. Filter cloth should be placed under the inlet to prevent erosion. Flexible pipes, which are positioned on top of the ground, should be securely anchored with grommets placed 10 feet on center. The outlet at the bottom of the slope should also be stabilized with riprap. The riprap should be placed along the bottom of a swale that leads to a sediment-trapping structure or another stabilized structure.

Slope drain pipe sizes are based on drainage area and the size of the design storm. Pipes should be connected to a diversion ridge at the top of the slope by covering it with compacted fill material where it passes through the ridge. Discharge from a slope drain should be to a sediment trap, sediment basin, or other stabilized outlet (UNEP, 1994).

Pipe slope drains should be installed perpendicular to the contour down the slope, and the design should be able to handle the peak runoff for the 10-year storm. Recommendations of slope drain diameter are summarized in Table 5-11 (NAHB, n.d).

Table 5-11. Recommended Pipe/Tubing Sizes for Slope Drains

Maximum Drainage Area (acres)	Pipe/Tubing Diameter[a](inches)	Pipe/Tubing Diameter[b] (inches)	Pipe/Tubing Diameter[c] (inches)
0-0.5			
0.5	12	12	8
0.75			10
1.0			12
1.5	18	18	Individually designed
2.5	21		
3.5	24	24	
5.0	30		

[a] UNEP, 1994.
[b] USDOT, 1995.
[c] IDNR, 1992.

Recently graded slopes that do not have permanent drainage measures installed should have a temporary slope drain and a temporary diversion installed. A temporary slope drain used in conjunction with a diversion conveys storm water flows and reduces erosion until permanent drainage structures are installed.

The following are design recommendations for temporary slope drains:

- The drain should consist of heavy-duty material manufactured for the purpose and have grommets for anchoring at a spacing of 10 feet or less.

- Minimum slope drain diameters should be observed for varying drainage areas.

- The entrance to the pipe should consist of a standard flare end section of corrugated metal. The corrugated metal pipe should have watertight joints at the ends. The rest of the pipe is typically corrugated plastic or flexible tubing, although for flatter, shorter slopes, a polyethylene-lined channel is sometimes used.

- The height of the diversion at the pipe should be the diameter of the pipe plus 0.5 foot.
- The outlet should be located at a reinforced or erosion-resistant location.

Temporary slope drains should be designed to adequately convey runoff for a desired frequency storm, typically either 2 years or 10 years depending on local regulations. Both the size and the spacing can be determined based on the contributing drainage area. Drains are spaced at intervals corresponding to the specified drainage areas. For larger drainage areas and critical locations, the drains should be sized on an individual basis (USDOT, 1995).

Slope drains should be constructed in conjunction with diversion berms such that the berms are not overtopped. At the pipe inlet, the top of the berm should be a minimum of 300 mm (11.81 inches) higher than the top of the pipe. The entrance should be constructed of a standard flared end section or a Tee section if designed properly. The entrance should be placed in a sump that is depressed 150 mm (5.90 inches) (USDOT, 1995).

The outlet of the slope drain must be protected with a riprap apron. If the slope drain is draining a disturbed area and sufficient right-of-way is available, the drain may empty into a sediment trap (USDOT, 1995). Table 5-12 summarizes slope drain characteristics.

Table 5-12. Slope Drain Characteristics

Capacity	2-yr frequency, 24-hr-duration storm event
Material	Strong, flexible pipe, such as heavy duty, nonperforated, corrugated plastic
Inlet section	Standard “T” or “L” flared-end section with metal toe plate
Connection to ridge at top of slope	Compacted fill over pipe with minimum dimensions, 1.5 ft depth, 4 ft top width, and 6 in higher than ridge
Outlet	Pipe extends beyond toe of slope and discharges into a sediment trap or basin unless contributing drainage area is stable

Source: IDNR, 1992.

Effectiveness

There is currently no information on the effectiveness of pipe slope drains.

Limitations

The area drained by a temporary slope drain should not exceed 5 acres. Physical obstructions substantially reduce the effectiveness of the drain. A common slope drain problem is overtopping of the inlet due to an undersized or blocked pipe, or erosion at the outlet point due to insufficient protection (UNEP, 1994). Other concerns are failures from overtopping because of inadequate pipe inlet capacity and reduced diversion channel capacity and ridge height.

Solutions to common problems include the following (IDNR, 1992):

- Washout - A washout along a pipe due to seepage and piping may be caused by inadequate compaction, insufficient fill, or installation that may be too close to the edge of the slope.
- Overtopping caused by undersized or blocked pipe - The drainage area may be too large.
- Overtopping caused by improper grade of channel and ridge - A positive grade should be maintained.
- Overtopping caused by poor entrance conditions and trash buildup at the pipe inlet - Deepen and widen the channel at the pipe entrance and frequently inspect and clear the inlet.
- Erosion at outlet - The pipe should be extended to a stable grade or an outlet stabilization structure is needed.
- Displacement or separation of pipe - The pipe should be tied down and the joints secured.

Maintenance

Pipe slope drains must be inspected after each significant runoff event for evidence of erosion and uncontrolled runoff. Any repairs to the drain should be made immediately. Significant amounts of sediment trapped at the outfall should also be removed in a timely manner and disposed of properly (NAHB, No Date).

The following actions should be taken to properly maintain a pipe slope drain (IDNR, 1992):

- Inspect slope drains and supporting diversions once a week and after every storm event.
- Check the inlet for sediment or trash accumulation; clear and restore to proper entrance condition.
- Check the fill over the pipe for settlement, cracking, or piping holes; repair immediately.
- Check for holes where the pipe emerges from the dike; repair immediately.
- Check the conduit for evidence of leaks or inadequate anchoring; repair immediately.
- Check the outlet for erosion or sedimentation; clean and repair, or extend if necessary.
- Once slopes have been stabilized, remove the temporary diversions and slope drains, and stabilize all disturbed areas.

Cost

The cost of pipe slope drains and their installation varies with the design and materials used. Site-specific cost estimates can be produced using unit cost values with site-specific quantity estimates. R. S. Means (2000) indicates a range of pipe costs for surface placement between $5.00 per linear foot for 4-inch diameter PVC piping, and $9.20 per linear foot for 10-inch diameter PVC piping. On construction sites, temporary inlets and outlets are usually formed by small rock-lined depressions. Assuming 4 cubic yards of crushed rock (1.5-inch mean diameter) per opening, an inlet and outlet together add approximately $200 per pipe installation, based on $25 per cubic yard of stone (R. S. Means, 2000).

5.1.5.2.5 Stone Check Dam

General Description

A check dam is a small temporary barrier constructed across a drainage channel or swale to reduce the velocity of the flow. By reducing the flow velocity, the erosion potential is reduced, detention times are lengthened, and more sediments are able to settle out of the water column. Check dams can be constructed of stone, gabions, treated lumber, or logs (NAHB, No Date).

Check dams are inexpensive and easy to install. They may be used permanently to settle sediment, reduce the velocity of runoff, and provide aeration. However, the use of check dams in a channel should not be a substitute for the use of other sediment-trapping and erosion control measures. As with most other temporary structures, check dams are most effective when used in combination with other storm water and erosion and sediment control measures.

Applicability

Check dams are commonly used (1) in channels that are degrading but where permanent stabilization is impractical because of their short period of usefulness and (2) in eroding channels where construction delays or weather conditions prevent timely installation of erosion-resistant linings (IDNR, 1992).

Check dams are also useful in steeply sloped swales, in small channels, in swales where adequate vegetative protection cannot be established, or in swales or channels that will be used for a short period of time where it is not practical to line the channel or implement other flow control practices (USEPA, 1993). In addition, check dams are appropriate where temporary seeding has been recently implemented but has not had time to fully develop and take root. The contributing drainage area should range from 2 to 10 acres. Check dams should be used only in small open channels that will not be overtopped by flow once the dams are built and should not be built in stream channels, either intermittent or perennial (UNEP, 1994).

Design and Installation Criteria

Check dams can be constructed from a number of different materials. Most commonly, they are made of rock, logs, sandbags, or straw bales. Rock or stone is often preferred because of its cost-effectiveness and longevity. Logs and straw bales will decay with time and are not recommended as they may cause waterway blockage if they fail. When using rock or stone, the material diameter should be 2 to 15 inches. The stones should be extended 18 inches beyond the banks, and the side slopes should be 2:1 or flatter. Lining the upstream side of the dam with a foot of 1- to 2-inch gravel may improve the efficiency of the dam (NAHB, No Date). Logs should have a diameter of 6 to 8 inches. Regardless of the material used, careful construction of a check dam is necessary to ensure its effectiveness.

The distance between rock check dams will vary depending on the slope of the ditch, with closer spacing when the slope is steeper. The size of stone used in the check dam should also vary with the expected design velocity and discharge. As velocity and discharge increase, the rock size should also increase. For most rock check dams, 3 inches to 12 inches is a suitable stone size. To improve the sediment-trapping efficiency of check dams, a filter stone can be applied to the upstream face. A well-graded coarse aggregate that is less than 1 inch in size can be used as a filter stone.

All check dams should have a maximum height of 3 feet. The center of the dam should be at least 6 inches lower than the edges. This design creates a weir effect that helps to channel flows away from the banks and prevent further erosion. Additional stability can be achieved by implanting the dam material approximately 6 inches into the sides and bottom of the channel (VDCR, 1995).

When installing more than one check dam in a channel, outlet stabilization measures should be installed below the final dam in the series. Because this area is likely to be vulnerable to further erosion, riprap or some other stabilization measure is highly recommended.

Effectiveness

Field experience has shown that rock check dams are more effective than silt fences or straw bales to stabilize wet-weather ditches (VDCR, 1995). Straw bales have been shown to have very low trapping efficiencies and should not be used for check dams. For long channels, check dams are most effective when used in a series, creating multiple barriers to sediment-laden runoff.

Limitations

Check dams should not be used in perennial streams unless approved by an appropriate regulatory agency (USEPA, 1992; VDCR, 1995). Because the primary function of check dams is to slow runoff in a channel, they should not be used as a stand-alone substitute for other sediment-trapping devices. Also, leaves have been shown to be a significant problem, as they clog check dams; therefore, increased inspection and maintenance might be necessary in the fall. Common problems with check dams include channel bypass and severe erosion when overtopped and ineffectiveness due to accumulated sediment and debris. When designing check dams, the fact that they will

reduce the capacity of a channel to transmit storm water runoff and thus will need to be sized appropriately should be taken into account (UNEP, 1994). The check dam may also kill grass linings in the channel if the water level remains high after it rains or if there is significant sedimentation. In addition, a check dam may reduce the hydraulic capacity of the channel and create turbulence, which erodes the channel banks (NAHB, No Date).

Maintenance

Check dams should be inspected periodically to ensure that they have not been repositioned as a result of storm water flow. In addition, the center of a check dam should always be lower than its edges. Additional stone may have to be added to maintain the correct height. Sediment should not be allowed to accumulate to more than half the original dam height. Any required maintenance should be performed immediately. When check dams are removed, care must be taken to remove all dam materials to ensure proper flow within the channel. The channel should subsequently be seeded for stabilization (NAHB, No Date).

Cost

The cost of check dams varies based on the material used for construction and the width of the channel to be dammed. In general, it is estimated that check dams constructed of rock cost about $100 per dam (USEPA, 1992). Brown and Schueler (1997) estimated that a rock check dam would cost approximately $62 per installation, including the cost for filter fabric bedding. Other materials, such as logs and sandbags, may be a less expensive alternative, but they might require higher maintenance costs.

5.1.5.2.6 Lined Waterways

General Description

Lined channels convey storm water runoff through a stable conduit. Vegetation lining the channel reduces the flow velocity of concentrated runoff. Lined channels usually are not designed to control peak runoff loads by themselves and are often used in combination with other BMPs such as subsurface drains and riprap stabilization. Where moderately steep slopes require drainage, lined channels can include excavated depressions or check dams to enhance runoff storage, decrease flow rates, and enhance pollutant removal. Peak discharges can be reduced through temporary detention in the channel. Pollutants can be removed from storm water by filtration through vegetation, by deposition, or in some cases by infiltration of soluble nutrients into the soil. The degree of pollutant removal in a channel depends on the residence time of the water in the channel and the amount of contact with vegetation and the soil surface, but pollutant removal is not generally the major design criterion.

Often construction increases the velocity and volume of runoff, which causes erosion in newly constructed or existing urban runoff conveyance channels. If the runoff during or after construction will cause erosion in a channel, the channel should be lined or flow control practices instituted. The

first choice of lining should be grass or sod because this reduces runoff velocity and provides water quality benefits through filtration and infiltration. If the velocity in the channel would erode the grass or sod, riprap, concrete, or gabions can be used (USEPA, 2000). Geotextile materials can be used in conjunction with either grass or riprap linings to provide additional protection at the soil-lining interface.

Applicability

Lined channels typically are used in residential developments, along highway medians, or as an alternative to curb and gutter systems. Grass-lined channels should be used to convey runoff only where slopes are 5 percent or less. These channels require periodic mowing, occasional spot-seeding, and weed control to ensure adequate grass cover (UNEP, 1994).

Lined channels should be used in areas where erosion-resistant conveyances are needed, such as in areas with highly erodible soils and slopes of less than 5 percent. They should be installed only where space is available for a relatively large cross-section. Grassed channels have a limited ability to control runoff from large storms and should be used with the recommended allowable velocities for the specific soil types and vegetative cover.

Design and Installation Criteria

The design of a lined waterway requires proper determination of the channel dimensions. It must ensure that (1) the velocity of the flowing water will not wash out the waterway and that (2) the capacity of the waterway is sufficient to carry the surface flow from the watershed without overtopping.

Vegetation-Lined Channels. Grass-lined channels have been previously discussed in detail and are only summarized in this section. The allowable velocity of water in the waterway depends upon the type, condition, and density of the vegetation, as well as the erosive characteristics of the soil. Uniformity of vegetative cover is important because the stability of the most sparsely covered area determines the stability of the channel. Grasses are a better vegetative cover than legumes because grasses resist water velocity more effectively.

Vegetative-lined channels may have triangular, parabolic, or trapezoidal cross-sections. Side slopes should not exceed 3:1 to facilitate the establishment, maintenance, and mowing of vegetation. A dense cover of hardy, erosion-resistant grass should be established as soon as possible following grading. This may necessitate the use of straw mulch and the installation of protective netting until the grass becomes established. If the intent is to create opportunities for runoff to infiltrate into the soil, the channel gradient should be kept near zero, the channel bottom must be well above the seasonal water table, and the underlying soils should be relatively permeable (generally, with an infiltration rate greater than 2 centimeters [0.78 inches] per hour).

Rock-Lined Channels. Riprap-lined channels may be installed on somewhat steeper slopes than grass-lined channels. They require a foundation of filter fabric or gravel under the riprap. Generally,

side slopes should not exceed 2:1, and riprap thickness should be 1.5 times the maximum stone diameter. Riprap should form a dense, uniform, well-graded mass (UNEP, 1994).

Lined channels should be sited in accordance with the natural drainage system and should not cross ridges. The channel design should not have sharp curves or significant changes in slope. Channels should not receive direct sedimentation from disturbed areas and should be established only on the perimeter of a construction site to convey relatively clean storm water runoff. They should also be separated from disturbed areas by a vegetated buffer or other BMP to reduce sediment loads.

Basic design recommendations for lined channels include the following:

- Construction and vegetation of the channel should occur before grading and paving activities begin.
- Design velocities should be less than 5 feet per second.
- Geotextiles can be used to stabilize vegetation until it is fully established.
- Covering the bare soil with sod or geotextiles can provide reinforced storm water conveyance immediately.
- Triangular-shaped channels should be used with low velocities and small quantities of runoff; parabolic grass channels are used for larger flows and where space is available; trapezoidal channels are used with large flows of low velocity (low slope).
- Outlet stabilization structures might be needed if the runoff volume or velocity has the potential to exceed the capacity of the receiving area.
- Channels should be designed to convey runoff from a 10-year storm without erosion.
- The sides of the channel should be sloped less than 3:1, with V-shaped channels along roads sloped 6:1 or less for safety.
- All trees, bushes, stumps, and other debris should be removed during construction.

Effectiveness

Lined channels can effectively transport storm water from construction areas if they are designed for expected flow volumes and velocities and if they do not receive sediment directly from disturbed areas.

Limitations

Lined channels, if improperly installed, can alter the natural flow of surface water and have adverse impacts on downstream waters. Additionally, if the design capacity is exceeded by a large storm event, the vegetation might not be sufficient to prevent erosion and the channel might be destroyed. Clogging with sediment and debris reduces the effectiveness of grass-lined channels for storm water conveyance.

Common problems in lined channels include erosion of the channel before vegetation is fully established and gullying or head cutting in the channel if the grade is too steep. In addition, trees and brush tend to invade lined channels, causing maintenance problems.

Riprap-lined channels can be designed to safely convey greater runoff volumes on steeper slopes. However, they should generally be avoided on slopes exceeding 10 percent because stone displacement, erosion of the foundation, or channel overflow and erosion resulting from a channel that is too small can occur. Thus, channels established on slopes greater than 10 percent will usually require protection with rock gabions, concrete, or other highly stable and protective surfaces (UNEP, 1994).

Maintenance

Maintenance requirements for lined channels are relatively minimal. During the vegetation establishment period, the channels should be inspected after every rainfall. Other maintenance activities that should be carried out after vegetation is established are mowing, litter removal, and spot vegetation repair. The most important objective in the maintenance of lined channels is maintaining a dense and vigorous growth of turf. Periodic cleaning of vegetation and soil buildup in curb cuts is required so that water flow into the channel is unobstructed. During the growing season, channel grass should be cut no shorter than the level of design flow, and the cuttings should be removed promptly.

Cost

Costs of grassed channels range according to depth, with a 1.5-foot-deep, 10-foot-wide grassed channel estimated at $6,395 to $17,075 per trench, while a 3.0-foot-deep, 21-foot-wide grassed channel is estimated at $12,909 to $33,404 per trench (SWRPC, 1991).

Readers are also referred to the discussion of costs for grass-lined channels, which contains many of the design and cost elements required for installing lined waterways. Designers have a range of options for lining new channels. Geosynthetic turf reinforcement mattings (TRMs) can be used for immediate erosion protection in channels exposed to runoff flows. The Erosion Control Technology Council (a geotextile industry support association) suggests TRMs cost approximately $7.00 per square yard (installed) for channel protection (ECTC, 2002a). R. S. Means indicates machine-placed riprap costs of approximately $40 per cubic yard. The riprap maximum size is typically between 6 and 12 inches, depending on the channel design velocity. A cubic yard of riprap will

cover between 36 and 18 square feet of channel bed for these riprap sizes (assuming depth of riprap is 1.5 times the maximum size). These estimates suggest that riprap lining will be between $10 and $20 per square foot of channel (costs include materials, labor, and equipment, with overhead and profit).

5.1.5.3 Sediment Trapping Devices

The devices listed under this group of BMPs trap sediment primarily through impounding water and allowing for settling to occur (Haan et al., 1994). Silt fence, super silt fence, straw bale dikes, sediment traps, and sediment basins all control flow through a porous flow control system such as filter fabric or straw bales or they use a dam to impound water with a pipe, open channel, or rock fill outlet. The filtering capacity of silt fence (filter fabric) contributes only a small amount of trapping, but serves to make the fence less porous and hence increases ponding. For steady-state flows, the trapping that occurs behind the flow control device can be shown to be directly proportional to the surface area and indirectly proportional to flow through the system (Haan et al., 1994). The ratio of the surface area to flow is known as the overflow rate, and trapping in such systems is predicted by the ratio of overflow rate to particle settling velocity. Although flows in nature are inherently non-steady state and more complex than steady-state systems, studies have shown that the best predictor of trapping in such systems is still the ratio of settling velocity to overflow rate (Hayes et al., 1984). In the case of non-steady state, the overflow rate is best defined by the ratio of peak discharge to surface area (Hayes et al., 1984; McBurnie et al., 1990).

The amount of trapping in these structures depends on the size of the structure, flow rates into the system, hydraulics of the flow control system, the size distribution of the sediment flowing into the structure, and the chemistry of the sediment-water system (Haan et al., 1994). Trapping can be enhanced by chemical treatment of flows into the structure, but the impacts have not been widely defined for varying mineralogy and chemistry of the sediment-water system (Haan et al., 1994; Tapp and Barfield, 1986). Recent studies have been conducted on the application of polyacrylamides (PAM) to disturbed areas for enhancing settling (Benik et al., 1998; Masters et al., 2000; Roa-Espinosa et al., 2000), but results have not been definitive. No known studies have evaluated the impacts of PAM application to disturbed areas on settling in sediment trapping devices.

Sediment flowing into sediment trapping devices is composed of primary particles and aggregated particles. Aggregates are formed when clays, silts, and sands are cemented together to form larger particles that have settling velocities far greater than those of any individual particles alone, although the degree of aggregation depends on the amount of cementing material present (typically clays and organic matter). Since the aggregates have higher settling velocities than primary particles, the degree of aggregation that is present has a large impact on the trapping that occurs. Procedures are available to measure the combined size distribution of aggregate and primary particle size distribution (Barfield et al., 1979; Haan et al., 1994). Procedures are also available to predict particle size distributions of aggregates and primary particles (Foster et al., 1985), but have not been found to be very accurate for subsoils exposed during construction in at least one study (Barfield et al., 1983).

In the absence of chemical treatment, the sediment that can be captured in sediment trapping devices is typically the larger settleable solids. To trap the smaller size clay particles, structures with surface areas larger than the construction site itself would have to built in many cases (Barfield, 2000). Chemical treatment can be used to reduce the size captured, but it has not been adopted on a wide scale because of the cost and complexity of the operation (Tapp et al., 1981).

Sediment trapping devices also provide some storm water detention by virtue of detaining flows long enough to allow sediment to settle out and be deposited. However, to operate as a storm water detention structure, the design should include adequate volume for detention.

Virtually all of the available information on sediment trapping structures, both theoretical and experimental, is on impacts to receiving waters and not downstream effects. In a very limited analysis, Barfield (2000) combined the SEDIMOT II computer model together with the FLUVIAL model to theoretically evaluate the impact of sediment trapping structures on downstream geomorphology in a Puerto Rican watershed.

5.1.5.3.1 Silt Fence

General Description

Silt fences are used as temporary sediment barriers consisting of filter fabric anchored across and supported by posts. Their purpose is to retain sediment from small disturbed areas by reducing the velocity of sediment-laden runoff and promoting sediment deposition (Smolen et al., 1988). Silt fences capture sediment by ponding water and allowing for deposition, not by filtration. Silt fence fabric first screens silt and sand from runoff, resulting in clogging of the lower part of the fence. The pooling water allows sediments to settle out of the runoff. Silt fences work best in conjunction with temporary basins, traps, or diversions.

Applicability

Silt fences are generally placed at the toe of fills, along the edge of waterways, and along the site perimeter. The fences should not be used in drainage areas with concentrated and high flows, in large drainage areas, or in ditches and swales where concentrated flow is present.

The drainage area for the fence should be selected based on design storms and local hydrologic conditions so that the silt fence is not expected to overtop. A typical design calls for no greater than ¼ acre of drainage area per 100 feet of fence, but this is highly variable depending on climate. The fence should be stable enough to withstand runoff from a 10-year peak storm. Table 5-13 lists the maximum slope length specified by the USDOT. These slope lengths should be based on sediment load and flow rates. This would mean that the values given below should be adjusted for climatic conditions instead of “one size fits all” to ensure maximum effectiveness.

Table 5-13. Maximum Slope Lengths for Silt Fences

Slope (%)	18- inch (460 mm) Fence	30- inch (760 mm) Fence
≤2	250 ft (75 m)	500 ft (150 m)
5	100 ft (30m)	250 ft (75 m)
10	50 ft (15 m)	150 ft (45 m)
20	25 ft (8 m)	70 ft (21 m)
25	6 m (20 ft)	55 ft (17 m)
30	15 ft (5 m)	45 ft (14 m)
35	15 ft (5 m)	40 ft (12 m)
40	15 ft (5 m)	35 ft (10 m)
45	10 ft (3 m)	30 ft (9 m)
50	10 ft (3m)	25 ft (8m)

Source: USDOT, 1995.

Typical standards and specifications call for the silt fence to be located on fairly level ground and follow the land contour. However, field evaluations by Barfield and Hayes (1992, 1999) in South Carolina and Kentucky indicate that installations on the contour as well as along a slope have problems with undercutting. In either case, the installations are such that a slight slope may occur along the fence in spite of the best installation practices. Runoff can move down the contour until a weak spot occurs in the buried toe and undercuts the fence. Alternatively, flow may move to a low spot where it accumulates and causes an overtopping. In either case, trapping by the silt fence is essentially zero, and flows will then have been concentrated, causing downslope erosion.

Design and Installation Criteria

Design criteria are of two types:

- Hydrologic design for a required trapping of sediment and flow rate to pass the design storm.
- Selection of appropriate installation criteria such that the silt fence will perform as designed.

Hydrologic Design

The fence should be designed to pass the design storm without causing damage while trapping the required amount of sediment. It is necessary to use either a database or some type of model to develop the appropriate hydrologic design. Efforts to model the sediment trapping that occurs through the use of a silt fence have resulted in models that predict the settling in the ponded area upstream from the fence (Barfield et al., 1996; Lindley et al., 1998). The results from model simulations show that trapping depends primarily on the surface area of the impounded water and the flow rate through the filter. The models utilize a clear water flow rate, typically specified by the manufacturer, to predict discharge. However, numerous studies have shown that sediment laden flows cause clogging of the geotextiles used to construct the fence, dependent on the opening size

and size of the sediment (Britton et al., 2001; Wyant, 1980; Barrett et al., 1995; Fisher and Jarret, 1984). Thus, results from model studies to date are suspect and need to be modified to account for the impacts of clogging on flow rate. Barfield et al., (2001) developed a model of flow rate using conditional probability concepts, but the results have not been experimentally verified.

Design aids have been developed for silt fence, using simulations from the SEDIMOT III model (Hayes and Barfield, 1995). In the model, predictions are made about trapping efficiency using the ratio of settling velocity for the d_{15}[4] of the eroded sediment, divided by the ratio of discharge to ponded surface area. The design aids yield conservative estimates as compared to the SEDIMOT III model, but the database used for generating the design aid is based on the assumption that clogging does not impact flow rates. The discussion above shows that assumption to be erroneous.

SEDCAD takes the approach of using a slurry flow rate, not a clean water flow rate, when it simulates fence effectiveness, reporting slurry rates rangING between 0.1 and 15 gpm/sq. ft. Based on this discussion, one can conclude that it is difficult to predict with accuracy the trapping efficiency of silt fence under a given set of conditions. In addition, the quality of installation and maintenance are important to the long-term performance of the fence. The best available estimate of sediment trapping obtained from modeling of hydrologic events should be applied with care in any site design problem.

Installation Criteria

General installation criteria for the silt fence should incorporate the following factors:

- The fabric must have sufficient strength to counter forces created by contained water and sediment (Sprague, 1999).
- The posts must have sufficient strength to counter the forces transferred to them by the fabric (Sprague, 1999).
- The fabric must be installed to ensure that the loads are all adequately transferred through the fabric to the posts or the ground without overstressing (Sprague, 1999).
- The fence must be designed based on site-specific hydrologic and soil conditions such that it will not overtop during design events.
- The fence must be installed (anchored) with a buried toe of sufficient depth so that it does not become detached from the soil surface.

[4] d_{15}:15 percent by weight of suspended solids are smaller than those that are trapped by this device; Similarly d_{50} indicates that 50 percent by weight of suspended solids are smaller than those trapped.

- In general, the fence requires a metal wire backing to provide sufficient strength to prevent failure from the weight of trapped sediment and to prevent the toe of the fabric from being removed from the ground.

- Maximum drainage area behind the fence should be determined based on the local rainfall and the infiltration characteristics of the soil and cover.

Silt fence material is typically synthetic filter fabric or a pervious sheet of polypropylene, nylon, polyester, or polyethylene yarn. The fabric should have ultraviolet ray inhibitors and stabilizers to provide for a minimum useful construction life of 6 months or the duration of construction, whichever is greater. The height of the fence fabric should not exceed 3 feet. If standard strength filter fabric is used, it should be reinforced with a wire fence, extending down into the trench that buries the toe. The wire should be of sufficient strength to support the weight of the deposited sediment and water. In general, a minimum 14 gauge and a maximum mesh spacing of 6 inches is called for (Smolen et al., 1988). Typical requirements for the silt fence physical properties, as specified in selected local BMP standards and specifications, are included in Table 5-14.

Table 5-14. Typical Requirements for Silt Fence Fabric

Physical Property	Requirements	
	Woven Fabric	Non-Woven Fabric
Filtering Efficiency	85%	85%
Tensile Strength at 20% (maximum) Elongation	Standard Strength —30 pound/linear inch Extra Strength —50 pound/linear inch	Standard Strength —50 pound/linear inch Extra Strength —70 pound/linear inch
Slurry Flow Rate	0.3 gallon/square feet/minute	4.5 gallon/square feet/minute
Water Flow Rate	15 gallon/square feet/minute	220 gallon/square feet/minute
UV Resistance	70%	85%

Source: NCDNR, 1988; IDNR 1992.

It should be pointed out that these numbers, particularly the flow rates, could vary widely depending on the local soil condition due to possible clogging of the filter material.

Material for the posts used to anchor the filter fabric can be constructed of either wood or steel. Wooden stakes should be buried at a depth sufficient to keep the fence, when loaded with sediment and water, from falling over. The depth of burial should depend on post diameter and soil strength characteristics when saturated. Many standards and specifications set a minimum post length of 5 feet with 4-inch diameter for posts composed of softwood (e.g, pine) and 2-inch diameter for posts composed of hardwood (e.g., oak) (Smolen et al., 1988). Steel posts should also be designed based on local wet soil strength characteristics. Some standards and specifications for these posts set a minimum weight of 1.33 pounds per linear feet with a minimum length of 4 feet. Steel posts should also have projections to adhere filter fabric to the post (Smolen et al., 1988).

A silt fence should be erected in a continuous fashion from a single roll of fabric so as to eliminate unwanted gaps in the fence. If a continuous roll of fabric is not available, the fabric should overlap from both directions only at posts with a minimum overlap of 6 inches and be rolled together with a special flexible rod to keep the ends from separating. Fence posts should be spaced at a distance based on wet soil strength characteristics and post size and strength; generally, the posts are spaced approximately 4 to 6 feet apart. If standard strength fabric is used in combination with wire mesh, the spacing can be larger. Typically, standards and specifications call for the posts to be no more than 10 feet apart. If extra-strength fabric is used without wire mesh reinforcement, some standards call for the support posts to be spaced no more than 6 feet apart (VDCR, 1995). Again, this spacing should depend on wet soil strength characteristics and post size.

A silt fence must provide sufficient storage capacity or be stabilized over flow outlets such that the storage volume of water will not overtop the fence. The return period event (size of the rainfall event managed) used for design is typically a prerogative of the regulatory agency. For temporary fences, a 2-year storm event is typically used as a design standard. Fences that will be in place for 6 months or longer are commonly designed based on a 10-year storm event (Sprague, 1999). The space behind the fence used for impoundment volume must be sufficient to adequately contain the sediment that will be deposited. Each storm will deposit sediment behind the fence, and after a period of time the amount of sediment accumulated will render the fence useless. Frequency of fence management is a function of its sizing (i.e. whether the fence was installed for a 2-year or a 10-year storm event) (Sprague, 1999) and the amount of erosion that occurs in the area draining to the fence.

Effectiveness

The performance of silt fences has not been well defined. Laboratory studies using carefully controlled conditions have shown trapping efficiencies in the range of 40 to 100 percent, depending on the type of fabric, overflow rate, and detention time (Barrett et al., 1995; Wyant, 1980; Wishowski et al., 1998). Field studies have been limited and quite inadequate; however, the results show that field-trapping efficiencies are very low. In fact, Barrett et al. (1995) obtained a value of zero percent trapping averaged over several samples with a standard error of 26 percent. Barrett et al. (1995) cite the following reasons for the field tests not showing the expected results:

- Inadequate fabric splices
- Sustained failure to correct fence damage resulting from overtopping
- Large holes in the fabric
- Under-runs due to inadequate “toe-ins”
- Silt fence damaged and partially covered by the temporary placement of stockpiles of materials

Field inspections conducted by Barfield and Hayes (1992) were made in which more than 50 construction sites in South Carolina and Kentucky were visited. Inspections found that silt fence was seldom installed and, when installed, was rarely set up according to specifications. In areas where installations did meet standards, it was obvious that flows sought the weakest spot on the fence and either flowed through cuts in the fabric or undercut or overtopped the fence. This flow was thus changed from the overland flow coming into the site to concentrated flow, causing significant erosion.

Silt fences are effective at removing large particle sediment, primarily aggregates, sands, and larger silts. Sediment is removed through impounding of water to slow velocity. It is argued that the silt fence will not contribute to a reduction in small particle sediment and is not effective against other pollutants (WYDEQ, 1999). EPA (1993) reports the following effectiveness ranges for silt fences constructed of filter fabric: average total suspended solids removal of 70 percent, sand removal of 80 to 90 percent, silt-loam removal of 50 to 80 percent, and silt-clay-loam removal of 0 to 20 percent. However, the EPA numbers from the Nationwide Urban Runoff Program should not be considered to apply to every location. The actual trapping will vary widely for a given design because of differences in hydrologic regimes and soil types.

The advantages of using silt fences include minimal labor requirement for installation, low cost, high efficiency in removing sediment, durability, and sometimes reuse (Sprague, 1999). Silt fences are the most readily available and cost-effective control options where options like diversion are not possible. Silt fences are also a popular choice because contractors have used them extensively and their familiarity makes silt fence use more likely for future construction activities. The visibility of a silt fence is also an advantage (i.e., the fence is “advertising” the use of erosion and sediment control practices). In addition, the silt fence visibility makes site inspection easier for contractors and government inspectors (CWP, 1996).

Limitations

Silt fences should not be installed along areas where rocks or other hard surfaces will prevent uniform anchoring of fence posts and entrenching of the filter fabric because an insufficient anchor will greatly reduce their effectiveness and may create runoff channels. In addition, open areas where wind velocity is high may present a maintenance challenge, as high winds may accelerate deterioration of the filter fabric (Smolen et al., 1988). When the pores of the silt fence fabric become clogged with sediment, pools of water are likely to form uphill of the fence. Siting and design of the silt fence should account for this problem, and care should be taken to avoid unnecessary diversion of storm water from these pools which might cause further erosion damage. Silt fences can act as a diversion if placed slightly off-contour and can control shallow, uniform flows from small, disturbed areas and deliver sediment-laden water to deposition areas.

Silt fences will sag or collapse if a site is too large, if too much sediment accumulates, if the approach slope is too steep, or if the fence was not adequately supported. If the fence bottom is not properly installed or the flow velocity is too fast, fence undercuts or blowouts can occur

because of excess runoff. Erosion around the end of the fence can occur if the fence ends do not extend upslope to prevent flow around the fence (IDNR, 1992).

Maintenance

Site operators should inspect silt fences after each rainfall event to ensure they are intact and that there are no gaps at the fence-ground interface or tears along the length of the fence. If gaps or tears are found, they should be repaired or the fabric should be replaced immediately. Accumulated sediments should be removed from the fence base when the sediment reaches one-third to halfway up the height of the fence. Sediment removal should occur more frequently if accumulated sediment is creating a noticeable strain on the fabric and there is the possibility that the fence might fail from a sudden storm event.

Cost

There is a wide range of data on installation costs for silt fences. EPA estimates these costs at approximately $6.00 per linear foot (USEPA, 1992) while SWRPC estimates unit costs between $2.30 and $4.50 per linear foot (SWRPC, 1991). Silt fences have an annual maintenance cost that is 100 percent of installation cost (Brown and Schueler, 1997). These values are significantly greater than that reported by R. S. Means (2000), which indicates a 3-foot-tall silt fence installation cost between $0.68 and $0.92 per linear foot (for favorable and challenging installations). It should be noted that the R. S. Means value covers just a single installation, without the expected costs of maintenance (e.g., removal of collected sediment). In addition, the type of silt fence fabric employed will also affect the total installation costs.

5.1.5.3.2 Super Silt Fence

General Description

Super silt fence is a modification of a standard silt fence. The two central differences between the standard silt fence and the super silt fence is that the super silt fence has toe that is buried more deeply and the backing material is chain link fence held in place by steel posts—a concept that originated in Maryland. The Maryland super silt fence requires a Geotextile Class F fabric over a chain link fence to intercept sediment-laden runoff from small drainage areas. The super silt fence provides a barrier that can collect and hold debris and soil more effectively than a standard silt fence, preventing material from entering critical areas. It is best used where the installation of a dike would destroy sensitive areas, woods, and wetlands.

Applicability

Super silt fences can be used in the same conditions as a silt fence. Fences should follow the contour of the land. Table 5-15 lists the distance a super silt fence should be from a slope to ensure maximum effectiveness (MDE, 1994).

Table 5-15. Slope Lengths for Super Silt Fences

Slope (%)	Slope Length	
	Minimum	**Maximum**
0-10	Unlimited	Unlimited
10-20	200 feet	1,500 feet
20-33	100 feet	1,000 feet
33-50	100 feet	500 feet
50+	50 feet	250 feet

Design and Installation Criteria

As with the standard silt fence, design criteria are of two types, hydrologic design for a required trapping of sediment and flow rate to pass the design storm and selection of appropriate installation criteria such that the silt fence will perform as designed.

Hydrologic Design

Hydrologic design criteria are the same as the criteria for the standard silt fence.

Installation Criteria

The criteria used for the Maryland super silt fence indicate the following, although they have not been tested with field data:

- The fence should be placed as close to the contour as possible, with no section of the silt fence exceeding a grade of 5 percent for a distance of more than 50 feet.
- Fabric should be no more than 42 inches in height and should be held in place with a 6-foot chain link fence.
- Fabric should be attached to the steel pole using wire ties or staples. Fabric should be securely fastened to the chain link fence with ties spaced every 24 inches at the top and midsection.
- Fabric should be embedded into the ground at a minimum of 8 inches.
- Edges of fabric should overlap by 6 inches.

Table 5-16 describes the physical properties of Geotextile class F fabric (MDE, 1994).

Table 5-16. Minimum Requirements for Super Silt Fence Geotextile Class F Fabric

Physical Properties	Requirements
Tension Strength	50 pound/inch
Tensile Modulus	20 pound/inch
Flow Rate	0.3 gallon/ft^2/minute
Filtering Efficiency	75%

Effectiveness

Performance data have not been collected for super silt fences. The fences have been proposed for locations within a sensitive watershed, or where site conditions prohibit the use of a standard silt fence. However, until performance data are collected under field conditions, effectiveness is speculative.

Limitations

Super silt fences are not as likely to fail structurally as are standard silt fences, but they are more expensive than standard silt fences.

Maintenance

Maintenance requirements for super silt fences are generally the same as for standard silt fences.

Cost

The cost of the super silt fence is more than the standard silt fence because of deeper burial at the toe and the cost of chain linked fencing. R. S. Means (2000) indicates a rental price of $10 to $11 per linear foot of chain linked fence for periods up to 1 year. Overall, rental is expected for most construction site installation because rental rates are approximately half the price of permanent chain link fencing.

5.1.5.3.3 Straw Bale Dike

General Description

The straw bale dike is a temporary measure used to trap sediment from small, sloping disturbed areas. It is constructed of straw bales (not hay bales) wedged tightly together and placed along the contour downslope of disturbed areas. The bales are placed in a shallow excavation, and the upslope side is sealed with soil. Stakes are driven through the bales into the soil to help hold the bales in place. The dike works by impounding water, which allows sediment to settle out in the upslope area (Haan et al., 1994). Straw bale dikes are recommended for short duration application and are usually effective for less than 3 months because of rapid decomposition (USDOT, 1995).

Applicability

Straw bale dikes are generally placed at the toe of fills to provide for a broad shallow sediment pool. The dikes should not be used in drainage areas with concentrated and high flows, in large drainage areas, or in ditches and swales. The location of the straw bale dike should be fairly level, at least 10 feet from the toe, and should follow the land contour. Table 5-17 lists the distance a straw bale dike should be placed from a slope to ensure maximum effectiveness.

Table 5-17. Maximum Land Slope and Distances Above a Straw Bale Dike

Land Slope (%)	Maximum Distance Above Dam (ft)
Less than 2	100
2-5	75
5-10	50
10-20	25
More than 20	15

Source: USDOT, 1995.

Design and Implementation Criteria

Hydrologic Design

Hydrologic design dictates the structure necessary to withstand a storm without causing damage while trapping the required amount of sediment. Either a database or some type of model are needed to find the appropriate design. Efforts to model the sediment trapping that occurs in straw bale dikes have resulted in models that predict the settling in the ponded area upstream from the fence (Barfield et al., 1996; Lindley et al., 1998). The results from model simulations show that trapping depends primarily on the surface area of the impounded water and flow rate through the filter. The models use a clear water slurry flow rate to predict discharge. It is anticipated, based on visual observations, that sediment will clog the straw bale barrier, reducing the slurry flow rate. Thus, results from model studies to date are suspect and need to be modified to account for the impact of clogging on flow rate.

Installation Criteria

The US DOT's BMP Manual and the Indiana BMP Manual call for bales to be:

- Anchored by driving two 36-inch long (minimum) steel rebars or 2 x 2-inch hardwood stakes through each bale;
- Sized according to the standard bale size of 14 inches x 18 inches x 35 inches;
- Placed in an excavated trench at least 4 inches deep, a bale's width, and long enough that the end bales are somewhat upslope of the sediment pool;

- Abutted tightly against each other; and,
- Sized such that impounded water depth should not exceed 1.5 feet.

The USDOT BMP Manual does not require that straw bale dikes be designed; however, the Indiana Manual limits the drainage area to 1/4 acre per 100 feet of dam and the total drainage area draining to a straw bale dike to 2 acres.

Effectiveness

The information on performance of straw bale dikes is very limited. In laboratory studies of bales at varying orientations, Kouwen (1990) found that trapping efficiencies ranged from 60 to 100 percent. Field data on trapping have not been collected; however, visual inspection of sites indicate that straw bales are not properly installed to prevent flows from undercutting or flowing between bales (Barfield and Hayes, 1992, 1999). In addition, bales deteriorate rapidly and need to be replaced frequently. Because of these problems, the use of straw bale dikes as a perimeter control is not recommended, except in special circumstances. Only 27 percent of erosion and sediment control experts rated the straw bale dike as an effective erosion and sediment control practice, although its use was still allowed in half of the communities surveyed (Brown and Caraco, 1997).

Limitations

Straw bale dikes should not be used as a diversion, in streams, in channels, or in areas with concentrated flow. The bales are not recommended for paved areas because of the inability to anchor the bales (IDNR, 1992).

Care must be taken to ensure that the bales are not installed in an area where there is a concentrated flow of runoff, in a drainage area that is too large, or on an excessive slope (IDNR, 1992). Under these conditions, erosion around the end of the bales, overtopping and undercutting of the bales, and bale collapsing and dislodging are likely to occur. Overtopping will also occur if the storage capacity is underestimated and where provisions are not made for safe bypass of storm flow (IDNR, 1992). Undercutting will occur if the bales are not entrenched at least 4 inches and backfilled with compacted soil or were not abutted or chinked properly. Straw bale dikes are likely to collapse or dislodge if the bales are not adequately staked, or if too much sediment is allowed to accumulate before cleanout (IDNR, 1992).

Maintenance

For the straw bale dike to be most effective, it is important to replace deteriorated bales when appropriate.

Cost

The cost of straw bale dikes are relatively low, making their use attractive. R. S. Means (2000) indicates a staked straw bale unit cost of $2.61 per linear foot (Costs include materials, labor, and equipment, with profit and overhead).

5.1.5.3.4 Sediment Trap

General Description

A sediment trap is a temporary control device used to intercept sediment-laden runoff and to trap sediment to prevent or reduce off-site sedimentation. It is normally a more temporary type of structure than a sediment pond and is constructed to control sediment on the construction area during a selected phase of the construction operation. A sediment trap can be formed by excavation and/or embankments constructed at designated locations accessible for cleanout. The outlet for a sediment trap is typically a porous rock fill structure, which serves to detain the flow, but a pipe structure can also be used. A temporary sediment trap may be located in a drainageway, at a storm drain inlet, or at other points of discharge from a disturbed area. They may be constructed independently or in conjunction with diversions and may be used in most drainage situations to prevent excessive siltation of pipe structures (USEPA, 1992).

Applicability

Sediment traps can simplify the storm water control plan design process by trapping sediment at specific spots at a construction site (USEPA, 1992). They should be installed as early in the construction process as possible and are primarily effective as a short-term solution to trapping sediment from construction sites (WYDEQ 1999). Natural drainage patterns should be noted, and sites where runoff from potential erosion can be directed into the traps should be selected. Traps are most effective when capturing runoff from areas where 2 to 5 acres drain to one location. Sediment traps should not be located in areas where their failure resulting from excess runoff can lead to further erosive damage of the landscape. Alternative diversion pathways should be designed to accommodate these potential overflows. Traps should be accessible for clean-out and located so that they do not interfere with construction activity. In addition, the traps are easily adaptable to most conditions.

Design and Implementation Criteria

Hydrologic Design

A sediment trap should be designed to maximize surface area and sediment settling. This will increase the effectiveness of the trap and decrease the likeliness of backup during and after periods of high runoff intensity. The design of a trap includes determining the storage volume, surface area, dimensions of spillway or outlet, and elevations of embankment (USDOT, 1995). Sediment

traps should be designed to meet a 2-year, 24-hour storm event, but the selection of a return period varies among regulatory agencies (IDNR, 1992).

Storage volume is created by a combination of excavation of land and construction of an embankment to detain runoff (USDOT, 1995). Trap storage volume and length of spillway are determined as a function of the runoff volume and rate for the design storm. These parameters will vary depending on return period rainfall and watershed hydrologic characteristics. Some standards specify a storage volume per acre disturbed. For example, Smolen et al. (1998) specified that approximate storage capacity of each trap should be at least 67 cubic yards per acre disturbed draining into the trap, but more recent guidelines suggest 134 cubic yards per acre of drainage area (VDCR, 2001). Any national standard, however, should be based on runoff volume and peak discharge to be generally applicable. Local regulations can translate this into applicable volume and area standards.

A more important criterion than storage volume relates to sediment trapping. If a trapping efficiency is specified, as in the case of South Carolina (SCDHEC, 1995), it is necessary to design for trapping efficiency. If a TSS or settleable solids effluent criterion is adopted (SCDHEC, 1995), settleable solids must be estimated. In both cases, a national standard should address how to estimate trapping efficiency or settleable solids. Efforts to model the sediment trapping that occurs in sediment traps have resulted in models that predict the settling in the ponded area (Barfield et al., 1996; Lindley et al., 1998). The results from model simulations show that trapping depends primarily on surface area of the impounded water and flow rate through the rock fill outlet. In fact, the ratio of peak outflow rate to surface area is the best simple predictor of trapping. The models use a modification of the Herrera and Felton (1991) relationship developed by Haan et al. (1994) to predict discharge rates. The predicted flow rates do not take into account clogging that can occur in rock fill. No models or procedures are available to estimate this clogging or its impact on flow criteria.

Design aids have also been developed for sediment traps, using simulations from the SEDIMOT III (Barfield et al., 2001; Hayes et al., 2001). In the model, predictions are made of trapping efficiency using the ratio of settling velocity for the d_{15} of the eroded sediment, divided by the ratio of discharge to ponded surface area. The design aid yields conservative estimates, but the database used for generating the design aid is based on the assumption that flow rates are not impacted by clogging. This latter assumption is not likely to be a critical issue, but should be addressed in future research.

Installation Specifications

USDOT standards call for the embankment to be constructed of compacted earth, at a maximum height of 5 feet (1.5 meters), a width of 4 to 5 feet (1.2 meters), and side slopes of 2:1or flatter. These values may change as a result of local criteria and with changing soil characteristics. Temporary vegetation should be applied to the embankment.

Two types of outlet structures are typically used for sediment traps, a rock outlet and a pipe outlet. Spillways of large stones or aggregate are the most common type of outlet designed for sediment traps. The crest of the spillway should be constructed 1 foot below the top of the embankment and the spillway depth 1.5 feet below the top of the embankment. Weir length of the spillway is determined based on the contributing drainage area (Table 5-18) (USDOT, 1995). The outlet apron should be a minimum of 5 feet long, and situated on level ground with a filter fabric foundation to ensure exit velocity of drainage to receiving stream is nonerosive (IDNR, 1992).

The length of the rock outlet should be determined based on peak discharge required and rock characteristics, typically rock diameter. Flow rate calculations can be made with the relationship of Herrera and Felton (1991) as modified by Haan et al. (1994). Alternatively, the USDOT has specified the weir length for a given drainage area as shown in Table 5-18. However, the values should be adjusted for each climatologic area to account for local hydrologic and return period rainfall.

Table 5-18. Weir Length for Sediment Traps

Contributing Drainage Area	Weir Length (ft)
1	4
2	5
3	6
4	10
5	12

Source: USDOT, 1995.

The pipe outlet, constructed of corrugated metal or PVC pipe riser, is an alternative to the rock outlet. Pipe diameter is based on the peak discharge rate required. To obtain appropriate freeboard, the top of pipe should be placed 1.5 feet below embankment elevation. Perforated pipe is sometimes used. USDOT suggests perforations of 1-inch (25 mm) diameter holes or 0.5 x 6 inch (13 x 15 mm) slits in the upper two-thirds of the pipe; however, the discharge should be calculated for this pipe specification to ensure that it matches the required peak discharge.

The pipe should be placed vertically and horizontally above wet storage elevation (USDOT, 1995). Riprap should be used as an outlet protection and placed at the outlet of the barrel to prevent scour from occurring (USDOT, 1995). A stable channel should be provided to convey discharge to the receiving channel (USDOT, 1995).

Effectiveness

If it is assumed that the flow can be accurately controlled by the rock fill outlet, sediment traps should operate as effectively as sediment basins, with trapping efficiencies reduced as a result of smaller surface areas. The NURP study (USEPA, 1993), Stahre and Urbonas (1990), and Haan, et al., (1994), report that sediment basins effectively trapped sediment and chemicals as shown in Table 5-19.

Table 5-19. Range of Measured Pollutant Removal for Sediment Detention Basins

Item	Removable Percentage
Total suspended solids (TSS)	50-70
Total phosphorus (TP)	10-20
Nitrogen	10-20
Organic matter	20-40
Lead	75-90
Zinc	30-60
Hydrocarbons	50-70
Bacteria	50-90

Source: Stahre and Urbonas, 1990.

Information on the actual effectiveness of sediment traps is limited. The discussion should start first with the flow hydraulics of the rock fill outlet typically employed as a principal spillway for sediment traps. Procedures for estimating flow through rock fill have been developed by Herra and Felton (1991) to estimate flow as a function of average rock diameter, standard deviation of rock size, and flow length. If these parameters could be controlled in an actual situation, the flow could be accurately predicted. However, given that standard construction practices consist of end-dumping the rock fill in place, one would expect little correlation between design and construction and the actual discharge and trapping efficiency would be expected to be dramatically different from the design. This analysis does not mean that sediment traps are ineffective, but that a given design could not be guaranteed to meet the effluent criteria, even though the predictions indicate compliance. Sediment trapping efficiency is a function of surface area and inflow rate (Smolen et al., 1988). Those traps that provide pools with large length-to-width ratios have a greater chance of success.

Sediment traps remove larger sized sediment, primarily sized from silt to sands, by slowing water velocity and allowing for sediment settling in ponded water (Haan et al., 1994). Although sediment traps allow for settling of eroded soils, because of their short detention periods for storm water they typically do not remove fine particles such as silts and clays without chemical treatment. Sediment settling ability is related to the square of the particle size; halving particle sizes quadruples the time needed to achieve settlement (WYDEQ 1999). To increase overall effectiveness, traps should be constructed in smaller areas with low slopes.

Sediment traps are typically designed to remove only sediment from surface water, but some non-sediment pollutants are trapped as well (Haan et al., 1994).

Limitations

Common concerns associated with sediment traps are included in Table 5-20.

Table 5-20. Common Concerns Associated with Sediment Traps

Common Concern	Result
Inadequate spillway size	Results in overtopping of the dam and possible failure of the structure
Omission or improper installation of geotextile fabric	Results in piping under the sides or bottom of the stone and outlet section
Low point in embankment caused by inadequate compaction and settling	Results in overtopping and possible failure
Stone outlet apron does not extend to stable grade	Results in erosion below the dam
Stone size too small or backslope too steep	Results in stone displacement
Inadequate vegetative protection	Results in erosion of embankment
Sediment not removed from the basin with enough frequency	Results in inadequate storage capacity
Contact slope between stone spillway and earth embankment too steep	Results in piping failure
Outlet pipe installed in vertical side of trench	Results in piping failure of embankment
Corrugated tubing used as outlet pipe	Results in crushed pipe and inadequate outlet capacity

Source: IDNR, 1992.

Maintenance

The primary maintenance consideration for temporary sediment traps is the removal of accumulated sediment from the basin, which must be done periodically to ensure the continued effectiveness of the sediment trap. Sediments should be removed when the basin reaches approximately 50 percent sediment capacity.

A sediment trap should be inspected after each rainfall event to ensure the trap is draining properly. Inspectors should also check the structure for damage from erosion or piping. The depth of the spillway should be checked and maintained at a minimum of 1.5 feet below the low point of the trap embankment.

Cost

The cost of installing temporary sediment traps ranges from $0.20 to $2.00 per cubic foot of storage (about $1,100 per acre of drainage). EPA estimated the following costs for sediment traps, which vary as a function of the volume of storage: $513 for 1,800 cubic yards, $1,670 for 3,600 cubic yards, and $2,660 for 5,400 cubic yards (USEPA, 1993). Evaluation of a series of more recent data sources (USEPA, 2003) indicated that sediment traps have an average cost of $0.30 per cubic foot of storage. In addition, it has been reported that a sediment trap has an annual maintenance cost of 20 percent of installation cost (Brown and Schueler, 1997).

5.1.5.3.5 Sediment Basin

General Description

A sediment basin is a storm water detention structure formed by constructing a dam across a drainageway or excavating a storage volume at other suitable locations and using it to intercept sediment-laden runoff. Sediment basins are generally larger and more effective in retaining sediment than temporary sediment traps and typically remain active throughout the construction period. Jurisdictions that require postdevelopment flow to be less than or equal to predevelopment flow during construction may employ the designed detention facilities as a temporary sediment basin during construction.

When sediment basins are designed properly, they can control sediment pollution through the following functions (Faircloth, 1999):

- Sediment-laden runoff is caught to form an impoundment of water and create conditions where sediment will settle to the bottom of the basin.
- Treated runoff is released with less sediment concentration than when it entered the basin.
- Storage is provided for accumulated sediment, and resuspension by subsequent storms is limited.

Applicability

Sediment basins should be located at a convenient concentration point for sediment-laden flows (NCDNR, 1988). Ideal sites are areas where natural topography allows a pond to be formed by constructing a dam across a natural swale; such sites are preferred to those that require excavation (Smolen et al., 1988).

Sediment basins are also applicable in drainage areas where it is anticipated that other erosion controls, such as sediment traps, will not be sufficient to prevent off-site transport of sediment. Choosing to construct a sediment basin with either an earthen embankment or a stone/rock dam will depend on the materials available, location of the basin, and desired capacity for storm water runoff and settling of sediments.

Rock dams are suitable where earthen embankments would be difficult to construct or where riprap is readily available. Rock structures are also desirable where the top of the dam structure is to be used as an emergency overflow outlet. These riprap dams are best for drainage areas of less than 50 acres. Earthen damming structures are appropriate where failure of the dam will not result in substantial damage or loss of property or life. If properly constructed, sediment basins with earthen dams can handle storm water runoff from drainage basins as large as 100 acres.

Design and Implementation Criteria

Hydrologic Design

A sediment basin can be constructed by excavation or by erecting an earthen embankment across a low area or drainage swale. Sediment basins can be designed to drain completely during dry periods, or they can be constructed so that a shallow, permanent pool of water remains between storm events. Depending on the size of the basin constructed, the basin may be subject to additional regulation, particularly state and federal regulations related to dam safety.

Sediment basins can be used for any size watershed, but the U.S. Department of Transportation recommends a drainage area range of 5 to 100 acres (USDOT, 1995). Components of a sediment basin that must be considered in the hydrologic design include the following (Haan et al., 1994):

- A sediment storage volume sized to contain the sediment trapped during the life of the structure or between cleanouts.
- A permanent pool volume (if included) above the sediment storage to protect trapped sediment and prevent resuspension as well as providing a first flush of discharge that has been subjected to an extended detention period.
- A detention volume that contains storm runoff for a period sufficient to trap the necessary quantity of suspended solids.
- A principal spillway that can be a drop-inlet pipe and barrel, a trickle tube, or other type of controlled release structure.
- An emergency spillway that is designed to handle excessive runoff from the rarer events and prevent overtopping.

The following recommended procedures for conducting the hydrologic design are summarized from Haan et al. (1994).

Sediment Storage Volume. This volume should be sufficient to store the sediment trapped during the life of the structure or between cleanouts. Sediment storage volume can be calculated based on sediment yield using relationships such as the Revised Universal Soil Loss Equation with an appropriate delivery ratio (Renard et al., 1994) or a computer model such as SEDIMOT III (Barfield et al., 1996) or SEDCAD (Warner, 1998). Many design specifications, however, base the sediment storage volume on a volume per acre disturbed. This volume is highly site-specific, depending on rainfall distributions, soil types, and construction techniques. It is recommended that care be exercised in developing appropriate values to be sure that variations in rainfall throughout a state or region are incorporated in statutory requirements.

Permanent Pool Volume. Providing a first flush of discharge that has been subjected to an extended detention period can help to minimize degradation of water quality and justify some permanent pool. The recommended capacity of the permanent pool varies with the regulatory agency. The U.S. Department of Transportation, for example, recommends 67 cubic yards per acre (126 m^3/ha) (USDOT, 1995). If an effluent criterion such as allowable peak TSS or peak settleable solids is used, the final design of both permanent pool and detention volume should be selected only after using a computer model to predict the expected peak effluent concentrations.

Detention Volume. Storm runoff must be contained for a period of time sufficient to trap the necessary quantity of suspended solids. Since inflow is occurring simultaneously with outflow, the detention time for each plug of flow is different and should be considered individually. The size of the detention volume, as stated above, should also be developed in concert with determining the size of the permanent pool volume as well as the size of the principal spillway. When effluent TSS and settleable solids criteria are used, the size of the detention volume and permanent pool volume should be determined through a computer model calculation of expected effluent concentrations for a given design. The return period used to size the detention volume depends on the regulatory agency, but a return period of 10 years is typical for sediment basins that eventually become storm water detention ponds (i.e., are used to limit future flooding due to storm water). EPA's review of State construction site regulations found the majority of States specify detention volume in terms of cubic feet per acre that drains to the sediment basin. State design values range between 1,800 and 5,400 cubic feet per acre, with 3,600 cubic feet per acre as the typical value.

Principal Spillway. The principal spillway is a hydraulic outlet structure sized to provide the appropriate outflow rate to meet the effluent or trapping efficiency criteria. The principal spillway should have a dewatering device that slowly releases water contained in the detention storage over an extended period of time and at a rate determined to trap the required amount of sediment and/or provide for the appropriate effluent concentration in the design storm. The more common outlet structures are the drop-inlet structure and the trickle tube. Sizing of the principal spillway should follow standard design procedures with respect to hydrology and sediment considerations, but sizing the structure to simply pass the design storm is inappropriate and will not result in meeting an effluent or trapping efficiency standard. The size to be used in a given structure should be determined based on the effluent or trapping efficiency standard being targeted and site-specific hydrologic and soil conditions. Appropriate design will require the use of a computer model such as SEDIMOT III (Barfield et al., 1996) or design aids such as those developed for South Carolina (Hayes and Barfield, 1995). In general, the design is developed to maximize surface area, which will minimize peak discharge. Since failure of the dam could result in downstream damage, the design should be done and certified by a licensed engineer with expertise in hydrologic computation.

It has been proposed that a surface skimmer made of PVC, aluminum, or stainless steel and designed to prevent trash from clogging can also be used to replace conventional principal spillways. The skimmer puts the basin drain just below the water surface, allowing for a constant head rather than variable head from the bottom. It is proposed that the skimmer allows water to be released from the top of the basin, which would be the cleanest water, and that the skimmer

properly regulates the filling and draining of the basin (Fairchild, 1999). The skimmer floats on the surface of the basin and rises as water in the basin rises during a storm. After the storm the skimmer slowly releases water from the basin. As the basin drains, the skimmer settles to the bottom, draining the entire pool except for a pool directly under the skimmer. The skimmer can be attached directly to an outlet pipe that drains through the dam or can be attached to an outlet pipe through a riser. It is important to point out that use of the skimmer is controversial and not universally recognized as a good concept. Conventional hydraulic flow theory would not concur with the statement that the flow would come only from the surface, unless the pond had significant thermal gradients preventing flow from deeper levels. A single hole placed just above the sediment cleanout level can also dewater the basin slowly.

Emergency Spillway. Since overtopping of the dam can cause failure and downstream damage, an emergency spillway is necessary to handle excessive runoff from the larger, less frequent events and prevent overtopping. The design storm for the emergency spillway will depend on the hazard classification of the sediment basin. Typical return periods vary between 25 and 100 years, with 25 years recommended by the USDOT. Sizing of the emergency spillway is typically accomplished to simply transmit the rare event without eroding the base of the spillway. Procedures for making the hydrologic and hydraulic computations are summarized in Haan et al. (1994). Again, since failure of the dam could result in downstream damage, the design should be done and certified by a licensed engineer with expertise in hydrologic computation.

Installation Criteria

The embankment for permanent sediment basins should be designed using standard geotechnical construction techniques. The fill is typically constructed of earthen fill material placed and compacted in continuous layers over the entire length of the fill. USDOT recommends 6- to 8-inch layers (USDOT, 1995). The embankment should be stabilized with vegetation after construction of the basin. A cutoff trench should be excavated along the centerline of the dam to prevent excessive seepage beneath the dam and be sized using standard geotechnical computations. USDOT recommends that a minimum depth of the cutoff trench should be approximately 2 feet (600 mm), the height should be to the riser crest elevation, the minimum bottom width should be 4 feet (1.2 m) or wide enough for compaction equipment, and slopes should be no steeper than 1:1.

Sediment basins can also be constructed with rock dams in a design that is similar to a sediment basin with an earthen embankment. It is important to remember that rock fill is highly heterogeneous and that flow rates calculated with any available procedure are not likely to match those that will actually occur. Since sediment trapping is inversely proportional to flow rate, the trapping efficiency will be impacted significantly. No data are available to determine the variability of rock fill in actual installations so that confidence intervals can be placed on predicted flow rates. Such data should be collected and the confidence intervals calculated prior to recommending the use of rock dams as outlets on any structures other than sediment traps.

Effectiveness

The effectiveness of a sediment basin depends primarily on the sediment particle size and the ratio of basin surface area to inflow rate (Smolen et al., 1988; Haan et al., 1994). Basins with a large surface area-to-volume ratio will be most effective. Studies by Barfield and Clar (1985) showed that a surface area-to-peak discharge ratio of 0.01 acres per cubic foot would trap more than 75 percent of the sediment coming from the Coastal Plain and Piedmont regions in Maryland. This efficiency might vary for other regions of the country and should not be used as a national standard. Studies by Hayes et al. (1984) and Stevens et al. (2001), however, show that similar relationships can be developed for other locations.

Laboratory data collected on pilot-scale facilities are available on the trapping efficiency of sediment basins, effluent concentrations, dead storage and flow patterns, and the impacts of chemical flocculants on sediment trapping (Tapp et al., 1981; Wilson and Barfield, 1984; Griffin et al., 1985; Jarrett, 1999; Ward et al., 1977, 1979). In general, the laboratory studies show that pilot-scale ponds can be expected to trap 70 to 90 percent of sediment, depending on the sediment characteristics, pond volume, and flow rate. The trapping efficiency and effluent concentration are, in general, related to the overflow rate and can be reasonably well predicted using a plug flow model (Ward et al., 1977, 1979) and a Continuously Stirred Tank Reactor (CSTR) model (Wilson et al., 1982; Wilson et al., 1984). Extensive field-scale data are available on long term trapping efficiency in storm water detention basins (Brune, 1953) in which the annual trapping efficiency is related to the annual capacity inflow ratio of the basin. These structures are not representative of those used for sediment ponds but would be representative of those used for regional detention. A more limited database is available on single storm sediment trapping in the larger structures (Ward, et al., 1979) and on a field laboratory structure at Pennsylvania State University (Jarret et al., 1999).

For maximum trap efficiency, Smolen et al. (1988) recommend the following:

- Allow the largest surface area possible, maximize the length-to-width ratio of the basin to prevent short circuiting, and ensure use of the entire design settling area;
- Locate inlets for the basin at the maximum distance from the principal spillway outlet;
- Allow the maximum reasonable time to detain water before dewatering the basin; and,
- Reduce the inflow rate into the basin and divert all sediment-free runoff.

Jarett (1999) has shown that the smaller the depth of the basin, the more sediment is discharged. A 0.15-meter-deep (0.49-foot-deep) basin lost twice as much sediment as a 0.46-meter-deep (1.50-foot-deep) basin. Jarrett also found that the performance of a sediment basin will increase with the use of a skimmer in the principal spillway. The sediment discharged was 1.8 times greater with only a perforated riser than with a skimmer in the principal spillway. In addition, increasing the dewatering time, which will allow for more sediment deposition, decreases the sediment loss from the basin (Jarett, 1999).

Limitations

Neither a sediment basin with an earthen embankment nor a rock dam should be used in areas of continuously running water (live streams). The use of sediment basins is not intended for areas where failure of the earthen or rock dam will result in loss of life, damage to homes or other buildings, or interference with the use of public roads or utilities.

Because sediment basins are usually temporary structures, they are often designed poorly and rarely receive adequate attention and maintenance. As a result, these basins will not achieve the function for which they were designed, especially when conventional outlets cannot properly meter outflow to create an impoundment, thus allowing rapid release of sediment-laden water from the bottom of the basin to escape (Faircloth, 1999).

Common concerns associated with sediment basins are included in Table 5-21.

Table 5-21. Common Concerns Associated with Sediment Basins

Common Concern	Result
Improper compaction, omission of anti-seep collar, leaking pipe joints, or use of unsuitable soil	Results in piping failure along conduit
Inadequate vegetation or improper grading and sloping	Results in erosion of spillway or embankment slopes
Inadequate compaction or use of unsuitable soil	Results in slumping or settling of embankment
Steep side slopes	Results in bank failure due to slumping
Inadequate outlet protection	Results in erosion and caving below principal spillway
Basin not located properly for access	Results in difficult, ineffective, and costly maintenance
Sediment not properly removed	Results in inadequate storage capacity and potential resuspension
Lack of anti-flotation measures	Results in the riser and barrel being blocked with debris
Principal and emergency spillway on design plans	Results in improper disposal of accumulated sediment
Gravel clogging the dewatering system	Results in a safety or health hazard from pond water
Principal spillway too small	Results in frequent operation of emergency spillway and increased erosion potential

Source: IDNR, 1992.

Maintenance

Routine inspection and maintenance of sediment basins is essential to their continued effectiveness. Basins should be inspected after each storm event to ensure proper drainage from the collection pool and determine the need for structural repairs. Erosion from the earthen embankment or stones moved from rock dams should be repaired or replaced immediately.

Sediment basins must be located in an area that is easily accessible to maintenance crews for removal of accumulated sediment. Sediment should be removed from the basin when its storage capacity has reached approximately 50 percent. Trash and debris from around dewatering devices should be removed promptly after rainfall events.

Cost

If constructing a sediment basin with less than 50,000 cubic feet of storage space, the cost of installing the basin ranges from $0.20 to $1.30 per cubic foot of storage (approximately $1,100 per acre of drainage) with an average cost of approximately $0.60 per cubic foot of storage (USEPA, 1993). If constructing a sediment basin with more than 50,000 cubic feet of storage space, the cost of installing the basin ranges from $0.10 to $0.40 per cubic foot of storage (approximately $550 per acre of drainage) with an average cost of approximately $0.30 per cubic foot of storage (USEPA, 1993). A review of state highway project bids and county bonding estimates conducted in 2003 confirmed this value of $0.30 per cubic foot (USEPA, 2003). Annual maintenance costs are 25 percent of installation costs (Brown and Schueler, 1997).

As an alternative costing method, designers can use cost curves developed for permanent basins used to manage storm water from urban areas. However, since permanent storm water basins typically include design features that would not be included in temporary sediment basins, this approach is expected to greatly overestimate the actual costs to construct sediment basins. For many sites, sediment basins installed for erosion and sediment control during the construction phase are retained/modified to meet other runoff management requirements. For example, site flood prevention requirements for the 10-year rainfall event can be met with a pond made from a converted sediment basin. As a result, sediment basin installation costs are partially offset by a later cost reduction or savings. Work by the Center for Watershed Protection (1996) provides capital cost equations for different types of sediment basins for permanent installations. For example, for dry extended detention ponds, the following equation can be used to estimate costs:

$$CC = 8.16\ (Vs)^{0.78}$$

For all ponds regardless of type (including wet ponds), the following equation can be used:

$$CC = 20.18\ (Vs)^{0.70}$$

Where:
CC = base construction cost, not including design, engineering, and contingencies
Vs = Storage volume below the crest of the emergency spillway, in cubic feet

Design, engineering, and contingency costs are given as approximately 32 percent of the base construction costs. Base construction costs for permanent ponds are composed of approximately 48 percent excavation/grading cost, 36 percent control structure cost, and 16 percent appurtenances cost. R. S. Means (2000) suggests the cost to remove the eroded sediment collected in a small basin during construction is approximately $4 per cubic yard (this value includes a 100 percent surcharge for wet excavation). Disposal of material on-site will result in an additional cost that can only be computed from site-specific conditions. The cheapest management of dredged material is application to land areas adjacent to the basin followed with application of a vegetative cover.

5.1.5.4 Other Control Practices

5.1.5.4.1 Stone Outlet Structure

Description

A stone outlet structure is a temporary stone dike installed in conjunction with and as a part of an earth dike. The purpose of the stone outlet structure is to impound sediment-laden runoff, provide a protected outlet for an earth dike, provide for diffusion of concentrated flow, and allow the area behind the dike to dewater slowly. The stone outlet structure can extend across the end of the channel behind the dike or be placed in the dike itself. In some cases, more than one stone outlet structure can be placed in a dike.

Applicability

Stone outlet structures apply to any point of discharge where there is a need to discharge runoff at a protected outlet or to diffuse concentrated flow for the duration of the period of construction. The drainage area to this practice is typically limited to one-half acre or less to prevent excessive flow rates. The stone outlet structure should be located so as to discharge onto an already stabilized area or into a stable watercourse. Stabilization should consist of complete vegetative cover and paving that are sufficiently established to be erosion resistant.

Design and Installation Criteria

Design criteria are of two types, hydrologic design for a required trapping of sediment and/or flow rate to pass the design storm; and selection of appropriate installation criteria such that the stone outlet will perform as designed.

Hydrologic Design

The hydrologic design should be based on the design storm and standard hydraulic calculations. It should include the following considerations:

- Design rainfall and design storm. The design storm should be specified by the regulatory authority. Typically a return period of 2 to 5 years is used. Runoff rates should be calculated with standard hydrologic procedures as allowed by the regulatory authority.

- Drainage area. The drainage area to this structure is typically limited to less than half an acre to ensure that the flow rates are not excessive.

- Length of crest and height of stone fill. The crest length and height of stone fill should be of sufficient size to transmit the design storm without overtopping. The volume of water stored behind the dike can be estimated, but would require routing the storm flow in the design storm. Flow through the stone outlet can be calculated using the relationships of Herrera and Felton (1991) as modified by Haan et al. (1994). The height of the fill should be small enough to prevent excessive flow velocities through the stone fill and prevent undercutting.

- Outlet stabilization. The discharge from the stone outlet should be stabilized with vegetated waterways or riprap until the flow reaches a stable channel. Design of the stabilized outlet should follow procedures presented earlier.

Installation Criteria Specifications

A stone outlet structure should conform to the following specifications:

- The outlet should be composed of 2- to 3-inch stone or recycled concrete, but clean gravel may be used if stone is not available.

- The crest of the stone dike should be at least 6 inches lower than the lowest elevation of the top of the earth dike and should be level.

- The stone outlet structure should be embedded into the soil a minimum of 4 inches.

- The minimum length of the crest of the stone outlet structure should be 6 feet.

- The baffle board should extend 1 foot into the dike and 4 inches into the ground and be staked in place.

- The drainage area to this structure should be less than half an acre.

5.1.5.4.2 Rock Outlet Protection

Description

Rock outlet structures are rocks that are placed at the outfall of channels or culverts to reduce the velocity of flow in the receiving channel to nonerosive rates.

Applicability

This practice applies where discharge velocities and energies at the outlets of culverts are sufficient to erode the next downstream reach and is applicable to outlets of all types such as sediment basins, storm water management ponds, and road culverts.

Design and Installation Criteria

Hydrologic Design

Hydrologic design consists primarily of selecting the design runoff rate and sizing outlet protection. Standard hydrologic calculations should be used with an appropriate return period storm for the outlet being protected (typical return periods range from 2 to 10 years).

The process for sizing outlet protection involves selecting the type and geometry of the outlet protection and the size of the rock lining. The outlet protection may consist of a plunge pool (scour hole), an apron-type arrangement, or an energy dissipation basin (Haan et al., 1994). The design of each differs. Plunge pools are typically used for outlet pipes that are elevated above the water surface. Aprons are used for other types of outlets. Plunge pool geometry is based on the flow rate, pipe size and slope, tailwater depth, and size of the riprap lining (Haan et al., 1994). Apron dimensions are determined by the ratio of the tailwater depth to pipe diameter (Haan et al., 1994). Energy dissipation basins are used as an alternative to the plunge pool. Dimensions are a function of the brink depth in the pipe at the design flow, pipe diameter, and size of riprap (Haan et al., 1994). The size of the rock lining is a function of the discharge, pipe size, tailwater depth, and geometry selected. Details on sizing the rock are given in Haan et al. (1994).

The design method presented here applies to the sizing of rock riprap and gabions to protect a downstream area. It does not apply to rock lining of channels or streams. The design of rock outlet protection depends entirely on the location. Pipe outlets at the top of cuts or on slopes steeper than 10 percent cannot be protected by rock aprons or riprap sections due to reconcentration of flows and high velocities encountered after the flow leaves the apron.

Installation Criteria

The following criteria should be considered:

- Bottom grade: The outlet protection apron should be constructed with zero slope along its length. There should be no obstruction at the end of the apron. The elevation of the downstream end of the apron should be equal to the elevation of the receiving channel or adjacent ground.

- Alignment: The outer protection apron should be located so that there are no beds in the horizontal alignment.

- Materials: The outlet protection may be accomplished using rock riprap or gabions. Riprap should be composed of a well-graded mixture of stone sized so that 50 percent of the pieces, by weight, should be larger than the size determined using charts. The minimum d_{50} size to be used should be 9 inches. A well-graded mixture is defined as a mixture composed primarily of larger stone sizes but with a sufficient mixture of other sizes to fill the smaller voids between the stones. The diameter of the largest stone in such a mixture should be 2 times the size selected in Table 5-22 (MDE, 1994).

- Thickness: The SHA riprap specification values are summarized in Table 5-22.

Table 5-22. Riprap Sizes and Thicknesses (SHA Specifications)

	D_{50} (inches)	D_{100} (inches)	Thickness (inches)
Class I	9.5	15	19
Class II	16	24	32
Class III	23	34	46

- Stone Quality: Stone for riprap should consist of field stone or rough-hewn quarry stone. The stone should be hard and angular and of a quality that will not disintegrate on exposure to water or weathering. The specific gravity of the individual stones should be at least 2.5. Recycled concrete equivalent may be used provided it has a density of at least 150 pounds per cubic foot and does not have any exposed steel or reinforcing bars.

- Filters: A layer of material placed between the riprap and the underlying soil surface can prevent soil movement into and through the riprap to prevent piping, reduce uplift pressure, and collect water. Riprap should have a filter placed under it in all cases. A filter can be of two general forms: a gravel layer or a geotextile.

- Gabions: Gabion baskets may be used as rock outlet protection, provided they are made of hexagonal triple twist mesh with heavily galvanized steel wire. The maximum lined dimension of the mesh opening should not exceed 4.5 inches. The area of the mesh opening should not exceed 10 square inches. Gabions should be fabricated in such a manner that the sides, ends, and lid can be assembled at the construction site into a rectangular basket of the specified sizes.

Gabions should be of a single unit construction and should be installed according to the manufacturer's specifications. Foundation conditions should be the same as for placing rock riprap. Geotextiles should be placed under all gabions, and gabions must be keyed in to prevent undermining of the main gabion structure.

- The subgrade for the filter, riprap, or gabion should be prepared to the required lines and grades. Any fill required in the subgrade shall be compacted to a density of approximately that of the surrounding undisturbed material.

- The rock or gravel should conform to the specified grading limits when installed in the riprap or filter, respectively.

- Geotextiles should be protected from punching, cutting, or tearing. Any damage other than occasional small holes should be repaired by placing another piece of geotextile fabric over the damaged part or by completely replacing the geotextile fabric. All overlaps, whether for repairs or for joining two pieces of geotextile fabric, should be a minimum of 1 foot in length.

- Stone for the riprap or gabion outlets may be placed by equipment. They should be constructed to the full course thickness in one operation and in such a manner as to avoid displacement of underlying materials. Care should be taken to ensure that the stone is not placed so that rolling will cause segregation of stone by size, i.e., the stone for riprap or gabion outlets should be delivered and placed in a manner that will ensure that it is reasonably homogeneous, with smaller stones filling the voids between larger stones. Riprap must be placed in a manner to prevent damage to the filter blanket or geotextile fabric. Hand placement will be required to the extent necessary to prevent damage to the permanent works.

- Stone should be placed so that it blends in with the existing ground and the depth to the stone surface is sufficient to transmit the flow without spilling over onto the unprotected surface.

Effectiveness

There is currently no information on the effectiveness of rock outlet structures.

Limitations

Common problems with rock outlet structures include the following:

- If the foundation is not excavated deeply or wide enough, the flow cross-section might be restricted, resulting in erosion around the apron and scour holes at the outlet. Also, the riprap apron should be placed on a suitable foundation to prevent downstream erosion.

- If the riprap that is installed is smaller than specified, rock displacement might result; selectively grouting over the rock materials may stabilize the installation.

- If the riprap is not extended enough to reach a stable section of the channel, downstream erosion could result.

- If a filter is not installed under the riprap, stone displacement and erosion of the foundation might result.

Maintenance

Once a riprap outlet has been installed, the maintenance needs are very low. It should be inspected after high flows to see if scour has occurred beneath the riprap, if flows have occurred outside the boundaries of the riprap and caused scour, or if any stones have been dislodged. Repairs should be made immediately.

Cost

R. S. Means (2000) indicates machine-placed riprap costs of approximately $40 per cubic yard. For a riprap maximum size between 15 and 24 inches, a cubic yard of riprap will cover between 13.5 and 17 square feet at channel bed (assuming depth of riprap as given in Table 5-22). This suggests that riprap lining will be between $21 and $27 per square foot of outlet (includes materials, labor, and equipment, with overhead and profit). R. S. Means (2000) provides a cost range for gabions ($2.80 to $9 per square foot of coverage) for stone fill depths of 6 to 36 inches, respectively. These costs include all costs of materials, labor, and installation.

5.1.5.4.3 Sump Pit

Description

A sump pit is a temporary pit from which pumping is conducted to remove excess water while minimizing sedimentation. The purpose of the sump pit is to filter water being pumped to reduce sedimentation to receiving streams.

Applicability

Sump pits are constructed when water collects and must be pumped away during excavating, cofferdam dewatering, maintenance or removal of sediment traps and basins, or other uses as applicable, such as for concrete wash out.

Design and Installation Criteria

Hydrologic Design

The only hydrologic calculation is determining the expected flow rate and volume to be handled. This should follow standard hydrologic computational procedures based on design rainfall, surface and soil conditions, and the size of the pump.

Installation Criteria and Specifications

The number of sump pits and their locations should be determined by the designer and included on the plans. Contractors may relocate sump pits to optimize use, but discharge location changes should be coordinated with inspectors.

A perforated vertical standpipe should be wrapped with ½-inch hardware cloth and geotextiles and then placed in the center of an excavated pit, which is then backfilled with filter material ranging from clean gravel to stone. Water is then pumped from the center of the standpipe to a suitable discharge area such as into a sediment trap, sediment basin, or stabilized area.

A sump pit should conform to the following specifications:

- Pit dimensions are variable, with the minimum diameter being twice the diameter of the standpipe.
- The standpipe should be constructed by perforating a 12- to 36-inch diameter pipe, then wrapping it with ½-inch hardware cloth and geotextiles. The perforations should be ½-inch slits or 1-inch diameter holes placed 6 inches on center.
- The standpipe should extend 12 to 18 inches above the lip of the pit or riser crest elevation (basin dewatering), and filter material should extend 3 inches minimum above the anticipated standing water level.

Effectiveness

There is currently no information on the effectiveness of the sump pit.

Limitations

The sump pit must be properly maintained and pumped regularly to avoid clogging.

Maintenance

To maintain, sump pits must be removed and reconstructed when water can no longer be pumped out of the standpipe.

Cost

R. S. Means (2000) provides information appropriate for assessment of a wide range of dewatering scenarios (i.e., different sump sizes, dewatering durations, and discharge conditions). In general, installation of earthen sump pits are listed as costing approximately $1.50 per cubic foot of sump volume. Piping to and away from the sump ranges from $30 to $60 per linear foot. Pump rentals

and operation range between $150 and $500 per day of pumping, depending on the rate of dewatering. All costs include materials, labor, and equipment, with overhead and profit.

5.1.5.4.4 Sediment Tank

Description

A sediment tank is a compartmented container through which sediment-laden water is pumped to trap and retain sediment prior to pumping the water to drainageways, adjoining properties, and rights-of-way below the sediment tank site.

Applicability

A sediment tank should be used on sites where excavations are deep and space is limited, such as urban construction, where direct discharge of sediment-laden water to streams and storm drainage systems should be avoided.

Design and Installation Criteria

The location of sediment tanks should facilitate easy cleanout and disposal of the trapped sediment to minimize interference with construction activities and pedestrian traffic. The tank size should be determined according to the storage volume of the sediment tank, with 1 cubic foot of storage for each gallon per minute of pump discharge capacity.

Effectiveness

There is currently no information on the effectiveness of sediment tanks.

Limitations

The sediment tank does not provide any natural infiltration; thus, the trapped sediment and storm water must be disposed of properly.

Maintenance

To facilitate maintenance of sediment tanks, they need to be located with easy access for regular pump out. The rate at which a tank is pumped depends on site specific considerations such as rainfall and sediment loads to the system. Regular inspections will help to determine pump out frequency and prevent overloading and failure of the system.

Cost

There is currently no information on the cost of sediment tanks.

5.1.5.4.5 Stabilized Construction Entrance

Description

The purpose of stabilizing entrances to a construction site is to minimize the amount of sediment leaving the area as mud attached to tires. Installing a pad of gravel over filter cloth where construction traffic leaves a site can help stabilize a construction entrance. As a vehicle drives over the gravel pad, mud and other sediments are removed from the vehicle's wheels (sometimes by washing) and offsite transport of sediment is reduced. The gravel pad also reduces erosion and rutting on the soil beneath the stabilization structure. The fabric reduces the amount of rutting caused by vehicle tires by spreading the vehicle's weight over a larger soil area than just the tire width. The filter fabric also separates the gravel from the soil below, preventing the gravel from being ground into the soil.

Applicability

Stabilized construction entrances typically are installed at locations where construction traffic leaves or enters an existing paved road. However, the applicability of site entrance stabilization should be extended to any roadway or entrance where vehicles will access or leave the site.

From a public relations point of view, stabilizing construction site entrances can be a worthwhile exercise. If the site entrance is the most publicly noticeable part of a construction site, stabilized entrances can improve the appearance to passersby and improve public perception of the construction project by reducing the amount of mud tracked onto adjacent streets.

Design and Installation Considerations

Hydrologic Design

Not applicable.

Installation Criteria and Specifications

All entrances to a site should be stabilized before construction begins and further disturbance of the site area occurs. The stabilized site entrances should be long enough and wide enough so that the largest construction vehicle that will enter the site will fit in the entrance with room to spare. If many vehicles are expected to use an entrance in any one day, the site entrance should be wide enough for the passage of two vehicles at the same time with room on either side of each vehicle. For optimum effectiveness, a rock construction entrance should be at least 50 feet long and at least 10 to 12 feet wide (USEPA, 1992).
If a site entrance leads to a paved road, the end of entrance should be "flared" (made wider as in the shape of a funnel) so that long vehicles do not go off the stabilized area when turning onto or off of the paved roadway.

If a construction site entrance crosses a stream, swale, roadside channel, or other depression, a bridge or culvert should be provided to prevent erosion from unprotected banks.

Stone and gravel used to stabilize the construction site entrance should be large enough so that nothing is carried off-site with vehicle traffic. In addition, sharp-edged stone should be avoided to reduce the possibility of puncturing vehicle tires. Stone or gravel should be installed at a depth of at least 6 inches for the entire length and width of the stabilized construction entrance.

Effectiveness

Stabilizing construction entrances to prevent sediment transport off-site is effective only if all entrances to the site are stabilized and maintained. Also, stabilization of construction site entrances may not be very effective unless a wash rack is installed and routinely used (Corish, 1995), although this can be problematic for sites with multiple entrances that have high vehicle traffic.

Limitations

Although stabilizing a construction entrance is a good way to help reduce the amount of sediment leaving a site, some sediment may still be deposited from vehicle tires onto paved surfaces. To further reduce the chance that these sediments will pollute storm water runoff, sweeping of the paved area adjacent to the stabilized entrance is recommended.

For sites using wash stations, a reliable water source to wash vehicles before leaving the site might not be initially available. In this case, water may have to be trucked to the site at an additional cost. Discharge from the wash station should be directed to an appropriate sediment control structure.

Maintenance

Stabilization of site entrances should be maintained until the remainder of the construction site has been fully stabilized. Stone and gravel might need to be periodically added to each stabilized construction site entrance to maintain its effectiveness. Soil that is tracked offsite should be swept up immediately and disposed of properly.

For sites with wash racks at each site entrance, sediment traps will have to be constructed and maintained for the life of the project. Maintenance will entail the periodic removal of sediment from the traps to ensure their continued effectiveness.

Cost

Without a wash rack, construction site entrance stabilization costs range from $1,000 to $4,000. On average, the initial construction cost is approximately $2,000 per entrance. When maintenance costs are included, the average total annual cost for a 2-year period is approximately $1,500. If a wash rack is included in the construction site entrance stabilization, the initial construction costs range from $1,000 to $5,000, with an average initial cost of $3,000 per entrance. Total annual cost,

including maintenance for an estimated 2-year life span, is approximately $2,200 per year (USEPA, 1993).

5.1.5.4.6 Land Grading

Description

Land grading involves reshaping the ground surface to planned grades as determined by an engineering survey, evaluation, and layout. Land grading provides more suitable topography for buildings, facilities, and other land uses and helps to control surface runoff, soil erosion, and sedimentation both during and after construction.

Applicability

Land grading is applicable to sites with steep topography or easily erodible soils because it stabilizes slopes and decreases runoff velocity. Grading activities should maintain existing drainage patterns as much as possible.

Design and Installation Criteria

Before grading activities begin, decisions should be made regarding the steepness of cut-and-fill slopes and how the slopes will be protected from runoff, stabilized, and maintained. A grading plan that establishes which areas of the site will be graded, how drainage patterns will be directed, and how runoff velocities will affect receiving waters should be prepared. The grading plan also includes information regarding when earthwork will start and stop, establishes the degree and length of finished slopes, and dictates where and how excess material will be disposed of (or where borrow materials will be obtained if needed). Berms, diversions, and other storm water practices that require excavation and filling should also be incorporated into the grading plan.

One low-impact development technique that can be incorporated into a grading plan is site fingerprinting. This involves clearing and grading only those areas necessary for building activities and equipment traffic. Adhering to strict limits of clearing and grading helps to maintain undisturbed temporary or permanent buffer zones in the grading operation and provides a low-cost sediment control measure that will help reduce runoff and off-site sedimentation. The lowest elevation of the site should remain undisturbed to provide a protected storm water outlet before storm drains or other construction outlets are installed.

Effectiveness

Land grading is an effective means of reducing steep slopes and stabilizing highly erodible soils when implemented with storm water management and erosion and sediment control practices in mind. Land grading is not effective when drainage patterns are altered or when vegetated areas on the perimeter of the site are destroyed.

Limitations

Construction sites are routinely graded to prepare a site for buildings and other structures. Improper grading practices that disrupt natural storm water patterns might lead to poor drainage, high runoff velocities, and increased peak flows during storm events. Clearing and grading of the entire site without vegetated buffers promotes off-site transport of sediments and other pollutants. Grading plans should be designed with erosion and sediment control and storm water management goals in mind; grading crews should be carefully supervised to ensure that the plan is implemented as intended.

Maintenance

All graded areas and supporting erosion and sediment control practices should be periodically checked, especially after heavy rainfalls. All sediment should be promptly removed from diversions or other storm water conveyances. If washouts or breaks occur, they should be repaired immediately. Prompt maintenance of small-scale eroded areas is essential to prevent these areas from becoming significant gullies.

Cost

Land grading is practiced at virtually all construction sites—additional site planning to incorporate storm water and erosion and sediment controls in grading plans can require several hours of planning by a certified engineer or landscape architect. Extra time might be required to excavate diversions and construct berms, and fill materials might be needed to build up low-lying areas or fill depressions.

Where grading is performed to manage on-site storm water, R. S. Means (2000) suggests the cost of fine grading, soil treatment, and grassing to be approximately $2 per square yard of earth surface area. Shallow excavation/trenching (1 to 4 feet deep) with a backhoe in areas not requiring dewatering can be performed for $4 to $5 per cubic yard of removed material. Larger scale grading requires a site-specific assessment of an alternative grading apparatus and a detailed fill/excavation material balance to retain as much soil on site as possible.

5.1.5.4.7 Temporary Access Waterway Crossing

Description

A temporary stream crossing is a structure erected to provide a safe and stable way for construction vehicle traffic to cross a running watercourse. The primary purpose of such a structure is to provide streambank stabilization, to reduce the risk of damaging the streambed or channel, and to reduce the risk of sediment loading from construction traffic. A temporary stream crossing may be a bridge, culvert, or ford.

Applicability

Temporary stream crossings are applicable wherever heavy construction equipment must be moved from one side of a stream channel to the other or where lighter construction vehicles will cross the stream a number of times during the construction period. In either case, an appropriate method for ensuring the stability of the streambanks and preventing large-scale erosion is necessary.

A bridge or culvert is the best choice for most temporary stream crossings. If properly designed, each can support heavy loads, and materials used to construct most bridges and culverts can be salvaged after they are removed. Fords are appropriate in steep areas subject to flash flooding, where normal flow is shallow or intermittent across a wide channel. Fords should be used only where stream crossings are expected to be infrequent.

Design and Installation Criteria

Because of the potential for stream degradation, flooding, and safety hazards, stream crossings should be avoided on a construction site whenever possible. Consideration should be given to alternative site access routes before arrangements are made to erect a temporary stream crossing. If it is determined that a stream crossing is necessary, an area where the potential for erosion is low should be selected. The stream crossing structure should be installed during a dry period if possible to reduce sediment transport into the stream.

If needed, over-stream bridges are generally the preferred temporary stream crossing structure. The expected load and frequency of the stream crossing, however, will govern the selection of a bridge as the correct choice for a temporary stream crossing. These types of temporary bridges usually cause minimal disturbance to a stream's banks and cause the least obstruction to stream flow and fish migration. They should be constructed only under the supervision and approval of a qualified engineer.

As general guidelines for constructing temporary bridges, clearing and excavation of the stream shores and bed should be kept to a minimum. Sufficient clearance should be provided for floating objects to pass under the bridge. Abutments should be parallel to the stream and be placed on stable banks. If the stream is less than 8 feet wide at the point where a crossing is needed, no additional in-stream supports should be used. If the crossing is to extend across a channel wider than 8 feet (as measured from the top of one bank to the other), the bridge should be designed with one in-water support for each 8 feet of stream width.

A temporary bridge should be anchored by steel cable or chain on one side only to a stable structure on shore. Examples of anchoring structures include trees with a large diameter, large boulders, and steel anchors. By anchoring the bridge on one side only, there is a decreased risk of causing a downstream blockage or flow diversion if a bridge is washed out.

When constructing a culvert, filter cloth should be used to cover the streambed and streambanks to reduce settlement and improve the stability of the culvert structure. The filter cloth should extend a

minimum of 6 inches and a maximum of 1 foot beyond the end of the culvert and bedding material. The culvert piping should not exceed 40 feet in length and should be of sufficient diameter to allow for complete passage of flow during peak flow periods. The culvert pipes should be covered with a minimum of 1 foot of aggregate. If multiple culverts are used, at least 1 foot of aggregate should separate the pipes.

Fords should be constructed of stabilizing material such as large rocks.

Effectiveness

Both temporary bridges and culverts provide an adequate path for construction traffic crossing a stream or watercourse.

Limitations

Bridges can be considered the greatest safety hazard of all temporary stream crossing structures if not properly designed and constructed. Bridges might also prove to be more costly in terms of repair costs and lost construction time if they wash out or collapse (Smolen et al., 1988).

The construction and removal of culverts are usually very disturbing to the surrounding area, and erosion and downstream movement of sediments are often great. Culverts can also create obstructions to flow in a stream and inhibit fish migration. Depending on their size, culverts can be blocked by large debris and are therefore vulnerable to frequent blockage and washout.

If given a choice between building a bridge or a culvert as a temporary stream crossing, a bridge is preferred because of the relative minimal disturbance to streambanks and the opportunity for unimpeded flow through the channel. The approaches to fords often have high erosion potential. In addition, excavation of the streambed and approach to lay riprap or other stabilization material causes major stream disturbance. Mud and other debris are transported directly into the stream unless the crossing is used only during periods of low flow.

Maintenance

Temporary stream crossings should be inspected at least once a week and after all significant rainfall events. If any structural damage is reported to a bridge or culvert, construction traffic should be excluded until appropriate repairs are made. Streambank erosion should be repaired immediately.

Fords should be inspected closely after major storm events to ensure that stabilization materials remain in place. If the material has moved downstream during periods of peak flow, the lost material should be replaced immediately.

Cost

In general, temporary bridges are more expensive to design and construct than culverts. Bridges are also associated with higher maintenance and repair costs should they fail. Temporary bridging costs vary as a function of the width of the bridge span and the amount of time the bridge is installed. If the bridging is permanent, a mean cost of $50 per square foot for an 8-foot wide steel arch bridge (no foundation costs included) can be used for conceptual cost estimation (R. S. Means, 2000). If rental bridging is employed, then rates are probably on the order of 20 to 50 percent of the bridge (permanent) cost, but will vary based on the rental duration and mobilization distance.

5.1.5.4.8 Dust Control

General Description

Dust control measures are practices that help reduce ground surface and air movement of dust from disturbed soil surfaces. Construction sites are good candidates for dust control measures because land disturbance from clearing and excavation generates a large amount of soil disturbance and open space for wind to pick up dust particles. To illustrate this point, research at construction sites has established an average dust emission rate of 1.2 tons/acre/month for active construction (WA Dept. of Ecology, 1992). These airborne particles pose a dual threat to the environment and human health. First, dust can be carried off-site, thereby increasing soil loss from the construction area and increasing the likelihood of sedimentation and water pollution. Second, blowing dust particles can contribute to respiratory health problems and create an inhospitable work environment.

Applicability

Dust control measures are applicable to any construction site where dust is created and there is the potential for air and water pollution from dust traveling across the landscape or through the air. Dust control measures are particularly important in arid or semiarid regions where soil can become extremely dry and vulnerable to transport by high winds.

Also, dust control measures should be implemented on all construction sites where there will be major soil disturbances or heavy construction activity, such as clearing, excavation, demolition, or excessive vehicle traffic. Earthmoving activities are the major source of dust from construction sites, but traffic and general disturbances can also be major contributors (WA Dept. of Ecology, 1992).

The specific dust control measures implemented at a site will depend on the topography, land cover, soil characteristics and amount of rainfall at the site.

Design and Installation Criteria

When designing a dust control plan for a site, the amount of soil exposed will dictate the quantity of dust generation and transport. Therefore, construction sequencing and disturbing small areas at one time can greatly reduce problematic dust from a site. If land must be disturbed, additional temporary stabilization measures should be considered prior to disturbance.

A number of methods can be used to control dust from a site. The following is a brief list of control measures and their design criteria. Not all control measures will be applicable to a given site. The owner, operator, and contractors responsible for dust control should determine which practices accommodate their needs based on specific site and weather conditions.

Sprinkling/Irrigation: Sprinkling the ground surface with water until it is moist is an effective dust control method for haul roads and other traffic routes (Smolen et al., 1988). This practice can be applied to almost any site.

Vegetative Cover: In areas not expected to handle vehicle traffic, vegetative stabilization of disturbed soil is often desirable. Vegetative cover provides protection to surface soils and slows wind velocity at the ground surface, thus reducing the potential for dust to become airborne.

Mulch: Mulching can be a quick and effective means of dust control for a recently disturbed area (Smolen et al., 1988).

Wind Breaks: Wind breaks are barriers (either natural or constructed) that reduce wind velocity and therefore reduce the possibility of carrying suspended particles. Wind breaks can be trees or shrubs left in place during site clearing or constructed barriers such as a wind fence, snow fence, tarp curtain, hay bale, crate wall, or sediment wall (USEPA, 1992).

Tillage: Deep tillage in large open areas brings soil clods to the surface where they rest on top of dust, preventing it from becoming airborne.

Stone: Stone can be an effective dust deterrent for construction roads and entrances.

Spray-on Chemical Soil Treatments (palliatives): Examples of chemical adhesives include anionic asphalt emulsion, latex emulsion, resin-water emulsions, and calcium chloride. Chemical palliatives should be used only on mineral soils. When considering chemical application to suppress dust, consideration should be taken as to whether the chemical is biodegradable or water-soluble and what effect its application could have on the surrounding environment, including waterbodies and wildlife.

Table 5-23 shows application rates for some common spray-on adhesives as recommended by Smolen et al. (1988).

Table 5-23. Application Rates for Spray-On Adhesives

Spray on Adhesive	Water Dilution	Type of Nozzle	Application
Anionic Asphalt Emulsion	7:1	Coarse spray	1,200
Latex Emulsion	12.5:1	Fine spray	235
Resin in Water	4:1	Fine spray	300

Source: Smolen et al., 1988.

Effectiveness

Sprinkling/irrigation: Not available.

Vegetative cover: Not available.

Mulch: Can reduce wind erosion by 80 percent.

Wind breaks/barriers: For each foot of vertical height, an 8- to 10-foot deposition zone develops on the leeward side of the barrier. The barrier density and spacing will change its effectiveness at capturing windborne sediment.

Tillage: Roughening the soil can reduce soil losses by approximately 80 percent.

Stone: The sizes of the stone can affect the amount of erosion that will take place. In areas of high wind, small stones are not as effective as 20-cm stones.

Spray-on chemical soil treatments (palliatives): Effectiveness of polymer stabilization methods ranges from 70 to 90 percent.

Limitations

In areas where evaporation rates are high, water application to exposed soils may require near constant attention. If water is applied in excess, runoff may result from the site and possibly create conditions where vehicles could track mud onto public roads.

Chemical applications should be used sparingly and only on mineral soils (not high organic content soils) because their misuse can create additional surface water pollution from runoff or could contaminate ground water if infiltrated. Chemical applications might also present a health risk if excessive amounts are used.

Maintenance

Because dust controls are dependent on specific site conditions, including the weather, inspection and maintenance are unique for each site. Generally, however, dust control measures involving application of either water or chemicals require more monitoring than structural or vegetative

controls to remain effective. If structural controls are used, they should be inspected for deterioration on a regular basis to ensure they are still achieving their intended purpose.

Cost

Chemical dust control measures can vary widely in cost depending on specific needs of the site and level of dust control desired. One manufacturer of a chloride product estimated a cost of $1,089 per acre for application to road surfaces, but cautioned that cost estimates without a specific site evaluation can be inaccurate.

5.1.5.4.9 Storm Drain Inlet Protection

Description

Storm drain inlet protection measures are controls that help prevent soil and debris from on-site erosion from entering storm drain inlets. Typically, these measures are temporary controls that are implemented prior to large-scale disturbance of the surrounding site. These controls are advantageous because their implementation allows storm drains to be used during even the early stages of construction activities. The early use of storm drains during project development significantly reduces the occurrence of future erosion problems (Smolen et al., 1988).

Three temporary control measures to protect storm drain drop inlets are:

- Excavation around the perimeter of the drop inlet
- Fabric barriers around inlet entrances
- Block and gravel protection

Excavation around a storm drain inlet creates a settling pool to remove sediments. Weep holes protected by gravel are used to drain the shallow pool of water that accumulates around the inlet. A filter fabric barrier erected around an inlet can create an effective shield to sediment while allowing water to flow into the storm drain. This type of barrier can slow runoff velocity while catching soil and other debris at the drain inlet. Block and gravel inlet protection uses standard concrete blocks and gravel to form a barrier to sediments while permitting water runoff through select blocks that are laid sideways. In addition to these materials, limited temporary storm water drop inlet protection can also be achieved with the use of straw bales or sandbags to create barriers to sediment.

For permanent storm drain drop inlet protection after the surrounding area has been stabilized, sod can be installed as a barrier to slow storm water entry to storm drain inlets and capture sediments from erosion. This final inlet protection measure can be used as an aesthetically pleasing way to slow storm water velocity near drop inlet entrances and remove sediments and other pollutants from runoff.

A new technology that uses an insert trap into the inlet itself has been developed (Adams et al., 2000). This technique showed good results on initial tests, trapping more than 50 percent of the incoming sediment in flows typical of those into urban storm drains. This technique is being further developed with a pending patent application.

Applicability

All temporary controls should have a drainage area no greater than 1 acre of drainage area per inlet. It is also important for temporary controls to be constructed prior to disturbance of the surrounding landscape. Excavated drop inlet protection and block and gravel inlet protection are applicable to areas of high flow where overflow is anticipated into the storm drain. Fabric barriers are recommended for smaller, relatively flat drainage areas (slopes less than 5 percent leading to the storm drain).

Temporary drop inlet control measures are often used in combination with each other and with other storm water control techniques.

Design and Installation Considerations

Hydrologic Design

Hydrologic computations are not necessary with present technologies. A specified limitation of 1 drainage acre per inlet limits flow rates, dependent on local rainfall and runoff considerations.

Installation Criteria and Specifications

The following criteria should be followed until future research establishes better techniques:

- With the exception of sod drop inlet protection, these controls should be installed before any soil disturbance in the drainage area.

- Excavation around drop inlets should be dug a minimum of 1 foot deep (2 feet maximum) with a minimum excavated volume of 35 cubic yards per acre disturbed. Side slopes leading to the inlet should be no steeper than 2:1. The shape of the excavated area should be designed such that the dimensions fit the area from which storm water is anticipated to drain. For example, the longest side of an excavated area should be along the side of the inlet expected to drain the largest area.

- Fabric inlet protection is essentially a filter fence placed around the inlet. The fabric should not be used as a stand-alone sediment control measures. To increase inlet protection effectiveness, these practices should be used in combination with other measures, such as small impoundments or sediment traps (USEPA, 1992). Temporary storm drain inlet protection is not intended for use in drainage areas larger than 1 acre. Generally, storm water inlet protection measures are practical for relatively low sediment and low volume flows.

- Frequent maintenance of storm drain controls is necessary to prevent clogging. If sediment and other debris clog the water intake, drop intake control measures can actually cause erosion in unprotected areas.

Maintenance

All temporary control measures must be checked after each storm event. To maintain the sediment capacity of the shallow settling pools created from these techniques, accumulated sediment should be removed from the area around the drop inlet (i.e., from the excavated area, around the fabric barrier, or around the block structure) when the sediment storage is reduced by approximately 50 percent. Additional debris should be removed from the shallow pools on a periodic basis.

Weep holes in excavated areas around inlets can become clogged and prevent water from draining from the shallow pools that form. Should this happen, unclogging the water intake may be difficult and costly.

Cost

The cost of implementing storm drain drop inlet protection measures will vary depending on the control measure chosen. Generally, initial installation costs range from $50 to $150 per inlet, with an average cost of $100 (USEPA, 1993). Maintenance costs can be high (annually, up to 100 percent of the initial construction cost) because of frequent inspection and repair needs. The Southeastern Wisconsin Regional Planning Commission has estimated that the cost of installation of inlet protection devices ranges from $106 to $154 per inlet (SWRPC, 1991).

5.1.5.4.10 Polyacrylamide (PAM)

General Description

The term polyacrylamide (PAM) is a generic term that refers to a broad class of compounds. There are hundreds of specific PAM formulations, and all have unique properties that depend on polymer chain length and number and kinds of functional group substitutions along the chain. PAMs are classified according to their molecular weight and ionic charge and are available in solid, granular, liquid, or emulsion forms.

PAM's effectiveness to prevent or reduce erosion is due to its affinity for soil particles, largely via coulombic and Van der Waals attraction. These surface attractions enhance particle cohesion, stabilizing soil structure against shear-induced detachment and transport in runoff. In a soil application, PAM aggregates soil particles, increasing pore space and infiltration capacity and resulting in reduced runoff. These larger particle aggregates are less susceptible to raindrop and scour erosion, thus reducing the potential to mobilize sediments.

Applicability

Because of ease in application, PAM is well suited as a short-term erosion prevention BMP, especially for areas with limited access or steep slopes that hinder personnel from applying other cover materials. PAM can be used to augment other cover practice BMPs, though it can be effective when applied alone. Thus, the ease of application, low maintenance, and relatively low cost associated with PAM make it a practical solution to soil stabilization during construction.

Application Criteria

PAM can be applied to soil through either a dry granular powder or a liquid spray form. Optimal application rates to prevent erosion on construction sites are generally less than 1 kg/ha (approximately 1 lb/ac) (Tobiason et al., 2000). However, the concentration required can vary for specific soil properties and construction phases. WDOT (2002) suggests a dosage of 60 mg/L for roadway erosion and sediment control. This is higher than the rate recommended by the University of Nebraska for an agricultural application (10 parts per million). To put this into context, one half pound of PAM in1,000 gallons of water results in a PAM concentration of 60 mg/L, which treats 1 acre of exposed soil according to WDOT recommendations.

Effectiveness

A study performed in Dane County, Wisconsin, analyzed 15 meter square plots for runoff and sediment yield on a construction site. The study concluded that when a solution of PAM-mix with mulch/seeding was applied to dry soil and compared with the control (no PAM-mix application to dry soil), an average reduction of 93 percent in sediment yield was found. The lowest performance (average reduction in sediment yield of 77 percent) occurred when PAM-mix in solution was applied to moist soil. The application of dry PAM-mix to dry soil reduced sediment by 83 percent and decreased runoff by 16 percent when compared to the control. The results show that regardless of the application method, PAM-mix was effective in reducing sediment yield in the test plots (Roa-Espinosa et al., 2000).

A second study performed in Washington analyzed the runoff from three different construction sites: an erosion control test facility, a highway construction site, and an airport runway. Table 5-24 summarizes the 225 samples analyzed by Tobiason et al. (2000).

Table 5-24. Turbidity Reduction Values from PAM

	Volume, m^3	Turbidity Reduction (%)
Maximum	350	99.97
Median	285	97.6
Minimum	133	46

Limitations

Currently PAMs are most commonly produced as dry granules. They completely dissolve and remain dissolved if mixed properly. If added too quickly or if not stirred vigorously, the granules rapidly form nondissolvable gels on contact with water or collect in low turbulence areas as syrupy concentrations that dissolve slowly in an uncontrolled pattern over a period of hours or days (USDA, 1994). In addition, when spilled on hard surfaces, PAM solutions are extremely slippery and hazardous to foot and vehicle traffic. PAM dust is highly hygroscopic and, if inhaled, could impair breathing. Certain neutral and cationic PAMs at very high exposure levels produce irritation in humans and are somewhat toxic to certain aquatic organisms; therefore, PAM should be used in strict compliance with state and federal label requirements. Finally, although PAM is relatively inexpensive, there are considerable infrastructure needs and operating costs; thus, sophisticated onsite polymer treatment systems may not be appropriate for certain projects.

Cost

The cost of PAM ranges from $1.25 per pound to $5.00 per pound (Entry et al., 1999). The cost of PAM application depends on the system employed. PAM can be used in a centralized treatment system (e.g., at a sedimentation basin) to treat larger areas, or dispersed in granular or liquid form. In Tobiason et al. (2000), the startup costs for the batch treatment system amounted to $90,000. Monthly expenses averaged $18,000 for operations and maintenance and $13,000 for materials and equipment. The total costs for this phase totaled about $245,000, less than 1 percent of total construction costs. If dispersed through irrigation systems (for agriculture), the seasonal cost of PAM treatment is $9 to $15 per acre (Kay-Shoemake, et al., 2000), where a season probably requires between 5 and 10 applications.

For construction sites, it is more likely that PAM would be applied as an additive to the hydroseed mix and applied when final grade is established and cover vegetation is installed. There are numerous suppliers who provide PAM as a low-cost additive for hydroseeding, suggesting PAM application costs can be incorporated into that of hydroseeding ($540 to $700 per acre depending on which seed is applied). An additional cost would be incurred to sample site soils to customize the dosage and delivery mechanisms for individual sites. In addition, re-application of PAM in granular or liquid form to areas with rill development (poor vegetation cover) would require additional funds. Where re-application of granular PAM is used, R. S. Means (2000) suggests a cost of approximately $5 per 1,000 square feet for spreading soil admixtures by hand.

5.1.6 SUMMARY

The BMP information presented in sub-section 5.1 is summarized in Tables 5-25 through 5-28.

Table 5-25. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.1)

BMP Type	Physical Impact Mitigation		Other Impacts
	Receiving Water Quality	Downstream Impacts	
Planning/ Staging/ Scheduling	• Could be low cost. • One data set shows 42% reduction in sediment yield due to planning/staging/scheduling. • Requires additional advance planning and management. • Impact could be evaluated with models as well as experimentally since several computer models are available.	• Could be low cost. • Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No good cause-effect relationships available. • Other impacts not evaluated.
Vegetative Stabilization	• Could be low cost • Can be very effective in some cases with advance planning. • Can be important on streambanks. • Limited applicability in the active construction area. • Complements other practices. • Practice is seasonally dependent in most of nation. • Impact could be evaluated with models as well as experimentally since several computer models are available.	• Could be low cost. • Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No good cause-effect relationships available. • Other impacts not evaluated.
Grass-Lined Channels	• Long history of use in channels draining disturbed areas. • Well established procedures for design and extensive database on stable designs under widely varied conditions. • Some procedures are available, with limited validation, to obtain a first estimate of sediment trapping by grass-lined channels. • Limited database on trapping of sediment. • Maintenance is critical for pollution prevention.	• Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No good cause-effect relationships available. • Database shows wide variations in effectiveness in trapping chemicals. • Other impacts not evaluated.

Table 5-25. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.1)

BMP Type	Physical Impact Mitigation		Other Impacts
	Receiving Water Quality	Downstream Impacts	
Seeding	• Low-cost method for establishing vegetation. • Occurs near the end of active construction. • Requires significant time for establishment. • Needs a prepared seedbed. • Good database with impacts on soil erosion. • Should be supported by other BMPs.	• Should not be evaluated as stand-alone practice, but as part of a system. • Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No good cause-effect relationships available. • Other impacts not evaluated.
Sodding	• High-cost method of establishing vegetation. • Immediate stabilization. • Requires significant management attention during establishment. • Good database with impacts on soil erosion. • Very effective way of controlling erosion. • Works well for grass waterways and other significant problem areas. • Should be supported by other BMPs.	• Should not be evaluated as stand-alone practice, but as part of a system. • Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No good cause-effect relationships available. • Other impacts not evaluated.
Mulching	• Relatively low-cost method of providing cover. • Can be highly effective in reducing soil loss when properly anchored. • Good database with impacts on soil erosion. • Variety of materials can be used. • Installation is rapid. • Not a stand-alone practice. • Due to interference with construction operations, the times that it can be used during active construction are limited.	• Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No good cause-effect relationships available. • Other impacts not evaluated.

Table 5-25. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.1)

BMP Type	Physical Impact Mitigation		Other Impacts
	Receiving Water Quality	Downstream Impacts	
Erosion Control Matting /Geotextiles	• Cost is highly variable. • Effectiveness in controlling sediment is variable depending on types of materials. • Can provide immediate protection to exposed soils. • Not a stand-alone practice. • Due to interference with construction operations, the times that it can be used during active construction are limited. • Disposal is a significant problem and may require landfilling. • Can be used for channel linings as astand-alone practice or under riprap. • Fair database on effectiveness in preventing erosion.	• Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No good cause-effect relationships available. • Other impacts not evaluated.
Vegetative Buffer Strips	• Can be highly effective in trapping sediment. • Effectiveness is well established and considerable data have been collected. • Well-validated models are available to predict the impacts of constructed filter strips on sediment trapping. • Models are included in watershed storm water and sediment models. • Modifications needed for natural riparian zones. • Require routine maintenance. • May be most appropriate where sediment loads are relatively low.	• Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No good cause-effect relationships available. • Other impacts not evaluated.
Topsoiling	• Important in vegetative establishment. • No protection until cover is established. • Not a stand-alone practice; must be supported by other BMPs. • No known information to describe effectiveness • Cost not currently available.	• Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology	• No good cause-effect relationships available. • Other impacts not evaluated.

Table 5-26. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.2)

BMP Type	Physical Impact Mitigation		Other Impacts
	Receiving Water Quality	Downstream Impacts	
Earth Dike	• Used to protect down slope areas. • Should be stabilized prior to use. • Requires maintenance after every major storm. • Can be significant source of sediment if not properly constructed. • Little data available on its effectiveness as a BMP. • Can be relatively inexpensive, depending on design. • Not a stand-alone procedure.	• No known information available.	• No known information available.
Temporary Swale	• Effectively a grass-lined drainage ditch with shallow side slopes. • Can be applied in many areas, but use limited in arid areas. • Contaminants that will harm vegetation, such as oils and greases, cannot be discharged to the system. • Continuous water flow cannot be tolerated by the grass lining. • Effectiveness depends on infiltration. Ground water pollution might occur in areas with a high water table. • Export of bacteria might occur. • Some studies show high removal efficiency for TSS, fair removal for nutrients, are variable removal for metals. • No general relationships available to predict impacts under widely varied climates and conditions, hence the effectiveness cannot be predicted for a given situation beyond the limited database.	• No known information available.	• No known information available.

Table 5-26. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.2)

BMP Type	Physical Impact Mitigation		Other Impacts
	Receiving Water Quality	Downstream Impacts	
Temporary Storm Drain Diversion (Pipe)	• Reroutes existing drainage systems. Primary benefit is to separate drainage water originating from undisturbed and construction and reduce the volume of water to be treated. • Can be combined with other structures, such as sediment traps, and used for sediment trapping. • Require little maintenance. • Requires outlet stabilization. Can be a significant source of sediment without outlet stabilization. • Can be costly, depending on size, installation, and removal.	• No known information available.	• No known information available.
Pipe Slope Drain	• Routes runoff from concentrated flow to stabilized areas. • Can be very effective in eliminating gully erosion problems, if properly installed and maintained. • Can be constructed from low-cost corrugated PVC, but must be anchored or buried along slope. • Needs to be checked frequently for sedimentation and other maintenance problems.	• No known information available.	• No known information available.

Table 5-26. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.2)

BMP Type	Physical Impact Mitigation		Other Impacts
	Receiving Water Quality	Downstream Impacts	
Stone Check Dams	• Reduces velocity of flow and prevents erosion. • Stabilizes channel slope on steep sections by stairstepping. • Can trap small percentages of sediment behind dam. • Used for short periods of time where channel lining is impractical. • Limited lab studies show high effectiveness, but very limited field studies show low trapping efficiency. Must be installed such that overtopping occurs over the rock fill and not around the perimeter. • Should not be used in continuously flowing streams. • Relatively expensive, if properly installed. • Procedures for predicting impact of properly installed stone check dams are available and incorporated into watershed computer models.	• No known information available.	• No known information available.
Lined Waterways	• Designed for stability and capacity. • Local rainfall-runoff conditions and linings will influence channel dimensions. • Require some maintenance during vegetative establishment. • Not designed as sediment removal device, but to prevent channel erosion.	• No known information available.	• No known information available.

Table 5-27. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.3)

BMP Type	Physical Impact Mitigation		Other Impacts
	Receiving Water Quality	Downstream Impacts	
Silt Fence	• Most widely recognized sediment control BMP. • Frequently poorly installed with few design considerations. • Maintenance is frequently poor, resulting in frequent failure. Frequent maintenance is required for proper operation. • Laboratory studies show fair to good sediment trapping by filter fence, but limited field studies do not show the same results. • Evaluations of installations show that failure is frequent and results from undercutting of the fabric and subsequent gully erosion. • Should not be installed where rocks and other hard surfaces prevent anchoring. • No validated procedures are available to predict the effectiveness of the filter fence in trapping sediment, primarily because of the lack of validated relationships for predicting flow through the filter fence. • Procedures for evaluating the anchoring requirements and support post requirements have not adequately accounted for variable soil strength conditions, resulting in frequent failure of the fence under loading.	• Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No good cause-effect relationships available. • Other impacts not evaluated.
Super Silt fence	• Modification of standard silt-fence to improve it structurally. • No validation information is available. • Recommended to be used where destruction of the silt fence will destroy critical areas. • More expensive than standard silt fence.	• Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No good cause-effect relationships available. • Other impacts not evaluated.

Table 5-27. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.3)

BMP Type	Physical Impact Mitigation		Other Impacts
	Receiving Water Quality	Downstream Impacts	
Straw Bale Dike	• Works by impounding water. • Primary trapping mechanism is by settling behind straw bale dike. • Information on performance is very limited with much variation in the limited data. • Should not be used in waterways or as a perimeter control due to biodegradation. • Idealized models of performance are available for systems that are properly installed.	• Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No good cause-effect relationships available. • Other impacts not evaluated.
Sediment Traps	• Formed by excavation and/or embankment. • Can simplify storm water control by trapping sediment at specific spots. • Can be installed quickly and serve as a short-term solution to sediment trapping in small areas. • May require cleanout. • Detailed models as well as simplified design aids are available to predict performance in trapping sediment. • Data on performance are available from both laboratory studies and field studies. • Will likely control only the settleable solids unless enhanced settling with chemical flocculation is performed.	• Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• Data for trapping nutrients are available, but show wide variation. • General models of nutrient trapping are not available. • Other impacts not evaluated.

Table 5-27. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.3)

BMP Type	Physical Impact Mitigation		Other Impacts
	Receiving Water Quality	Downstream Impacts	
Sediment Basins	• Normally formed by construction of a dam. • Storm water detention basin may serve as sediment basin during construction. • Can be used for any size watershed. • May require cleanout. • Data on performance are available both from laboratory studies and field studies. • Will likely control only the settleable solids unless enhanced settling is developed with chemical flocculation. • Most reliable and stable structure for obtaining high sediment trapping efficiency under widely varying conditions. • Must consider dam safety issues since dam failure is a reasonable possibility. • Structures are relatively large and can be expensive.	• Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• Data for trapping nutrients are available, but show wide variation. • General models of nutrient trapping are not available. • Other impacts not evaluated.

Table 5-28. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.4)

BMP Type	Physical Impact Mitigation		Other Impacts
	Receiving Water Quality	Downstream Impacts	
Stone Outlet Structures	• Porous outlet structure constructed of dumped rock, used as the outlet for earth dikes. • Requires a stabilized outlet channel until the flow reaches a stable channel. • Effectiveness data are limited to visual observations of field installations where failure occurred due to poor installation. • Models are available to predict the performance of stone outlets, but field data have not been collected to evaluate the accuracy of the model.	• No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• General models of nutrient trapping are not available. • Other impacts not evaluated.
Rock Outlet Protection	• Used to reduce velocity of flow in receiving channel and prevent scouring. • Very effective when properly installed. • Design procedures are well established. • Maintenance is low, if properly installed. • Should be inspected after high flows. • No data on impact.	• No data available.	• No data available.
Sump Pit	• Used to dewater during excavation. • Effectiveness not evaluated. • Potential exists to theoretically evaluate the BMP's effectiveness in trapping sediment. • Could be used at times other than storm flow, such as for removal of ground water flow.	• Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No data available.

Table 5-28. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.4)

BMP Type	Physical Impact Mitigation		Other Impacts
	Receiving Water Quality	Downstream Impacts	
Storm Drain Inlet Protection	• Used to trap sediment that would otherwise flow into storm drain inlet. • Should be installed prior to land disturbance. • Effectiveness in removing sediment has not been evaluated, but is thought to be low during construction. • Potential exists to use computer models to evaluate effectiveness. • Cost can be high for maintenance requirements. • Should not be used as stand-alone sediment control.	• Database is poor. • No validated urban runoff models available for theoretical analysis of downstream impacts. • Some potential exists to modify existing models to analyze downstream impacts on geomorphology.	• No data available.
Sediment Tank	• Portable sediment trap. • Flows are pumped in and out of the tank. • Used where spaced is limited. • No effectiveness data are available. • Expected to be relatively expensive.	• No data available.	• No data available.
Stabilized Construction Entrance	• Used to minimize mud and sediment attached to tires. • Consists of an area that is covered with rocks over which all vehicles must drive. • Can be combined with a wash station. • Effective only if all entrances are maintained. • Relatively expensive. • Will not remove highly cohesive clays.	• No data available.	• No data available.
Land Grading	• Stabilizes slopes and decreases runoff velocity. • Can be incorporated into low-impact development plans. • Not effective when drainage patterns are altered. • Not effective when vegetative areas on perimeter are destroyed. • Practiced at virtually all construction sites. • No data available on BMP effectiveness.	• No data available.	• No data available.

Table 5-28. Summary of Information on Erosion Control and Prevention BMPs (Sub-section 5.1.5.4)

BMP Type	Physical Impact Mitigation		Other Impacts
	Receiving Water Quality	Downstream Impacts	
Temp Access Waterways Crossing	• Reduces risk to damaging streambed from construction equipment. • Can be a bridge, culvert, or ford. • Bridges and culverts preferred, but more expensive. • Data on effectiveness in reducing sediment are not available.	• No data available.	• No data available.
Dust Control	• Important in arid and semi-arid regions. • Applicable to any construction site. • Construction sequencing and limiting exposure area can reduce problems. • Spray-on adhesives are recommended. • Water application may require near-constant attention. • Excess water may cause runoff or tracking of mud. • Very limited effectiveness information available. • Costs can vary widely, depending on local conditions.	• No data available.	• No data available.

5.2 REFERENCES

Adams, J, J. Janatzen, D. Loudenslager. 2000. *A device to alleviate pollution from urban stormwater.* Design Report, Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, OK.

ASCE. 1999, National Stormwater Best Management Practices (BMP) Database, prepared by the Urban Water Resources Research Council of the American Society of Civil Engineers, prepared for the US EPA, Office of Science and Technology, Washington, D.C,

Barfield, B. J. 2000. *Presentation on nonpoint source sediment and stormwater*. University of Puerto Rico, San Juan, PR.

Barfield, B. J., Barnhisel, R. I., Powell, J. C., Hirschi, M. C., and Moore, I. D. 1983. *Erodibilities and eroded size distribution of western Kentucky mine spoil and reconstructed topsoil.* Final Report for Title III. Institute for Mining and Minerals Research, University of Kentucky, Lexington, KY.

Barfield, B.J., and Clar, M. 1985. *Development of new design criteria for sediment traps and basins*. Prepared for the Maryland Resource Administration. Annapolis, MD, pp. 33.

Barfield, B. J., Haan, C. T., Stevens, E., and Hayes, J. C., K. F. Holbrook. 2001. *Engineering Design Aids for Sediment Control Practices.* Proceedings of the International Symposium on Soil Erosion Research for the 21st Century. January 3-5, 2001. Honolulu, Hawaii. Symposium Sponsored and Published by American Society of Agricultural Engineers. St. Joseph, Michigan.

Barfield, B. J. and Hayes, J. C. 1992. *Unpublished results of field evaluation of sediment controls in South Carolina construction operations.* Biosystems and Agricultural Engineering, Oklahoma State University, Stillwater, OK.

Barfield, B. J. and Hayes, J. C. 1999. *Unpublished results of field evaluation of sediment controls in Louisville, KY construction operations*. Biosystems andAgricultural Engineering, Oklahoma State University, Stillwater, OK

Barfield, B. J., Hayes, J. C., Fogle, A. W., and Kranzler, K. A. 1996. "The SEDIMOT III - Model of Watershed Hydrology and Sedimentology," Proceedings of Fifth Federal Interagency Sedimentation Conference, Las Vegas, NV. 1996.

Barfield, B. J., Moore, I. D., and Williams, R. G. 1979. "Sediment yield in surface mined watersheds." In *Proceedings symposium on surface mine hydrology, sedimentology, and reclamation*. College of Engineering, University of Kentucky, Lexington, KY.

Barrett, M. E., Kearney, J. E., McCoy, T. G., Malina, J. F.,Charbeneau, R. J. and Ward, G. H. 1995. *An evaluation of the use and effectiveness of temporary sediment controls*. Technical Report CRWR 261, Center for Research in Water Resources, The University of Texas at Austin, Austin, TX 78712.

Benik, S. R., B. N. Wilson, D. D. Biesboer, B. Hanse, and D. Stenlund. 1998. *The efficacy of erosion control products at a MN/DOT construction site*. Paper No. 982156, American Society of Agricultural Engineers, St. Joseph, MI

Blench, T. 1970. *Regime theory design of canals with sand beds*. Proceedings of the American Society of Civil Engineers. 96(IR2): 205-213.

Britton, S. L., Robinson, K. M., and Barfield, B. J. 2001. *Modeling the effectiveness of silt fence*. Proceedings 7th Federal Interagency Sedimentation Conference, Reno, NV.

Brown, W. and D. Caraco. 1997. "Muddy water in - muddy water out?". *Watershed protection techniques.* 2(3): 1997.

Brown, W. and T. Schueler. 1997. *The economics of stormwater BMPs in the Mid-Atlantic Region.* Prepared for: Chesapeake Research Consortium. Edgewater, MD. Center for Watershed Protection, Ellicott City, MD.

CWP. 1996. *Design of stormwater filtering systems.* Prepared for Chesapeake Research Consortium, Solomons, MD, and U.S. EPA Region 5, Chicago, IL, by Center for Watershed Protection, Ellicott City, MD.

Chang, H. H. 1988. *Fluvial processes in river engineering*. Wiley Interscience, New York, 432 p.

Claytor, R. 1997. "Practical tips for construction site phasing." *Watershed Protection Techniques.* 2(3): 1997.

Corish, K. 1995. *Clearing and grading strategies for urban watersheds*. Metropolitan Washington Council of Governments, Washington, DC.

Dorman, M.E., J. Hartigan, R.F. Steg and T. Quasebarth. 1989. *Retention, detention and overland flow for pollutant removal from highway stormwater runoff. Vol. 1. Research report.* Federal Highway Administration. FHWA/RD 89/202. Also in: "Performance of grassed swales along East Coast highways." *Watershed protection techniques* 1994 1(3): 122-123.

ECTC, 2002a. *Flexible Channel Lining System: The Benefits of Geosynthetically Reinforced Vegetation Over Rock Riprap*. Tim Lancaster, North American Green, Inc.; Don Lutyens, American Excelsior Company; Deron Austin, Synthetic Industries. Erosion Control Technology Council.

ECTC, 2002b. *ECTC Offers a Website Tool to Help Landscape Architects with Erosion Problems*. Laurie L. Honnigford. Erosion Control Technology Council.

Ellis, B. 1998. A further guide to swales: costs of operation and maintenance. *PERMEATE*. Scottish Environmental Protection Agency, Stirling, Scotland. <http://www.sepa.org.uk/guidance/scontrol/swales.htm>

Ettinger, C. E. and J. E. Lichty. 1979. *Evaluation of performance capability of surface mine sediment ponds*. Final Report on Contract Number 68-03-2677, Industrial Environmental Research Laboratory, US EPA.

Faircloth, W. 1999. "Searching for a practical, efficient, economical sediment basin." *Proceedings of Conference 30*, Nashville, TN, pp. 272-282.

Fifield, J. 1999. *Designing effective sediment and erosion control for construction sites*.

Fisher, L. S. and Jarrett, A. R. 1984. "Sediment retention efficiency of synthetic filter fabric". *Transactions of the American Society of Agricultural Engineers*. 30(1):82-89.

Foster, G. R., Young, R. A., and Neibling, W. H. 1985. "Sediment composition for nonpoint source pollution analyses." *Transaction of the American Society of Agricultural Engineers*. 28(1):133-146.

Gillman, J.W. 1994. "Riparian Wetlands and Water Quality". *Journal of Environmental Quality*. 23:896-900.

Goldberg. 1993. *Dayton Avenue swale biofiltration study*. Seattle Engineering Department, Seattle, WA.

Griffin, M. L., Barfield, B. J., and Warner, R. C. 1985. "Laboratory studies of dead storage in sediment ponds". *Transactions of the American Society of Agricultural Engineers.* 28(3):799-804.

Haan, C. T., Barfield, B. J., and Hayes, J. C. 1994. *Design hydrology and sedimentology for small catchments.* Academic Press, San Diego, CA.

Harding, M.V. 1990. *Erosion control effectiveness: comparative studies of alternative mulching techniques.* Environmental Restoration, pp. 149-156, as cited in USEPA. 1993. *Guidance specifying management measures for sources of nonpoint pollution in coastal waters*. EPA 840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Harper, H. 1988. *Effects of stormwater management systems on groundwater quality. Final report.* Environmental Research and Design, Inc. Prepared for Florida Department of Environmental Regulation. Also in: "Runoff and groundwater dynamics of two swales in Florida. *Watershed Protection Techniques.* Fall 1994 1(3): 120-121.

Hayes, J. C., B. J. Barfield and R. I. Barnhisel. 1984. Performance of grass filters under laboratory and field conditions. Transactions of the American Society of Agricultural Engineers 27(5): 1321-1331.

Hayes, J. C. and Barfield, B. J. 1995. Engineering aids and design guidelines for control of sediment in South Carolina. In *South Carolina stormwater and sediment control handbook for land disturbance activities.* S. C. D. H. E. C.

Hayes, J. C., Akridge, A. L., Barfield, B. J. and Holbrook, K. F. 2001. Simplifying Design of sediment controls in Jefferson County, Kentucky. In *Proceedings soil erosion research for the 21st Century: An international symposium and exhibition,* Honolulu, HA, January 2001. Sponsored by ASAE, 2950 Niles Road, St. Joseph MI 49085-9659

Herrera, N. M. and G. K. Felton. 1991. "Hydraulics of flow through a rockfill dam using sediment-free water." *Transactions of the American Society of Agricultural Engineers.* 34(3):871-875.

Heyer, T. No Date. *Vegetative measures for streambank stabilization*. U.S. Department of Agriculture, Forest Service, St, Paul, Minnesota.

Hirschi, M. C. 1981. "Efficiency of small sediment controls." Unpublished Agricultural Engineering File Report, Agricultural Engineering, University of Kentucky, Lexington, KY. (Details of the report are given in Chapter 9 of Haan et al, 1994).

Holbrook, K. F., Hayes, J. C. and Barfield, B. J., and A.W. Fogle. 1998. "Engineering aids and design guidelines for control of sediment in South Carolina," Conference Proceedings. February 1998.

IDNR. 1992. *Indiana handbook for erosion controls in developing areas, guidelines for protecting water quality through the control of soil and erosion and sedimentation on construction sites*. Division of Soil Conservation, Indiana Department of Natural Resources, Indianapolis, Indiana.

Jarrett, A. 1999. "Designing sedimentation basins for better sediment capture". In *Proceeding of Conference 30*, Nashville, TN, pp. 218-233.

Kay-Shoemake, J, M. Watwood, R. Sojka, and R. Lentz. 2000. "Soil amidase activity in polyacrylamide (PAM) treated soils and potential activity toward common amide containing agrochemicals". *Biology and Fertility of Soils* 31(2): 183-186.

Kercher, W.C., J.C. Landon and R. Massarelli. 1983. "Grassy swales prove cost-effective for water pollution control. *Public Works* 16: 53-55.

Knisel, W. G., ed. 1980. *CREAMS: A field-scale model for chemicals, runoff, and erosion from agricultural management systems*. U. S. Department of Agriculture, Conservation Research Report No. 26, 640 pp.

Koon, J. 1995. *Evaluation of water quality ponds and swales in the Issaquah/East Lake Sammamish Basins*. King County Surface Water Management and Washington Department of Ecology, Seattle, WA.

Kouwen, N. 1990. *Silt fences to control sediment on construction sites*. Technical Publication MAT-90-03, Research and Development Branch, Ontario Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario, Canada M3M 1J8.

Lane, E. W. 1955. The importance of fluvial geomorphology in hydraulic engineering. Proceedings American Society of Civil Engineering, 81: 1-17.

Leopold, Luna B., M. Gordon Wolman, and John P. Miller, 1964. *Fluvial processes in geomorphology*. Dover Publications, Inc. Mineola, NY.

Lindley, M., B. J. Barfield, J. Ascough, B. N. Wilson, and E. Stevens. 1998. "The surface impoundment element for WEPP". *Transactions ASAE*. 41(3):555-564.

Masters, A., K. A. Flahive, S. Mostaghimi, D. Vaughan, A. Mendez, M. Peterie, S. Radke. 2000. *A comparative investigation of the effectiveness of polyacrylamide (PAM) for erosion control in urban areas.* Paper No. 002176, American Society of Agricultural Engineers, St. Joseph, MI, pp. 21.

McBurnie, J. C., Barfield, B. J., Clar, M. L. and Shaver, E. 1990. "Maryland sediment detention pond design criteria and performance". *Applied Engineering in Agriculture*. 6(2):167-173.

MDE, 1994. *Maryland standards and specifications for soil erosion and sediment control*. Water Management Administration, Maryland Department of the Environment, Soil Conservation Service, and State Soil Conservation Committee, Baltimore, MD.

NAHB. No Date. *NAHB Research Center storm water runoff & nonpoint source pollution control guide for builders and developers*. National Association of Home Builders, Washington. DC.

NCDNR. 1988. *North Carolina erosion and sediment control planning and design manual*. North Carolina Sedimentation Control Commission, the North Carolina Department of Natural Resources and Community Development, and the North Carolina Agricultural Extension Service, Raleigh, North Carolina.

Oakland, P.H. 1983. "An evaluation of stormwater pollutant removal through grassed swale treatment." In *Proceedings of the International Symposium of Urban Hydrology, Hydraulics and Sediment Control*, H. J. Sterling, Lexington, KY.

Occoquan Watershed Monitoring Laboratory. 1983. *Final report: Metropolitan Washington Urban Runoff Project*. Prepared for the Metropolitan Washington Council of Governments, Manassas, VA.

Pitt, R. and J. McLean. 1986. *Toronto area watershed management strategy study: Humber River Pilot Watershed Project*. Ontario Ministry of Environment and Energy, Toronto, Ontario.

Roa-Espinosa, A., G.D. Bubenzer, and E.S.Miyashita. 2000. *Sediment and runoff control on construction sites using four application methods of polyacrylamide mix*. National Conference on ools for Urban Water Resource Management and Protection, Chicago, February 7-10, 2000, pp. 278- .

Renard, K. G., Foster G. R., Weesies, G. A., McCool, KD. K. and Yoder D. C. 1994. *Predicting soil erosion by water—A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE*). ARS Publication, U.S. Department of Agriculture.

Rosgen, D. L. 1996. Applied River Morphology, Wildland Hydrology, Pagosa Springs, CO.

R.S. Means. 2000. *Building Construction Cost Data 58th Annual Edition*. R.S. Means Co., Kingston, Massachusetts.

Seattle Metro and Washington Department of Ecology. 1992. *Biofiltration swale performance: recommendations and design considerations*. Publication No. 657. Water Pollution Control Department, Seattle, Washington. Also in: *Watershed Protection Techniques.* Fall 1994 1(3): 117-119.

SCDHEC. 1995. *South Carolina stormwater management and sediment reductions regulations.* In South Carolina Stormwater Management and Sediment Control Sedimentology Resource, SCDHEC.

Schumm, S. A. 1977. *The fluvial system*. John Wiley and Sons, New York. 338 pp

Simons, D.B., and M.L. Albertson, 1960. "Uniform water conveyance channels in alluvial material." *Proc. Am. Soc. Civil Engr*. 86(HY5):33-71

Smiley, J., and C. T. Haan. 1976. *The dam problem of urban hydrology*. Proceedings National Symposium on Urban Hydrology, Hydraulics, and Sediment Control, College of Engineering, University of Kentucky, Lexington, KY.

Smolen, M.D., D.W. Miller, L.C. Wyall, J. Lichthardt, and A.L. Lanier. 1988. *Erosion and sediment control planning and design manual.* North Carolina Sedimentation Control Commission and North Carolina Department of Natural Resources and Community Development, Raleigh, NC.

Snodgrass, W.J., B.W. Kilgour, L. Leon, N. Eyles, J. Parish, and D.R. Barton. 1998. *Applying ecological criteria for stream biota and an impact flow model for evaluation of sustainable urban water resources in southern Ontario*. In: Sustaining Urban Water Resources in the 21st Century. Proceedings for an Engineering Foundation Conference. Edited by A.C. Rowney, P. Stahre, and L.A. Roesner. Malmo, Sweden. September 7 - 12, 1997.

Sprague, J. 1999. *Assuring the Effectiveness of Silt Fences and Other Sediment Barriers*. TRI/Environmental, Inc., Greenville, South Carolina. Also in Proceedings of Conference 30. International Erosion Control Association. Nashville, Tennessee, February 22-26, 1999.

Stahre, P., and B. Urbonas. 1990. *Stormwater Detention For Drainage, Water Quality, and CSO Management*. Prentice Hall, Englewood Cliffs, New Jersey.

Stevens, L.E., et al. 2001. "Planned Flooding and Colorado River Riparian Trade-offs Downstream from Glen Canyon Dam, Arizona." *Ecological Applications*. 11(3): 701-710.

SWRPC. 1991. *Costs of urban nonpoint source water pollution control measures*. Technical report no. 31. Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin.

Tobiason, S., D. Jenkins, E. Molash, and S. Rush. 2000. "Polymer use and testing for erosion and sediment control on construction sites: Recent experience in the Pacific Northwest". In: *Proceedings of Conference 31*. International Erosion Control Association. Palm Spring, CA, February 21-25, 2000, pp. 41-52.

Tapp, J. S., and Barfield, B. J. 1986. "Modeling the flocculation process in sediment ponds". *Transactions ASAE*. 29(3):741-747.

Tapp, J. S., Barfield, B. J., and Griffin, M. L. 1981. *Predicting suspended solids removal in pilot scale sediment ponds utilizing chemical flocculation.* Research Report IMMR 81/063, Institute for Mining and Minerals Research, University of Kentucky, Lexington, KY.

UNEP. 1994. *Guidelines for sediment control practices in the insular Caribbean*. CEP Technical Report No. 32 UNEP Caribbean Environment Programme, Kingston, Jamaica. <http://www.cep.unep.org/pubs/techreports/tr32en/content.html>.

USAF. 1998. *USAF landscape design: Erosion control measures*. U.S. Air Force, St. Paul, Minnesota. <www.afcee.brooks.af.mil/dc/dcd/land/ldg/s18ErosionControl/c05Control.html>.

USDA. 1979. *Engineering Field Handbook.* U.S. Department of Agriculture, Soil Conservation Service, Washington, DC.

USDA-Agricultural Research Service. 1994. *Polyacrylamide (PAM): A New Weapon in the Fight Against Irrigation-induced Erosion*. Note #01 - 94. By R.E. Sojka and R.D. Lentz. USDA-ARS Northwest Irrigation and Soils Research Lab Station. Kimberly, ID.

USDOT. 1995. *Best management practices for erosion and sediment control*. Report No. FHWA-FLP-94-005. Eastern Federal Lands Highway Design, U.S Department of Transportation, Sterling, Virginia.

USEPA, 2003. Memo to Record on Erosion and Sediment Control Unit Costs.

USEPA. 1971. *Control of sediment resulting from construction of highways and land development*. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 1992. *Storm water management for construction activities: developing pollution prevention plans and best management practices.* EPA 832-R-92-005. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA. 1992. *Storm water management for industrial activities: developing pollution prevention plans and best management practices*. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA. 1993. *Guidance specifying management measures for sources of nonpoint pollution in coastal waters*. EPA 840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA. 2000. *Urban nonpoint source management measure guidance - draft*. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Vanderwel, D. and S. Abday. 1998. *An introduction to water erosion control*. Alberta, Agriculture, Food and Rural Development, Alberta, Canada.

VDCR. 1995. *Virginia erosion & sediment control field manual*. Second Edition. Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation, Richmond, Virginia.

VDCR. 2001. *Virginia erosion and sediment control law, regulations, and certification regulations*. Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation, Richmond, Virginia.

Wang, T., D. Spyridakis, B. Mar and R. Horner. 1981. *Transport, deposition and control of heavy metals in highway runoff*. FHWA-WA-RD-39-10. Department of Civil Engineering. University of Washington, Seattle, WA.

Ward, A. D., Haan, C. T., and Barfield, B. J. 1977. *Simulation of the sedimentology of sediment detention basins*. Research Report No. 103, Water Resources Research Institute, University of Kentucky, Lexington, KY.

Ward, A. D., Haan, C. T., and Tapp, J. S. 1979. *The DEPOSITS sedimentation pond design manual.* OISTL, Institute for Mining and Minerals Research, University of Kentucky, Lexington, KY.

Warner, R.C. and P.J. Schwab. 1998. SEDCAD 4 for Windows 95 & NT-Design Manual and User's Guide. Civil Software Design, Ames, IA.

Washington State Department of Ecology (WDEC). 1992. *Stormwater management manual for the Puget Sound Basin*. Technical Manual. Washington State Department of Ecology, Olympia, WA.

Welborn, C., and J. Veenhuis. 1987. *Effects of runoff controls on the quantity and quality of urban runoff in two locations in Austin, TX.* USGS Water Resources Investigations Report. 87-4004, pp. 88.

Williams, J. R. No Date. "Sediment yield prediction with Universal Equation using runoff energy factor". *Present and Prospective Technology for Predicting Sediment Yields and Sources*.

Publication ARS-S-40, Agricultural Research Service, U.S. Department of Agriculture, Washington, DC. pp.

Wilson, B. N., and Barfield, B. J. 1984. "A sediment detention pond model using CSTRS mixing theory." *Transactions American Society of Agricultural Engineers*. 27(5):1339-1344.

Wilson, B. N., Barfield, B. J., and Moore, I. D. 1982. *A hydrology and sedimentology watershed model.* Department of Agricultural Engineering, University of Kentucky, Lexington, KY.

Wischmeier, W. H. and D. D. Smith. 1965. *Predicting rainfall-erosion losses from cropland east of the Rocky Mountains-guide for selection of practices for soil and water conservation*. U. S. Department of Agriculture, Agricultural Handbook No. 282. 47 pp.

Wishowski, J. M., Mamo, M., and Bubenzer, G. D. 1998. *Trap efficiencies of filter fabric fence.* Paper No 982158, American Society of Agricultural Engineers, St. Joseph, MI.

Wyant, D. C. 1980. *Evaluation of filter fabric for use as silt fences*. VA Highway and Transportation Research Council, Richmond, VA.

WYDEQ. 1999. *Urban best management practices for nonpoint source pollution*. Point and Nonpoint Source Programs, Water Quality Division, Wyoming Department of Environmental Quality, Cheyenne, Wyoming. <http://deq.state.wy.us/wqd/urbbmpdoc.htm>

Yousef, Y., M. Wanielista, H. Harper, D. Pearce and R. Tolbert. 1985. *Best management practices: Removal of highway contaminants by roadside swales. Final report.* University of Central Florida. Florida Department of Transportation. Orlando, FL. Also in: Pollutant Removal Pathways in Florida Swales. *Watershed Protection Techniques*. Fall 1995. 2(1): 299-301.

Yu, S., S. Barnes and V. Gerde. 1993. *Testing of best management practices for controlling highway runoff.* Virginia Transportation Research Council. FHWA/VA-93-R16, pp. 60. Also in: Performance of Grassed Swales Along East Coast Highways. *Watershed Protection Techniques.* Fall 1994. 1(3): 122-123.

SECTION 6: REGULATORY DEVELOPMENT AND RATIONALE

In this section, the methodology used by EPA to develop regulatory options for the construction and land development industry is described. Following the June 2002 proposal, EPA held a public comment period that ended on December 23, 2002. A number of issues were raised through comments that prompted several changes in EPA's analyses as well as development of a revised regulatory option (Option 4). The complete comment response document can be found in the public docket. EPA also refined its costing, environmental assessment and economic analyses. Consideration of all of these references, as well as other information, led to EPA deciding not to promulgate final effluent limitations guidelines. The following section discusses the regulatory options evaluated for the final action. Costs of regulatory options are discussed in Section 7 of this document and a description of the environmental benefits estimation is presented in Section 8. Industry financial analyses can be found in the document "Economic Analysis for Final Action for Effluent Guidelines and Standards for the Construction and Development Category," EPA-821-B-04-002.

6.1 REGULATORY OPTIONS FOR FINAL ACTION

EPA considered a series of regulatory options. These options were designed to control the discharge of sediment, storm water and other pollutants from sites when construction is taking place. EPA considered a range of options that incorporate varying levels of management and various control strategies.

The following discussion presents various options that EPA considered.

6.1.1 OPTION 1 - INSPECTION AND CERTIFICATION

Option 1 would establish a series of site inspection and certification provisions as minimum requirements for all construction sites subject to the NPDES storm water regulations. The permittee is required to conduct periodic inspections and provide certifications as to certain activities (such as SWPPP preparation, BMP installation, periodic maintenance, etc.). These inspections and certifications are to be performed by a qualified professional, such as a registered professional engineer or person trained in erosion and sediment control. The permittee may provide self-certifications if qualified.

A summary of the inspection and certification provisions considered under this option are:

<u>Inspections</u>

A. Inspections must be conducted in accordance with one of the two schedules listed below. You must specify in your SWPPP which schedule you will be following.

    1. At least once every 7 calendar days, OR

2. At least once every 14 calendar days and within 24 hours of the end of a storm event of 0.5 inches or greater.

B. Inspection frequency may be reduced to at least once every month if:

1. The entire site is temporarily stabilized,

2. Runoff is unlikely due to winter conditions (e.g., site is covered with snow, ice, or the ground is frozen), or

3. Construction is occurring during seasonal arid periods in arid areas and semi-arid areas.

C. A waiver of the inspection requirements is available until one month before thawing conditions are expected to result in a discharge if all of the following requirements are met:

1. The project is located in an area where frozen conditions are anticipated to continue for extended periods of time (i.e., more than one month);

2. Land disturbance activities have been suspended; and

3. The beginning and ending dates of the waiver period are documented in the SWPPP.

D. Inspections must be conducted by qualified personnel (provided by the operator or cooperatively by multiple operators). "Qualified personnel" means a person knowledgeable in the principles and practice of erosion and sediment controls who possesses the skills to assess conditions at the construction site that could impact storm water quality and to assess the effectiveness of any sediment and erosion control measures selected to control the quality of storm water discharges from the construction activity.

E. Inspections must include all areas of the site disturbed by construction activity and areas used for storage of materials that are exposed to precipitation. Inspectors must look for evidence of, or the potential for, pollutants entering the storm water conveyance system. Sedimentation and erosion control measures identified in the SWPPP must be observed to ensure proper operation. Discharge locations must be inspected to ascertain whether erosion control measures are effective in preventing significant impacts to waters of the United States, where accessible. Where discharge locations are inaccessible, nearby downstream locations must be inspected to the extent that such inspections are practicable. Locations where vehicles enter or exit the site must be inspected for evidence of off-site sediment tracking.

F. Utility line installation, pipeline construction, and other examples of long, narrow, linear construction activities may limit the access of inspection personnel to the areas described in Subpart 3.10.E above. Inspection of these areas could require that vehicles compromise temporarily or even permanently stabilized areas, cause additional disturbance of soils, and increase the potential for erosion. In these circumstances, controls must be inspected on the

same frequencies as other construction projects, but representative inspections may be performed. For representative inspections, personnel must inspect controls along the construction site for 0.25 mile above and below each access point where a roadway, undisturbed right-of-way, or other similar feature intersects the construction site and allows access to the areas described above. The conditions of the controls along each inspected 0.25 mile segment may be considered as representative of the condition of controls along that reach extending from the end of the 0.25 mile segment to either the end of the next 0.25 mile inspected segment, or to the end of the project, whichever occurs first.

G. For each inspection required above, you must complete an inspection report. At a minimum, the inspection report must include:

1. The inspection date;

2. Names, titles, and qualifications of personnel making the inspection;

3. Weather information for the period since the last inspection (or since commencement of construction activity if the first inspection) including a best estimate of the beginning of each storm event, duration of each storm event, approximate amount of rainfall for each storm event (in inches), and whether any discharges occurred;

4. Weather information and a description of any discharges occurring at the time of the inspection;

5. Location(s) of discharges of sediment or other pollutants from the site;

6. Location(s) of BMPs that need to be maintained;

7. Location(s) of BMPs that failed to operate as designed or proved inadequate for a particular location;

8. Location(s) where additional BMPs are needed that did not exist at the time of inspection; and

9. Corrective action required including any changes to the SWPPP necessary and implementation dates.

10. On a site map, indicate the extent of all disturbed site areas and drainage pathways. Indicate site areas that are expected to undergo initial disturbance or significant site work within the next 14-day period;

11. Indicate on a site map all areas of the site that have undergone temporary or permanent stabilization;

12. Indicate all disturbed site areas that have not undergone active site work during the previous 14-day period;

13. Inspect all sediment control practices and note the approximate degree of sediment accumulation as a percentage of the sediment storage volume (for example 10 percent, 20 percent, 50 percent, etc.). Record all sediment control practices in the site log book that have sediment accumulation of 50 percent or more; and

14. Inspect all erosion and sediment control BMPs and record all maintenance requirements such as verifying the integrity of barrier or diversion systems (earthen berms or silt fencing) and containment systems (sediment basins and sediment traps). Identify any evidence of rill or gully erosion occurring on slopes and any loss of stabilizing vegetation or seeding/mulching. Document in the site log book any excessive deposition of sediment or ponding water along barrier or diversion systems. Record the depth of sediment within containment structures, any erosion near outlet and overflow structures, and verify the ability of rock filters around perforated riser pipes to pass water.

H. Prior to filing of the Notice of Termination or the end of permit term, a final site erosion and sediment control inspection shall be conducted by the operator or designated agent. The inspector shall certify that the site has undergone final stabilization using either vegetative or structural stabilization methods and that all temporary erosion and sediment controls (such as silt fencing) not needed for long-term erosion control have been removed.

A record of each inspection and of any actions taken in accordance with this Part must be retained as part of the SWPPP for at least three years from the date that permit coverage expires or is terminated. The inspection reports must identify any incidents of non-compliance with the permit conditions. Where a report does not identify any incidents of non-compliance, the report must contain a certification that the construction project or site is in compliance with the SWPPP and all applicable permit conditions.

Site Log Book/Certification

The operator shall maintain a record of site activities in a site log book, as part of the SWPPP. The site log book shall be maintained as follows:

A. A copy of the site log book shall be maintained on site and be made available to the permitting authority upon request. The operator shall make a copy of the site log book available to the public upon request within a reasonable period;

B. In the site log book, the operator shall certify, prior to the commencement of construction activities, that the SWPPP meets all Federal, State and local erosion and sediment control requirements and is available to the permitting authority;

C. The operator shall have a qualified professional conduct an assessment of the site prior to groundbreaking and certify that the appropriate BMPs and erosion and sediment controls described in the SWPPP have been adequately designed, sized and installed to ensure overall preparedness of the site for initiation of groundbreaking activities. The operator shall record the date of initial groundbreaking in the site log book. The operator shall also certify that the site inspections, soil stabilization activities, and maintenance activities required have been satisfied within 48 hours of actually meeting such requirements;

D. The operator shall post at the site, in a publicly-accessible location, a summary of the site inspection activities on a monthly basis, as well as contact information for obtaining a copy of the SWPPP and a copy of the site inspection log book;

6.1.2 OPTION 2 - CODIFY PROVISIONS OF THE EPA CONSTRUCTION GENERAL PERMIT WITH INSPECTION AND CERTIFICATION

Option 2 would require the permittee to prepare a storm water pollution prevention plan (SWPPP) and implement the erosion and sediment controls contained in the EPA Construction General Permit (CGP). In addition, the permittee would be required to conduct periodic site inspections and provide certifications in a site log book. This option would only apply to sites with 5 or more acres of disturbed land. The specific requirements considered under this option are:

Storm Water Pollution Prevention Plans

A. A SWPPP or equivalent document such as an erosion and sediment control plan or construction site storm water management plan must be prepared prior to submission of your Notice of Intent and prior to commencement of construction activities. At least one SWPPP must be developed for each construction project covered by your permit and each SWPPP must be prepared in accordance with good engineering practices.

B. The SWPPP must:

   A. Identify all potential sources of pollution which may reasonably be expected to affect the quality of stormwater discharges from the construction site;

   B. Describe practices to be used to reduce pollutants in storm water discharges from the construction site; and

C. Once a definable area has been finally stabilized, you may mark this on your SWPPP and no further SWPPP or inspection requirements apply to that portion of the site (e.g., earth-disturbing activities around one of three buildings in a complex are done and the area is finally stabilized, one mile of a roadway or pipeline project is done and finally stabilized, etc).

D. You must implement the SWPPP as written from commencement of construction activity until final stabilization is complete.

Pollution Prevention Plan Contents: Site and Activity Description

A. The SWPPP must identify all operators for the project site, and the areas of the site over which each operator has control.

B. The SWPPP must describe the nature of the construction activity, including:

   1. The function of the project (e.g., low density residential, shopping mall, highway, etc.);

   2. The intended sequence and timing of activities that disturb soils at the site;

   3. Estimates of the total area expected to be disturbed by excavation, grading, or other construction activities, including dedicated off-site borrow and fill areas; and

   4. A general location map (e.g., USGS quadrangle map, a portion of a city or county map, or other map) with enough detail to identify the location of the construction site and waters of the United States within one mile of the site.

C. The SWPPP must contain a legible site map, showing the entire site, identifying:

   1. Direction(s) of storm water flow and approximate slopes anticipated after major grading activities;

   2. Areas of soil disturbance and areas that will not be disturbed;

   3. Locations of major structural and nonstructural BMPs identified in the SWPPP;

   4. Locations where stabilization practices are expected to occur;

   5. Locations of off-site material, waste, borrow or equipment storage areas;

   6. Locations of all waters of the United States (including wetlands);

   7. Locations where storm water discharges to a surface water; and

   8. Areas where final stabilization has been accomplished and no further construction-phase permit requirements apply.

D. The SWPPP must describe and identify the location and description of any storm water discharge associated with industrial activity other than construction at the site. This includes storm water discharges from dedicated asphalt plants and dedicated concrete plants, that are covered by this permit.

Pollution Prevention Plan Contents: Controls to Reduce Pollutants

A. The SWPPP must include a description of all pollution control measures (i.e., BMPs) that will be implemented as part of the construction activity to control pollutants in storm water discharges. For each major activity identified in the project description the SWPPP must clearly describe appropriate control measures, the general sequence during the construction process in which the measures will be implemented, and which operator is responsible for the control measure's implementation.

B. The SWPPP must include a description of interim and permanent stabilization practices for the site, including a schedule of when the practices will be implemented. Site plans should ensure that existing vegetation is preserved where possible and that disturbed portions of the site are stabilized. Use of impervious surfaces for stabilization should be avoided.

C. The following records must be maintained as part of the SWPPP:

    1. Dates when major grading activities occur;

    2. Dates when construction activities temporarily or permanently cease on a portion of the site; and

    3. Dates when stabilization measures are initiated.

D. The SWPPP must include a description of structural practices to divert flows from exposed soils, retain/detain flows or otherwise limit runoff and the discharge of pollutants from exposed areas of the site. Placement of structural practices in floodplains must be avoided to the degree practicable.

E. The SWPPP must include a description of all post-construction storm water management measures that will be installed during the construction process to control pollutants in storm water discharges after construction operations have been completed. Structural measures should be placed on upland soils to the degree practicable. Such measures must be designed and installed in compliance with applicable federal, local, state or tribal requirements.

F. The SWPPP must describe measures to prevent the discharge of solid materials, including building materials, to waters of the United States, except as authorized by a permit issued under section 404 of the CWA.

G. The SWPPP must describe measures to minimize, to the extent practicable, off-site vehicle tracking of sediments onto paved surfaces and the generation of dust.

H. The SWPPP must include a description of construction and waste materials expected to be stored on-site with updates as appropriate. The SWPPP must also include a description of

controls, including storage practices, to minimize exposure of the materials to storm water, and spill prevention and response practices.

I. The SWPPP must include a description of pollutant sources from areas other than construction (including storm water discharges from dedicated asphalt plants and dedicated concrete plants), and a description of controls and measures that will be implemented at those sites to minimize pollutant discharges.

Non-Storm Water Discharge Management

The SWPPP must identify all sources of non-storm water discharges allowable under your permit, except for flows from fire fighting activities, that are combined with storm water discharges associated with construction activity at the site. Non-storm water discharges should be eliminated or reduced to the extent feasible. The SWPPP must identify and ensure the implementation of appropriate pollution prevention measures for the non-storm water component(s) of the discharge. Examples of non-storm water discharges that may be allowable under your permit include:

A. Fire hydrant flushings;
B. Waters used to wash vehicles where detergents are not used;
C. Water used to control dust;
D. Potable water including uncontaminated water line flushings;
E. Routine external building wash down that does not use detergents;
F. Pavement wash waters where spills or leaks of toxic or hazardous materials have not occurred (unless all spilled material has been removed) and where detergents are not used;
G. Uncontaminated air conditioning or compressor condensate;
H. Uncontaminated ground water or spring water;
I. Foundation or footing drains where flows are not contaminated with process materials such as solvents;
J. Uncontaminated excavation dewatering;
K. Landscape irrigation.

Maintenance of Controls

A. All erosion and sediment control measures and other protective measures identified in the SWPPP must be maintained in effective operating condition. If site inspections identify BMPs that are not operating effectively, maintenance must be performed as soon as possible and before the next storm event whenever practicable to maintain the continued effectiveness of storm water controls.
B. If existing BMPs need to be modified or if additional BMPs are necessary for any reason, implementation must be completed before the next storm event whenever practicable. If implementation before the next storm event is impracticable, the situation must be documented in the SWPPP and alternative BMPs must be implemented as soon as possible.

C. Sediment from sediment traps or sedimentation ponds must be removed when design capacity has been reduced by 50 percent.

Applicable State, Tribal, or Local Programs

The SWPPP must be consistent with all applicable federal, state, tribal, or local requirements for soil and erosion control and storm water management, including updates to the SWPPP as necessary to reflect any revisions to applicable federal, state, tribal, or local requirements for soil and erosion control.

Inspections

A. Inspections must be conducted in accordance with one of the two schedules listed below. You must specify in your SWPPP which schedule you will be following.

    1. At least once every 7 calendar days, OR

    2. At least once every 14 calendar days and within 24 hours of the end of a storm event of 0.5 inches or greater.

B. Inspection frequency may be reduced to at least once every month if:

    1. The entire site is temporarily stabilized,

    2. Runoff is unlikely due to winter conditions (e.g., site is covered with snow, ice, or the ground is frozen), or

    3. Construction is occurring during seasonal arid periods in arid areas and semi-arid areas.

C. A waiver of the inspection requirements is available until one month before thawing conditions are expected to result in a discharge if all of the following requirements are met:

    1. The project is located in an area where frozen conditions are anticipated to continue for extended periods of time (i.e., more than one month);

    2. Land disturbance activities have been suspended; and

    3. The beginning and ending dates of the waiver period are documented in the SWPPP.

D. Inspections must be conducted by qualified personnel (provided by the operator or cooperatively by multiple operators). “Qualified personnel” means a person knowledgeable in the principles and practice of erosion and sediment controls who possesses the skills to assess conditions at the construction site that could impact storm water quality and to assess the

effectiveness of any sediment and erosion control measures selected to control the quality of storm water discharges from the construction activity.

E. Inspections must include all areas of the site disturbed by construction activity and areas used for storage of materials that are exposed to precipitation. Inspectors must look for evidence of, or the potential for, pollutants entering the storm water conveyance system. Sedimentation and erosion control measures identified in the SWPPP must be observed to ensure proper operation. Discharge locations must be inspected to ascertain whether erosion control measures are effective in preventing significant impacts to waters of the United States, where accessible. Where discharge locations are inaccessible, nearby downstream locations must be inspected to the extent that such inspections are practicable. Locations where vehicles enter or exit the site must be inspected for evidence of off-site sediment tracking.

F. Utility line installation, pipeline construction, and other examples of long, narrow, linear construction activities may limit the access of inspection personnel to the areas described in Subpart 3.10.E above. Inspection of these areas could require that vehicles compromise temporarily or even permanently stabilized areas, cause additional disturbance of soils, and increase the potential for erosion. In these circumstances, controls must be inspected on the same frequencies as other construction projects, but representative inspections may be performed. For representative inspections, personnel must inspect controls along the construction site for 0.25 mile above and below each access point where a roadway, undisturbed right-of-way, or other similar feature intersects the construction site and allows access to the areas described above. The conditions of the controls along each inspected 0.25 mile segment may be considered as representative of the condition of controls along that reach extending from the end of the 0.25 mile segment to either the end of the next 0.25 mile inspected segment, or to the end of the project, whichever occurs first.

G. For each inspection required above, you must complete an inspection report. At a minimum, the inspection report must include:

1. The inspection date;

2. Names, titles, and qualifications of personnel making the inspection;

3. Weather information for the period since the last inspection (or since commencement of construction activity if the first inspection) including a best estimate of the beginning of each storm event, duration of each storm event, approximate amount of rainfall for each storm event (in inches), and whether any discharges occurred;

4. Weather information and a description of any discharges occurring at the time of the inspection;

5. Location(s) of discharges of sediment or other pollutants from the site;

6. Location(s) of BMPs that need to be maintained;

7. Location(s) of BMPs that failed to operate as designed or proved inadequate for a particular location;

8. Location(s) where additional BMPs are needed that did not exist at the time of inspection; and

9. Corrective action required including any changes to the SWPPP necessary and implementation dates.

10. On a site map, indicate the extent of all disturbed site areas and drainage pathways. Indicate site areas that are expected to undergo initial disturbance or significant site work within the next 14-day period;

11. Indicate on a site map all areas of the site that have undergone temporary or permanent stabilization;

12. Indicate all disturbed site areas that have not undergone active site work during the previous 14-day period;

13. Inspect all sediment control practices and note the approximate degree of sediment accumulation as a percentage of the sediment storage volume (for example 10 percent, 20 percent, 50 percent, etc.). Record all sediment control practices in the site log book that have sediment accumulation of 50 percent or more; and

14. Inspect all erosion and sediment control BMPs and record all maintenance requirements such as verifying the integrity of barrier or diversion systems (earthen berms or silt fencing) and containment systems (sediment basins and sediment traps). Identify any evidence of rill or gully erosion occurring on slopes and any loss of stabilizing vegetation or seeding/mulching. Document in the site log book any excessive deposition of sediment or ponding water along barrier or diversion systems. Record the depth of sediment within containment structures, any erosion near outlet and overflow structures, and verify the ability of rock filters around perforated riser pipes to pass water.

H. Prior to filing of the Notice of Termination or the end of permit term, a final site erosion and sediment control inspection shall be conducted by the operator or designated agent. The inspector shall certify that the site has undergone final stabilization using either vegetative or structural stabilization methods and that all temporary erosion and sediment controls (such as silt fencing) not needed for long-term erosion control have been removed.

A record of each inspection and of any actions taken in accordance with this Part must be retained as part of the SWPPP for at least three years from the date that permit coverage expires or is terminated. The inspection reports must identify any incidents of non-compliance with the permit

conditions. Where a report does not identify any incidents of non-compliance, the report must contain a certification that the construction project or site is in compliance with the SWPPP and all applicable permit conditions.

Maintaining an Updated Plan

A. The SWPPP, including the site map, must be amended whenever there is a change in design, construction, operation, or maintenance at the construction site that has or could have a significant effect on the discharge of pollutants to the waters of the United States that has not been previously addressed in the SWPPP.

B. The SWPPP must be amended if during inspections or investigations by site staff, or by local, state, tribal or federal officials, it is determined that the SWPPP is ineffective in eliminating or significantly minimizing pollutants in storm water discharges from the construction site.

C. Based on the results of an inspection, the SWPPP must be modified as necessary to include additional or modified BMPs designed to correct problems identified. Revisions to the SWPPP must be completed within seven (7) calendar days following the inspection. If existing BMPs need to be modified or if additional BMPs are necessary for any reason, implementation must be completed before the next storm event whenever practicable. If implementation before the next storm event is impracticable, the situation must be documented in the SWPPP and alternative BMPs must be implemented as soon as possible.

Management Practices

A. All control measures must be properly selected, installed, and maintained in accordance with any relevant manufacturer specifications and good engineering practices. If periodic inspections or other information indicates a control has been used inappropriately, or incorrectly, the operator must replace or modify the control for site situations as soon as practicable.

B. If sediment escapes the construction site, off-site accumulations of sediment must be removed at a frequency sufficient to minimize off-site impacts.

C. Litter, construction debris, and construction chemicals that could be exposed to storm water must be prevented from becoming a pollutant source in storm water discharges.

D. Except as provided below, stabilization measures must be initiated as soon as practicable in portions of the site where construction activities have temporarily or permanently ceased, but in no case more than 14 days after the construction activity in that portion of the site has temporarily or permanently ceased.

    1. Where stabilization by the 14th day is precluded by snow cover or frozen ground conditions, stabilization measures must be initiated as soon as practicable.

2. Where construction activity on a portion of the site is temporarily ceased, and earth disturbing activities will be resumed within 14 days, temporary stabilization measures do not have to be initiated on that portion of the site.

3. In arid, semiarid, and drought-stricken areas where initiating perennial vegetative stabilization measures is not possible within 14 days after construction activity has temporarily or permanently ceased, final vegetative stabilization measures must be initiated as soon as practicable.

E. A combination of sediment and erosion control measures are required to achieve maximum pollutant removal.

1. Sediment Basins: For common drainage locations that serve an area with 10 or more acres disturbed at one time, a temporary (or permanent) sediment basin that provides storage for a calculated volume of runoff from the drainage area from a 2-year, 24-hour storm, or equivalent control measures, must be provided where attainable until final stabilization of the site. Where no such calculation has been performed, a temporary (or permanent) sediment basin providing 3,600 cubic feet of storage per acre drained, or equivalent control measures, must be provided where attainable until final stabilization of the site. When computing the number of acres draining into a common location, it is not necessary to include flows from offsite areas and flows from on-site areas that are either undisturbed or have undergone final stabilization where such flows are diverted around both the disturbed area and the sediment basin. In determining whether installing a sediment basin is attainable, the operator may consider factors such as site soils, slope, available area on-site, etc. In any event, the operator must consider public safety, especially as it relates to children, as a design factor for the sediment basin, and alternative sediment controls must be used where site limitations would preclude a safe design.

2. For drainage locations which serve 10 or more disturbed acres at one time and where a temporary sediment basin or equivalent controls is not attainable, smaller sediment basins and/or sediment traps should be used. At a minimum, silt fences, vegetative buffer strips, or equivalent sediment controls are required for all down slope boundaries (and for those side slope boundaries deemed appropriate as dictated by individual site conditions).

3. For drainage locations serving less than 10 acres, smaller sediment basins and/or sediment traps should be used. At a minimum, silt fences, vegetative buffer strips, or equivalent sediment controls are required for all down slope boundaries (and for those side slope boundaries deemed appropriate as dictated by individual site conditions) of the construction area unless a sediment basin providing storage for a calculated volume of runoff from a 2-year, 24-hour storm or 3,600 cubic feet of storage per acre drained is provided.

F. Velocity dissipation devices must be placed at discharge locations and along the length of any outfall channel to provide a non-erosive flow velocity from the structure to a water course so

that the natural physical and biological characteristics and functions are maintained and protected (e.g., no significant changes in the hydrological regime of the receiving water).

Site Log Book/Certification

The operator shall maintain a record of site activities in a site log book, as part of the SWPPP. The site log book shall be maintained as follows:

A. A copy of the site log book shall be maintained on site and be made available to the permitting authority upon request. The operator shall make a copy of the site log book available to the public upon request within a reasonable period;

B. In the site log book, the operator shall certify, prior to the commencement of construction activities, that the SWPPP meets all Federal, State and local erosion and sediment control requirements and is available to the permitting authority;

C. The operator shall have a qualified professional conduct an assessment of the site prior to groundbreaking and certify that the appropriate BMPs and erosion and sediment controls described in the SWPPP have been adequately designed, sized and installed to ensure overall preparedness of the site for initiation of groundbreaking activities. The operator shall record the date of initial groundbreaking in the site log book. The operator shall also certify that the site inspections, soil stabilization activities, and maintenance activities required have been satisfied within 48 hours of actually meeting such requirements;

D. The operator shall post at the site, in a publicly-accessible location, a summary of the site inspection activities on a monthly basis, as well as contact information for obtaining a copy of the SWPPP and a copy of the site inspection log book;

6.1.3 OPTION 3 - NO REGULATION

EPA also considered an option that would not establish effluent guidelines or any additional requirements for this industry. This was the option selected for this final action.

6.1.4 OPTION 4 - CODIFY PROVISIONS OF THE EPA CONSTRUCTION GENERAL PERMIT

EPA developed a revised regulatory option for consideration for the final action that consists solely of codifying certain provisions of the EPA construction general permit. This option would not contain the inspection and certification provisions of Option 2, but would rather incorporate the inspection provisions contained in the July 2003 EPA construction general permit. This option would only apply to sites with 5 or more acres of disturbed land. The specific requirements considered for this option are:

Storm Water Pollution Prevention Plans

A. A SWPPP or equivalent document such as an erosion and sediment control plan or construction site storm water management plan must be prepared prior to submission of your Notice of Intent and prior to commencement of construction activities. At least one SWPPP must be developed for each construction project covered by your permit and each SWPPP must be prepared in accordance with good engineering practices.

B. The SWPPP must:

   A. Identify all potential sources of pollution which may reasonably be expected to affect the quality of stormwater discharges from the construction site;

   B. Describe practices to be used to reduce pollutants in storm water discharges from the construction site.

C. Once a definable area has been finally stabilized, you may mark this on your SWPPP and no further SWPPP or inspection requirements apply to that portion of the site (e.g., earth-disturbing activities around one of three buildings in a complex are done and the area is finally stabilized, one mile of a roadway or pipeline project is done and finally stabilized, etc).

D. You must implement the SWPPP as written from commencement of construction activity until final stabilization is complete.

Pollution Prevention Plan Contents: Site and Activity Description

A. The SWPPP must identify all operators for the project site, and the areas of the site over which each operator has control.

B. The SWPPP must describe the nature of the construction activity, including:

   1. The function of the project (e.g., low density residential, shopping mall, highway, etc.);

   2. The intended sequence and timing of activities that disturb soils at the site;

   3. Estimates of the total area expected to be disturbed by excavation, grading, or other construction activities, including dedicated off-site borrow and fill areas; and

   4. A general location map (e.g., USGS quadrangle map, a portion of a city or county map, or other map) with enough detail to identify the location of the construction site and waters of the United States within one mile of the site.

C. The SWPPP must contain a legible site map, showing the entire site, identifying:

1. Direction(s) of storm water flow and approximate slopes anticipated after major grading activities;

2. Areas of soil disturbance and areas that will not be disturbed;

3. Locations of major structural and nonstructural BMPs identified in the SWPPP;

4. Locations where stabilization practices are expected to occur;

5. Locations of off-site material, waste, borrow or equipment storage areas;

6. Locations of all waters of the United States (including wetlands);

7. Locations where storm water discharges to a surface water; and

8. Areas where final stabilization has been accomplished and no further construction-phase permit requirements apply.

D. The SWPPP must describe and identify the location and description of any storm water discharge associated with industrial activity other than construction at the site. This includes storm water discharges from dedicated asphalt plants and dedicated concrete plants, that are covered by this permit.

Pollution Prevention Plan Contents: Controls to Reduce Pollutants

A. The SWPPP must include a description of all pollution control measures (i.e., BMPs) that will be implemented as part of the construction activity to control pollutants in storm water discharges. For each major activity identified in the project description the SWPPP must clearly describe appropriate control measures, the general sequence during the construction process in which the measures will be implemented, and which operator is responsible for the control measure's implementation.

B. The SWPPP must include a description of interim and permanent stabilization practices for the site, including a schedule of when the practices will be implemented. Site plans should ensure that existing vegetation is preserved where possible and that disturbed portions of the site are stabilized. Use of impervious surfaces for stabilization should be avoided.

C. The following records must be maintained as part of the SWPPP:

1. Dates when major grading activities occur;

2. Dates when construction activities temporarily or permanently cease on a portion of the site; and

3. Dates when stabilization measures are initiated.

D. The SWPPP must include a description of structural practices to divert flows from exposed soils, retain/detain flows or otherwise limit runoff and the discharge of pollutants from exposed areas of the site. Placement of structural practices in floodplains must be avoided to the degree practicable.

E. The SWPPP must include a description of all post-construction storm water management measures that will be installed during the construction process to control pollutants in storm water discharges after construction operations have been completed. Structural measures should be placed on upland soils to the degree practicable. Such measures must be designed and installed in compliance with applicable federal, local, state or tribal requirements.

F. The SWPPP must describe measures to prevent the discharge of solid materials, including building materials, to waters of the United States, except as authorized by a permit issued under section 404 of the CWA.

G. The SWPPP must describe measures to minimize, to the extent practicable, off-site vehicle tracking of sediments onto paved surfaces and the generation of dust.

H. The SWPPP must include a description of construction and waste materials expected to be stored on-site with updates as appropriate. The SWPPP must also include a description of controls, including storage practices, to minimize exposure of the materials to storm water, and spill prevention and response practices.

I. The SWPPP must include a description of pollutant sources from areas other than construction (including storm water discharges from dedicated asphalt plants and dedicated concrete plants), and a description of controls and measures that will be implemented at those sites to minimize pollutant discharges.

Non-Storm Water Discharge Management

The SWPPP must identify all sources of non-storm water discharges allowable under your permit, except for flows from fire fighting activities, that are combined with storm water discharges associated with construction activity at the site. Non-storm water discharges should be eliminated or reduced to the extent feasible. The SWPPP must identify and ensure the implementation of appropriate pollution prevention measures for the non-storm water component(s) of the discharge. Examples of non-storm water discharges that may be allowable under your permit include:

A. Fire hydrant flushings;
B. Waters used to wash vehicles where detergents are not used;
C. Water used to control dust;
D. Potable water including uncontaminated water line flushings;
E. Routine external building wash down that does not use detergents;

F. Pavement wash waters where spills or leaks of toxic or hazardous materials have not occurred (unless all spilled material has been removed) and where detergents are not used;
G. Uncontaminated air conditioning or compressor condensate;
H. Uncontaminated ground water or spring water;
I. Foundation or footing drains where flows are not contaminated with process materials such as solvents;
J. Uncontaminated excavation dewatering;
K. Landscape irrigation.

Maintenance of Controls

A. All erosion and sediment control measures and other protective measures identified in the SWPPP must be maintained in effective operating condition. If site inspections identify BMPs that are not operating effectively, maintenance must be performed as soon as possible and before the next storm event whenever practicable to maintain the continued effectiveness of storm water controls.

B. If existing BMPs need to be modified or if additional BMPs are necessary for any reason, implementation must be completed before the next storm event whenever practicable. If implementation before the next storm event is impracticable, the situation must be documented in the SWPPP and alternative BMPs must be implemented as soon as possible.

C. Sediment from sediment traps or sedimentation ponds must be removed when design capacity has been reduced by 50 percent.

Applicable State, Tribal, or Local Programs

The SWPPP must be consistent with all applicable federal, state, tribal, or local requirements for soil and erosion control and storm water management, including updates to the SWPPP as necessary to reflect any revisions to applicable federal, state, tribal, or local requirements for soil and erosion control.

Inspections

A. Inspections must be conducted in accordance with one of the two schedules listed below. You must specify in your SWPPP which schedule you will be following.

    1. At least once every 7 calendar days, OR

    2. At least once every 14 calendar days and within 24 hours of the end of a storm event of 0.5 inches or greater.

B. Inspection frequency may be reduced to at least once every month if:

1. The entire site is temporarily stabilized,

2. Runoff is unlikely due to winter conditions (e.g., site is covered with snow, ice, or the ground is frozen), or

3. Construction is occurring during seasonal arid periods in arid areas and semi-arid areas.

C. A waiver of the inspection requirements is available until one month before thawing conditions are expected to result in a discharge if all of the following requirements are met:

1. The project is located in an area where frozen conditions are anticipated to continue for extended periods of time (i.e., more than one month);

2. Land disturbance activities have been suspended; and

3. The beginning and ending dates of the waiver period are documented in the SWPPP.

D. Inspections must be conducted by qualified personnel (provided by the operator or cooperatively by multiple operators). "Qualified personnel" means a person knowledgeable in the principles and practice of erosion and sediment controls who possesses the skills to assess conditions at the construction site that could impact storm water quality and to assess the effectiveness of any sediment and erosion control measures selected to control the quality of storm water discharges from the construction activity.

E. Inspections must include all areas of the site disturbed by construction activity and areas used for storage of materials that are exposed to precipitation. Inspectors must look for evidence of, or the potential for, pollutants entering the storm water conveyance system. Sedimentation and erosion control measures identified in the SWPPP must be observed to ensure proper operation. Discharge locations must be inspected to ascertain whether erosion control measures are effective in preventing significant impacts to waters of the United States, where accessible. Where discharge locations are inaccessible, nearby downstream locations must be inspected to the extent that such inspections are practicable. Locations where vehicles enter or exit the site must be inspected for evidence of off-site sediment tracking.

F. Utility line installation, pipeline construction, and other examples of long, narrow, linear construction activities may limit the access of inspection personnel to the areas described in Subpart 3.10.E above. Inspection of these areas could require that vehicles compromise temporarily or even permanently stabilized areas, cause additional disturbance of soils, and increase the potential for erosion. In these circumstances, controls must be inspected on the same frequencies as other construction projects, but representative inspections may be performed. For representative inspections, personnel must inspect controls along the construction site for 0.25 mile above and below each access point where a roadway, undisturbed right-of-way, or other similar feature intersects the construction site and allows access to the areas described above. The conditions of the controls along each inspected 0.25 mile segment

may be considered as representative of the condition of controls along that reach extending from the end of the 0.25 mile segment to either the end of the next 0.25 mile inspected segment, or to the end of the project, whichever occurs first.

G. For each inspection required above, you must complete an inspection report. At a minimum, the inspection report must include:

1. The inspection date;

2. Names, titles, and qualifications of personnel making the inspection;

3. Weather information for the period since the last inspection (or since commencement of construction activity if the first inspection) including a best estimate of the beginning of each storm event, duration of each storm event, approximate amount of rainfall for each storm event (in inches), and whether any discharges occurred;

4. Weather information and a description of any discharges occurring at the time of the inspection;

5. Location(s) of discharges of sediment or other pollutants from the site;

6. Location(s) of BMPs that need to be maintained;

7. Location(s) of BMPs that failed to operate as designed or proved inadequate for a particular location;

8. Location(s) where additional BMPs are needed that did not exist at the time of inspection; and

9. Corrective action required including any changes to the SWPPP necessary and implementation dates.

A record of each inspection and of any actions taken in accordance with this Part must be retained as part of the SWPPP for at least three years from the date that permit coverage expires or is terminated. The inspection reports must identify any incidents of non-compliance with the permit conditions. Where a report does not identify any incidents of non-compliance, the report must contain a certification that the construction project or site is in compliance with the SWPPP and all applicable permit conditions.

Maintaining an Updated Plan

A. The SWPPP, including the site map, must be amended whenever there is a change in design, construction, operation, or maintenance at the construction site that has or could have a

significant effect on the discharge of pollutants to the waters of the United States that has not been previously addressed in the SWPPP.

B. The SWPPP must be amended if during inspections or investigations by site staff, or by local, state, tribal or federal officials, it is determined that the SWPPP is ineffective in eliminating or significantly minimizing pollutants in storm water discharges from the construction site.

C. Based on the results of an inspection, the SWPPP must be modified as necessary to include additional or modified BMPs designed to correct problems identified. Revisions to the SWPPP must be completed within seven (7) calendar days following the inspection. If existing BMPs need to be modified or if additional BMPs are necessary for any reason, implementation must be completed before the next storm event whenever practicable. If implementation before the next storm event is impracticable, the situation must be documented in the SWPPP and alternative BMPs must be implemented as soon as possible.

Management Practices

A. All control measures must be properly selected, installed, and maintained in accordance with any relevant manufacturer specifications and good engineering practices. If periodic inspections or other information indicates a control has been used inappropriately, or incorrectly, the operator must replace or modify the control for site situations as soon as practicable.

B. If sediment escapes the construction site, off-site accumulations of sediment must be removed at a frequency sufficient to minimize off-site impacts.

C. Litter, construction debris, and construction chemicals that could be exposed to storm water must be prevented from becoming a pollutant source in storm water discharges.

D. Except as provided below, stabilization measures must be initiated as soon as practicable in portions of the site where construction activities have temporarily or permanently ceased, but in no case more than 14 days after the construction activity in that portion of the site has temporarily or permanently ceased.

   1. Where stabilization by the 14th day is precluded by snow cover or frozen ground conditions, stabilization measures must be initiated as soon as practicable.

   2. Where construction activity on a portion of the site is temporarily ceased, and earth disturbing activities will be resumed within 14 days, temporary stabilization measures do not have to be initiated on that portion of the site.

   3. In arid, semiarid, and drought-stricken areas where initiating perennial vegetative stabilization measures is not possible within 14 days after construction activity has temporarily or permanently ceased, final vegetative stabilization measures must be initiated as soon as practicable.

E. A combination of sediment and erosion control measures are required to achieve maximum pollutant removal.

1. Sediment Basins: For common drainage locations that serve an area with 10 or more acres disturbed at one time, a temporary (or permanent) sediment basin that provides storage for a calculated volume of runoff from the drainage area from a 2-year, 24-hour storm, or equivalent control measures, must be provided where attainable until final stabilization of the site. Where no such calculation has been performed, a temporary (or permanent) sediment basin providing 3,600 cubic feet of storage per acre drained, or equivalent control measures, must be provided where attainable until final stabilization of the site. When computing the number of acres draining into a common location, it is not necessary to include flows from offsite areas and flows from on-site areas that are either undisturbed or have undergone final stabilization where such flows are diverted around both the disturbed area and the sediment basin. In determining whether installing a sediment basin is attainable, the operator may consider factors such as site soils, slope, available area on-site, etc. In any event, the operator must consider public safety, especially as it relates to children, as a design factor for the sediment basin, and alternative sediment controls must be used where site limitations would preclude a safe design.

2. For drainage locations which serve 10 or more disturbed acres at one time and where a temporary sediment basin or equivalent controls is not attainable, smaller sediment basins and/or sediment traps should be used. At a minimum, silt fences, vegetative buffer strips, or equivalent sediment controls are required for all down slope boundaries (and for those side slope boundaries deemed appropriate as dictated by individual site conditions).

3. For drainage locations serving less than 10 acres, smaller sediment basins and/or sediment traps should be used. At a minimum, silt fences, vegetative buffer strips, or equivalent sediment controls are required for all down slope boundaries (and for those side slope boundaries deemed appropriate as dictated by individual site conditions) of the construction area unless a sediment basin providing storage for a calculated volume of runoff from a 2-year, 24-hour storm or 3,600 cubic feet of storage per acre drained is provided.

F. Velocity dissipation devices must be placed at discharge locations and along the length of any outfall channel to provide a non-erosive flow velocity from the structure to a water course so that the natural physical and biological characteristics and functions are maintained and protected (e.g., no significant changes in the hydrological regime of the receiving water).

SECTION 7: APPROACH TO ESTIMATING COSTS

7.1 OVERVIEW

This section describes EPA's methodology for estimating costs associated with implementing the regulatory options considered for the final action on construction and development effluent guidelines. EPA estimated three distinct cost categories:

1. Erosion and sediment control (ESC) costs, including design, installation, operation, and maintenance;

2. Administrative costs to permittees for activities such as conducting site inspections and providing certifications;

3. Opportunity and interest costs to permittees.

The methodology for determining costs for categories 1 and 2 are described in this document. Costs for category 3 are described in the document "Economic Analysis for Final Action for Effluent Guidelines and Standards for the Construction and Development Category," EPA-821-B-04-002.

For each state, per site costs were evaluated individually for 24 combinations of site-size and land use types. EPA developed per-site costs based on model construction sites that reasonably represent common construction site features, and factors related to state regulations, topography, and hydrology. Using estimates of the population of new construction acreage developed annually in the U.S. obtained from the USDA's National Resources Inventory (NRI) and the U.S. Census Bureau (described in Section 4 of this document), EPA computed State total costs by multiplying modeled per-site costs by the population of construction sites in each land use/site-size combination for 48 states. Costs for Alaska and Hawaii, as well as the U.S. territories were not estimated because EPA lacked data on the annual amount of construction in these areas. However, due to the small amount of construction that occurs in these areas, EPA expects that these values would be low in comparison to the national costs. National level costs were calculated by summing the State costs. The total costs of the options considered are presented in Table 7-1.

Table 7-1. Total Costs of Options

Option	Annual Cost (millions 2002 dollars)
1 - Inspection and Certification for sites ≥1 acre	$280
2 - Codify EPA Construction General Permit (CGP) with Inspection and Certification for sites ≥5 acres	$585
3 - No Regulation	$0
4 - Codify EPA Construction General Permit (CGP) for sites ≥5 acres	$380

As detailed below, EPA employed a three-step process to compute the total national compliance cost:

1. Model site costs were estimated using national average unit costs;

2. Model site costs were computed using state-specific cost adjustment factors;

3. State totals were summed to produce the national compliance cost estimates; and

7.2 ANALYSIS OF STATE EQUIVALENCY

State construction general permits, erosion and sediment control regulations, and storm water management regulations were collected and compiled to determine if existing state programs were equivalent to requirements contained in the July 2003 EPA Construction General Permit (CGP). The data were collected by reviewing state web sites for general permits, erosion and sediment control regulations, storm water management regulations, and erosion and sediment control and storm water BMP design and guidance manuals. States without web-accessible information were contacted to obtain the appropriate information

For the analysis of equivalency with the construction general permit, EPA focused on six main areas:

1. Requirements for preparing a storm water pollution prevention plan (SWPPP) or equivalent document and for installing general erosion and sediment controls, such as silt fencing, inlet protection and soil stabilization;

2. The amount of time allowed for providing stabilization of exposed soil when construction activities have temporarily or permanently ceased;

3. Requirements for installing sediment traps for drainage areas of less than 10 acres;

4. Requirements for installing sediment basins for drainage areas of 10 or more acres;

5. Requirements for removing accumulated sediment from sediment controls when sediment storage capacity has been reduced by at least 50%; and

6. Requirements to conduct inspections at least every 7 days OR every 14 days and following rainfall of 0.5" or more.

This analysis indicates that many States have requirements similar to those contained in the EPA construction general permit, which is the basis for the requirements contained in Options 2 and 4. No states currently have requirements equivalent to the inspection and certification provisions of Option 1 and 2. For each State, EPA's review determined if certain key BMPs are required, and for what construction site size a particular BMP is required. This information was used to determine the baseline BMP sizes and quantities for each of the 24 model construction sites in each state across the U.S. By comparing these sizes and quantities with those required under each regulatory option, the incremental BMP quantities and size increases can be calculated. For sediment basins and sediment traps, the size of the BMP required by the state program was also noted. Where a state program did not note a sediment basin size, EPA assumed based on BPJ that the baseline size was 1,800 cubic feet per acre. A summary of the state equivalency analysis as of September 2003 is presented in Table 7-2 and detailed data sheets for each state are presented in Appendix D.

Table 7-2. State Equivalency with EPA CGP Requirements

State	Seeding Required 14 Days After Construction Activity Ends	Basic Sediment Controls Required	Sediment Trap for Drainage Areas < 10 acres	Sediment Basin for Drainage Areas ≥ 10 acres	Sediment Removal when Storage Capacity Reduced 50% or More	Inspections every 7 days OR Every 14 Days and Following Storms ≥ 0.5 inches	Sediment Trap Storage Volume (ft^3/ acre drained)	Sediment Basin Storage Volume (ft^3/ acre drained)
Alabama		Yes		Yes	Yes			3,600
Alaska	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
Arizona	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
Arkansas	Yes	Yes	Yes	Yes		Yes	1,800	3,600
California		Yes		Yes				3,600
Colorado		Yes				Yes		1,800
Connecticut		Yes				Yes		1,800
DC	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
Delaware	Yes	Yes		Yes				3,600
Florida	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
Georgia	Yes	Yes				Yes		1,800
Hawaii		Yes				Yes		1,800
Idaho	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
Illinois	Yes	Yes				Yes		1,800
Indiana	Yes	Yes						1,800
Iowa	Yes	Yes	Yes	Yes		Yes	1,800	3,600
Kansas		Yes		Yes		Yes		3,600
Kentucky	Yes	Yes		Yes	Yes	Yes		3,600
Louisiana		Yes	Yes	Yes	Yes	Yes	1,800	3,600
Maine	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
Maryland		Yes						1,800
Massachusetts	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
Michigan		Yes		Yes		Yes		3,600
Minnesota		Yes		Yes	Yes	Yes		3,600
Mississippi		Yes		Yes	Yes	Yes		3,600

Missouri		Yes						1,800
Montana		Yes				Yes		1,800
Nebraska		Yes	Yes			Yes	1,800	1,800
Nevada	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
New	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
New Jersey		Yes						1,800
New Mexico	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
New York	Yes	Yes	Yes	Yes		Yes	1,800	3,600
North Carolina				Yes	Yes	Yes		3,600
North Dakota		Yes				Yes		1,800
Ohio	Yes	Yes				Yes		1,800
Oklahoma	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
Oregon		Yes			Yes	Yes		1,800
Pennsylvania		Yes	Yes	Yes	Yes		1,800	3,600
Rhode Island		Yes				Yes		1,800
South Carolina	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
South Dakota	Yes	Yes		Yes	Yes	Yes		3,600
Tennessee	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
Texas	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
Utah	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
Virginia	Yes	Yes	Yes	Yes	Yes	Yes	1,800	3,600
Vermont		Yes				Yes		1,800
Washington		Yes				Yes		1,800
West Virginia	Yes	Yes	Yes	Yes			1,800	3,600
Wisconsin		Yes				Yes		1,800
Wyoming		Yes			Yes	Yes		1,800

Note: “Yes” indicates that the requirement for the particular element is equivalent to that contained in the EPA CGP.

7.3 DEVELOPMENT OF MODEL CONSTRUCTION SITES AND ESTIMATES OF BMP QUANTITIES

In order to determine BMP quantities for baseline conditions as well as for the regulatory options considered, EPA developed a series of model construction sites that contained representative BMPs for each of the 24 site size and land use combinations developed in Section 4 (see Table 4-9). This analysis used four land use types to account for variations in amounts of ESC BMPs expected to be used across the range of land uses resulting from construction, and six site-size classes to account for economies of scale that might occur with the design and installation costs for certain BMPs (i.e., some BMPs are employed only if the site size is greater than a threshold value).

As documented in detail within Appendix A, six-site geometries (one per construction site size category) were developed on which to base this analysis. Each model construction site was placed within a model watershed system where first order watersheds occupy 25 acres, in order to define topography and preexisting drainage pathways. The assessment of 19 ecoregions found first order streams can occupy between 22 and 57 acres, and a 25 acre watershed represents a reasonable lower end value. Next, for each site-size category, the area within each model construction site was apportioned to three surface flow pathways:

1. Disturbed areas that drain to a centralized point;

2. Undisturbed areas that drain to a centralized point; and

3. Perimeter drainage that discharges in diffuse fashion through the site perimeter.

This was necessary in order to account for the fact that construction sites typically contain multiple drainage pathways due to the topography of the site. Proper BMPs selection and sizing should account for these drainage patterns, and a single site will typically employ different BMPs to serve various portions of the site. A 25-foot width of perimeter drainage was assumed for portions of site border that would likely drain radially outward and away from the site through perimeter BMPs such as silt fencing. For the central drainage portion of each model site, a pattern of internal drainage features (pipes and swales) that are commonly employed were assumed, with these areas ultimately draining to a sediment control practice such as a sediment trap or basin. The division between disturbed and undisturbed acreage within this central drainage area was based on land use specific pervious/imperviousness ratios provided by CWP (2001) and shown in Table 7-3. This distinction was necessary in order to account for two factors. First, portions of each site will be maintained in a relatively undisturbed state as open space, and will contribute little or no sediment. EPA assumed that one half of the pervious footprint on each site would remain undisturbed.

Table 7-4 shows the resulting percentage of site area for each of the three pathways introduced above, for each of the four land uses evaluated to categorize the industry.

Table 7-3. Land Use-Specific Impervious Cover Factors

Land Use Category	Percentage Impervious Cover	Percent Used in EPA Modeled Land Use
Agriculture	2	Not modeled
Low Density Residential	11-14	Not modeled
Medium Density Residential	21-28	24.3 for Single Family Residential
High Density Residential	33-44	43.4 for Multi-Family Residential
Industrial	53	52.8 for Industrial
Commercial	72	72 for Commercial

Source: Adapted from Capiella and Brown, 2001

Table 7-4. Percentage of Construction Site in Each of Three Flow Pathways

Site Size (acres)	Centralized Drainage (Disturbed Acreage)				Centralized Drainage (Undisturbed Acreage) *				Perimeter Drainage **			
	SF	MF	Comm	Ind	SF	MF	Comm	Ind	SF	MF	Comm	Ind
0.5***	0%	0%	0%	0%	38%	28%	24%	14%	34%	34%	34%	34%
3	42%	51%	56%	66%	38%	28%	24%	14%	20%	20%	20%	20%
7.5	42%	51%	56%	66%	38%	28%	24%	14%	20%	20%	20%	20%
25	55%	64%	69%	78%	38%	28%	24%	14%	8%	8%	8%	8%
70	54%	64%	68%	78%	38%	28%	24%	14%	8%	8%	8%	8%
200	55%	64%	69%	79%	38%	28%	24%	14%	7%	7%	7%	7%

* Assumed to retain original topography and vegetative cover.
** The portion of the site that drains radially outward toward the site boundary.
*** Note, the half-acre site group percentages do not add up to 100 percent because they do not include the site fraction that is disturbed but unmanaged because the site falls below the CGP minium site size of 1 acre. These sites do not experience any incremental changes as a result of the options, but are carried through the analysis in order to have a complete accounting of baseline sediment loads for the loadings and benefits analysis presented in Section 8.
SF = single family
MF = multi-family
Comm = commercial
Ind = industrial

After defining the site geometries and drainage pathways for each of the six site size categories, the BMP quantities and sizes required by the EPA CGP (the technical basis for Options 2 and 4) were determined based on BPJ. Appendices A and B contain detailed descriptions of each of the model sites developed. The specific BMPs contained in the model site analyses include:

- Silt Fencing
- Runoff Diversions/Inlet Protection
- Seeding and Mulching
- Stabilized Construction Entrances
- Stone Check Dams
- Sediment Traps
- Sediment Basins

In addition, EPA estimated the number of certifications required to meet the provisions of Options 1 and 2, and the number of site inspections required to meet the inspection provisions of the CGP. The BMP quantities for each of the model site sized required by the EPA CGP are shown in Table 7-5. Next, the baseline BMP quantities and sizes were determined for each of the six site size categories for each state based on the equivalency analysis contained in Table 7-2. Tables B-10 and B-11 contain detailed BMP quantities for the six site size categories for all 48 states (excluding Alaska and Hawaii). One important assumption was made that the amount of acreage requiring seeding and mulching for erosion control does not change from baseline conditions. The assumption is that the EPA CGP requirement to provide stabilization of exposed soil areas within 14 days after construction activities have temporarily or permanently ceased does not actually change the quantity of acreage requiring stabilization, but that it merely changes the timing by which the stabilization must occur. As a result, there are no additional costs attributable to this requirement.

This data on BMP quantities, in combination with the state-level estimates of the number of construction sites contained in Appendix E, allowed for estimation of the total number and size of BMPs implemented for all construction sites nationally under baseline conditions as well as under the EPA CGP (see Tables B-10 and B-11 in Appendix B, and note than Baseline conditions are listed as Option 3 in these tables). For the inspection and certification provisions of Options 1 and 2, EPA estimated the total number of professional hours required to conduct these activities for each of the site sizes. Multiplying by the state-level estimates of the number of construction sites allowed for estimation of the total number of hours required to conduct these activities.

Table 7-5. BMP Quantities Required by EPA CGP for Model Construction Sites

Site Size (acres)	Silt Fencing (linear miles	Inlet Protection (Installations)	Seeding and Mulching (acres)[3]	Number of Stabilized Construction Entrances	Number of Stone Check Dams	Sediment Traps[2]		Sediment Basins[1]	
						Number	Size Each (cubic feet)	Number	Size Each (cubic feet)
0.5	0.09	2	0.31/0.43	1	0	0	0	0	0
3	0.20	3	1.9/2.6	1	3	0	0	0	0
7.5	0.50	6	4.7/6.5	1	6	2	4,725/5,400	0	0
25	0.63	10	13/21.5	1	11	0	0	2	31,500/36,000
70	1.36	20	36.4/60.2	2	20	0	0	3	58,800/67,200
200	7.73	60	124/172	4	62	0	0	10	50,400/57,600

[1] Range demonstrates variation with land use. Sediment basins designed to 3,600 cubic feet per acre in volume (1,800 cubic feet of which is for sediment storage) applicable to States equivalent to National Construction General Permit. Divide values in half to obtain values for non-equivalent States.
[2] Range demonstrates variation with land use. Sediment or silt traps are designed based on 1,800 cubic feet per acre served.
[3] Ranges between 62 and 86 percent of the site acreage depending on land use

7.4 ESTIMATION OF BMP COSTS

Estimated unit cost data for each BMP element was derived from literature sources including R.S. Means (2000), data from the article "The Economics of Stormwater Treatment: An Update" (Schueler, 2000), from the EPA Nonpoint Source Management Measures Guidance (EPA, 1993), and from evaluation of a variety of references that contain BMP unit cost data, primarily bids on highway construction projects and municipal bonding requirements (EPA, 2003). National average unit costs for the BMPs contained in the cost model are given in Table 7-6.

A single unit cost factor was used for sediment basins and silt traps. While basin costs are expected to be non-linear (i.e., the unit cost for large basins is less than for small basins), no single costing relationship was identified that satisfied the range of basin sizes encountered in the model site sizes. Hence a constant value of $13,068 per acre-foot (or $0.30 per cubic foot) was used to estimate costs for all site sizes and all options. This value was taken from the EPA Nonpoint Source Management Measures Guidance (EPA, 1993). Since this reference was somewhat dated, EPA evaluated a number of additional data sources (EPA, 2003) to determine if the cost factor of $0.30 per cubic foot was still valid. Based on a review of 32 recent references, it was determined that the value of $0.30 per cubic foot was still valid. As a result, this value was used to determine the unit costs of all sediment basins and sediment traps.

For site inspection costs, EPA estimated that the average construction site would require 16 hours to conduct an inspection, with an average labor costs of $28 per hour. For certification costs, EPA estimated that the average construction site would require $455 per certification, with an average labor costs of $57 per hour.

In order to account for state-level variation in supply, material and labor costs, EPA used the state-level cost adjustment factors shown in Table 7-7. All unit costs in Table 7-6 were multiplied by these cost adjustment factors to arrive at state-specific unit costs. In addition, EPA added costs to account for BMP design, operation and maintenance. Design costs only apply to certain BMPs that in general require customization for each construction site. In addition, only certain BMPs will incur O & M costs over the duration of the assumed construction period (estimated to be 1 year). The estimated design costs as a percentage of installation costs are presented in Table 7-8.

Using the state estimates of BMP quantities contained in Tables B-10 and B-11 in Appendix B along with the unit costs and cost adjustment factors contained in Tables 7-6 and 7-7, the total national installation costs were calculated for each option as well as under the baseline condition. Adding design and O&M costs contained in Table 7-8, the total national compliance costs (without opportunity and interest costs) were determined. Tables B-12 and B-13 in Appendix B contain national and state-level total costs by regulatory option (note than Baseline conditions are listed as Option 3 in these tables). Contingency costs were added according to the methodology contained in the Economic Analysis document. Please see the EA for an explanation of this methodology, as well as for information on calculating the total costs of the regulatory options.

Table 7-6. Unit Cost Factors For BMPs

BMP	National Unit Cost Value (no profit or overhead)	Unit Cost Units	Data Source
Silt Fence	$4,857.60	Per Mile	R.S. Means
Runoff Diversion	$2,904.00	Per Mile	R.S. Means
Mulching for Erosion Control	$1,113.20	Per Acre	R.S. Means
Construction Entrances	$692.00	Per installation	R.S. Means
Rock Check Dam	$45.53	Per installation	R.S. Means
Silt Trap	$13,068.00	Per acre foot of storage	EPA, 1993
Sediment Basins	$13,068.00	Per acre foot of storage	EPA, 1993
Inlet Protection	$100.00	Per installation	R.S. Means
Installation Certification	$455.00	Per Certification	BPJ
E&S Site Inspection	$113.48	Per inspection	BPJ

Table 7-7. State Cost Adjustment Factors

State	Unit Cost Adjustment Factor	State	Unit Cost Adjustment Factor
AL	0.80	NC	0.77
AR	0.80	ND	0.81
AZ	0.92	NE	0.84
CA	1.13	NH	0.90
CO	0.92	NJ	1.10
CT	1.07	NM	0.89
DC	0.95	NV	1.00
DE	0.99	NY	1.15
FL	0.86	OH	0.95
GA	0.78	OK	0.83
IA	0.87	OR	1.07
ID	0.92	PA	1.00
IL	1.00	RI	1.06
IN	0.92	SC	0.75
KS	0.88	SD	0.86
KY	0.88	TN	0.82
LA	0.86	TX	0.85
MA	1.10	UT	0.87
MD	0.90	VA	0.86
ME	0.84	VT	0.84
MI	0.98	WA	1.04
MN	1.00	WI	0.97
MO	0.92	WV	0.95
MS	0.78	WY	0.83
MT	0.95		

Reference: R.S. Means, 2000

Table 7-8. Design and O & M Costs as a Percentage of Installation Costs

Costed Items	Design as a Percent of Installation Cost*	Operation and Maintenance Costs as a Percent of Installation Cost**
Silt Fence	16	100
Runoff Diversion	16	10
Mulching for Erosion Control	16	2
Construction Entrances	16	5
Rock Check Dam	16	5
Silt Trap	16	20
Sediment Basin	16	25

* Source: focus groups conducted with NAHB
** Source: Best Professional Judgement

7.5 REFERENCES

Cappiella, Karen, and K. Brown. 2001. *Impervious Cover and Land Use in the Chesapeake Bay Watershed.* Prepared by the Center for Watershed Protection for the USEPA Chesapeake Bay Program, Land Growth and Stewardship Subcommittee. January, 2001.

Omernik, James M. 1987. *Ecoregions of the conterminous United States*. Annals of the Association of American Geographers. 77(1): 118-125.

R.S. Means. 2000. *Site work & landscape cost data, 19th Edition*. R.S. Means Co., Kingston, MA.

Schueler, Thomas R. 2000. "The economics of stormwater treatment: An update." Article No. 68 in *The practice of watershed protection*. Center for Watershed Protection, Ellicott City, MD. <http://www.stormwatercenter.net>

USEPA, 2003. Memo to Record on Erosion and Sediment Control Unit Costs.

USEPA. 1999. *Economic analysis of the final Phase II storm water rule*. U.S. Environmental Protection Agency. Washington, DC.

SECTION 8: APPROACH TO ESTIMATING POLLUTANT LOAD REDUCTIONS AND ENVIRONMENTAL BENEFITS

8.1 OVERVIEW

This section describes EPA's methodology for assessing the pollutant load reductions and environmental benefits of the regulatory options developed. EPA only estimated loading reductions for Option 2 and 4. We were not able to develop a methodology for estimating loading reductions attributable to the inspection and certification provisions of Options 1 and 2. As a result, no loading reductions or benefits estimates were made for Option 1, and the loading reductions and benefits estimates of Option 2 are the same as those for Option 4.

Adverse environmental impacts attributable to construction activities have been well documented and include (but are not limited to) alteration of stream flow patterns, change in river channels, and reduction in the water quality of receiving waters as a result of increased generation and transport of sediment and other pollutants. Aquatic habitats also can be damaged as a result of reduced water quality and altered hydrology. These environmental impacts can in turn cause additional environmental and economic damage by increasing the frequency and magnitude of flooding events in vulnerable areas.

Sediment from eroded soil was used as an indicator of the total pollutant load discharged from construction sites because the models available to simulate soil and sediment generation, transport and removal are widely available and recognized. Although EPA expects that there are significant loadings of other pollutants (such as phosphorus and certain metals) generated at construction sites, and therefore significant reductions attributable to the regulatory options, there was no nationally-applicable data source available to estimate these values. As a result, the benefits analysis estimates loading reductions and benefits only for sediment.

EPA used the suite of model construction sites discussed in Section 7 and documented in detail in Appendix A as the basis for calculating loads and removals. Per-state pollutant loadings were computed from a minimum of 24 construction site models (6 site size groups and 4 land uses). In most states, the variability of soils, slope, and climate resulted in 432 construction model sites that were individually defined for the state and evaluated to estimate per-site loadings and loading reductions. The computation of pollutant loadings and loading reductions accounted for the following:

- Current state erosion and sediment control and BMP requirements;
- Soil nature and the geographic distribution of soil types;
- Land slopes and flow paths on construction sites; and
- Climate and hydrology

The geographic basis for the analysis are areas created by overlapping state boundaries with the boundaries of 19 ecoregions (Omernik, 1987). Figure 8-1a and 8-1b illustrates these geographic areas for the western and eastern states, referred to as state-ecoregion areas. There are 146 state-

ecoregion areas in the assessment of the 48-contiguous states. (Hawaii and Alaska are not included in the analysis because the methodology relies on data on development and soil types that were not readily available for these two states.) For each state-ecoregion area, estimates were made of the amount of annual construction acreage and the number of associated model construction sites based on NRI data (USDA, 2000). NRI data estimates developed acreage by Hydrologic Unit Code (or "HUC"). By summing the acres of developed land for all of the HUCs within a given state-ecoregion area, the total annual developed acreage within that area could be estimated. (Ecoregion boundaries used in this assessment are based on large watersheds, which are roughly equivalent to the boundaries formed by the combinations of various HUCs.)

For each model construction site within each state-ecoregion area, the sediment generation and removal was calculated under baseline conditions and under each regulatory option using the Revised Universal Soil Loss Equation (RUSLE) (USDA, 1997) and SEDCAD (Warner, 1998), reflecting existing state programs. By summing to the national level, the total sediment reduction of the regulatory options could be estimated.

Following estimation of sediment loads for each HUC under baseline and each regulatory option, sites were randomly placed within each HUC and linked to the nearest stream reach using GIS. Loads were routed to stream reaches and in-stream water quality changes from baseline were modeled using the National Water Pollution Control Assessment Model (NWPCAM). Monetized benefits were estimated using both the continuous Water Quality Index (McClelland, 1974) and water quality ladder and willingness to pay based on Carson/Mitchell (1993). The total load reductions and benefits of the regulatory options are presented in Table 8-1.

Table 8-1. Loading Reductions and Benefits of Regulatory Options

	Option 1	Option 2	Option 4
Sediment Reduction (tons/year)	0	979,896	979,896
Net Benefit Using Water Quality Ladder	0	$28,357,000	$28,357,000
Net Benefit Using Water Quality Index	0	$15,203,000	$15,203,000

Figure 8-1a. State-Ecoregions in the Western United States

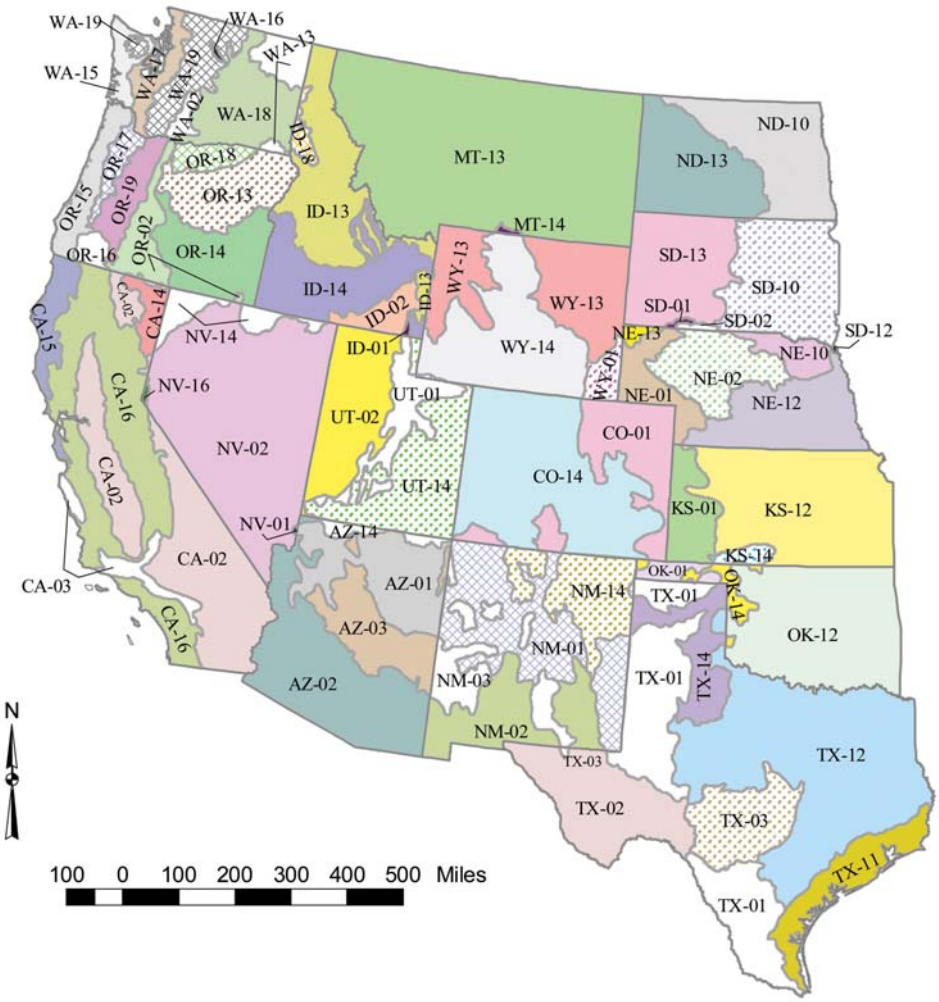
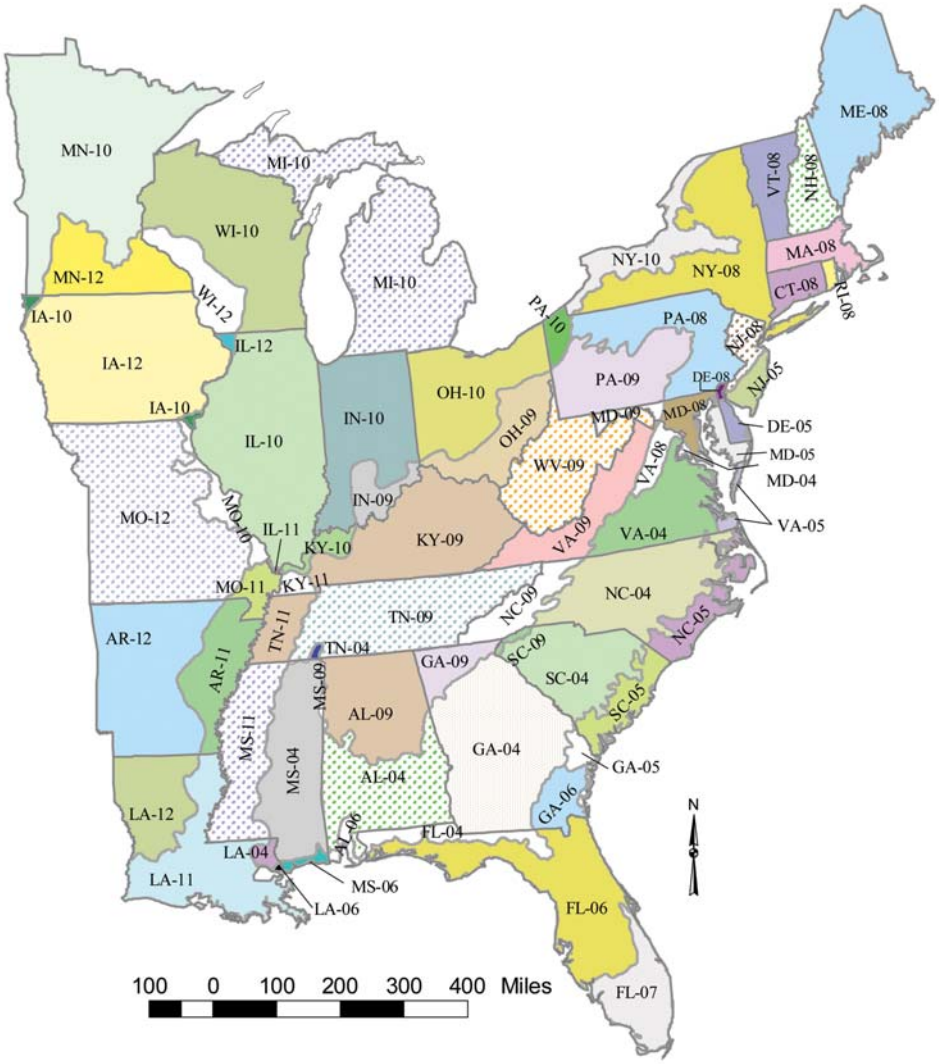


Figure 8-1b. State-Ecoregions in the Eastern United States



8.2. CATEGORIES OF REPORTED IMPACTS AND POLLUTANTS

8.2.1 INTRODUCTION

Construction and land development activities can generate a broad range of environmental impacts by introducing new sources of contamination and by altering the physical characteristics of the affected land area. In particular, these activities can result in both short- and long-term adverse impacts on surface water quality in streams, rivers, and lakes in the affected watershed by increasing the loads of various pollutants in receiving water bodies, including sediments, metals, organic compounds, pathogens, and nutrients. Ground water also can be adversely affected through diminished recharge capacity. Other potential impacts include the physical alteration of existing streams and rivers due to the excessive flow and velocity of storm water runoff.

Construction activities typically involve excavating and clearing existing vegetation. During the construction period, the affected land is usually denuded and the soil compacted, leading to increased storm water runoff and high rates of erosion. If the denuded and exposed areas contain hazardous contaminants or pollutants (either naturally occurring or due to previous land uses), they can be carried at increased rates to surrounding water bodies by storm water runoff. Although the denuded construction site is only a temporary state (usually lasting less than 6 months), the landscape is permanently altered even after the land has been restored by replanting vegetation. For example, a completed construction site typically has a greater proportion of impervious surface than the predevelopment site, leading to changes in the volume and velocity of storm water runoff. Changes in land use might also lead to new sources of pollution, such as oils and metals from motor vehicles, nutrients and pesticides from landscape maintenance, and pathogens from improperly installed or failing septic tanks. Increased pollutant loads are particularly evident when land development takes place in previously undeveloped environments. Together the short-term impacts from construction activities and the long-term impacts of development can profoundly change the environment.

Pollutants associated with construction activities and land development storm water discharges can adversely affect the environment in a number of ways. Potential effects include impairment of water quality, destruction of aquatic life habitats, and enlargement of floodplains. To the extent possible, this discussion distinguishes between environmental impacts generated during active construction and environmental impacts attributable to the more broad change in land use from undeveloped land areas such as agriculture, forest or rural area to urban conditions (termed "postdevelopment" throughout the remainder of this section). Although in most cases the differences are in magnitude and duration (e.g., sediment runoff), environmental impairment from such contaminants as pathogens are more likely to be associated with the overall urbanization of a watershed than with the types of activities that take place during construction. The discussion of environmental impacts first evaluates the impacts of contaminated runoff and then focuses on the physical impacts of construction and land development.

8.2.2 POLLUTANTS ASSOCIATED WITH CONSTRUCTION AND LAND DEVELOPMENT STORM WATER RUNOFF

There are a number of pollutants associated with construction and land development storm water runoff. This description does not represent the complete suite of contaminants that can be found in the runoff, but focuses instead on those that are currently known to be the most prevalent and of greatest concern to the environment. These pollutants include sediment, metals, polycyclic aromatic hydrocarbons (PAHs), oil, grease, and pathogens.[5]

8.2.2.1 Sediment

Sediment is an important and ubiquitous constituent in urban storm water runoff. Surface runoff and raindrops detach soil from the land surface, resulting in sediment transport into streams. Sediment level measurement can be divided into three distinct subgroups:

- Total suspended solids (TSS) are a measure of the suspended material in water. The measurement of TSS in urban storm water allows for estimation of sediment transport, which can have significant effects locally and in downstream receiving waters.

- Turbidity is a function of the suspended solids and is a measure of the ability of light to penetrate the water. Turbidity can exhibit control over biological functions, such as the ability of submerged aquatic vegetation to receive light

- Total dissolved solids are a measure of the dissolved constituents in water and are a primary indication of the purity of drinking water.

Sources of Sediment

Construction Sites
Erosion from construction sites can be a significant source of sediment pollution to nearby streams. A number of studies have shown high concentrations of TSS in uncontrolled runoff from construction sites, and results from these studies are summarized in Table 8-2. One study,

[5]Much of the data cited in this document was collected before the NPDES Phase I and II storm water regulations generally required permits for all construction sites of one or more acres. As a result, much of this data may not accurately reflect current sediment discharge rates from construction sites. However, the data is important to reinforce the need for continued erosion and sediment control nationwide and to provide perspective on the sediment discharge rates that can occur from uncontrolled construction sites. Since even well managed construction sites continue to discharge sediment, much of the receiving water data and discussion is still likely applicable, however. This is especially true for sediment mobilized as a result of receiving channel instability following urban development, which is well documented and still largely unaddressed in many areas of the country.

conducted in 1986, calculated that construction sites are responsible for an estimated export of 80 million tons of sediment into receiving waters each year (Goldman, 1986, cited in CWP, 2000). On a unit area basis, construction sites can export sediment at 20 to 1,000 times the rate of other land uses (CWP, 2000).

Table 8-2. Studies of Uncontrolled Soil Erosion as TSS From Construction Sites

Site	Mean Inflow TSS Concentration (mg/L)	Source
Seattle, Washington	17,500	Horner, Guerdy, and Kortenhoff, 1990
SR 204	3,502	Horner, Guerdy, and Kortenhoff, 1990
Mercer Island	1,087	Horner, Guerdy, and Kortenhoff, 1990
RT1	359	Schueler and Lugbill, 1990
RT2	4,623	Schueler and Lugbill, 1990
SB1	625	Schueler and Lugbill, 1990
SB2	415	Schueler and Lugbill, 1990
SB4	2,670	Schueler and Lugbill, 1990
Pennsylvania Test Basin	9,700	Jarrett, 1996
Georgia Model	1,500 – 4,500	Sturm and Kirby, 1991
Maryland Model	1,000 – 5,000	Barfield and Clar, 1985
Uncontrolled Construction Site Runoff (MD)	4,200	York and Herb, 1978
Austin, Texas	600	Dartiguenave, ECLille, and Maidment, 1997
Hamilton County, Ohio	2,950	Islam, Taphorn, and Utrata-Halcomb, 1998
Mean TSS (mg/L)	3,681	NA

Postdevelopment Conditions

Sediment sources in urban environments include bank erosion, overland flow, runoff from exposed soils, atmospheric deposition, and dust (Table 8-3). Streets and parking lots accumulate dirt and grime from the wearing of the street surface, exhaust particulates, “blown-on” soil and organic matter, and atmospheric deposition. Lawn runoff primarily contains soil and organic matter. Source area monitoring data from Bannerman (1993), Waschbusch (2000), and Steuer (1997) are shown in Table 8-4. Hot spots (areas that are particularly high pollutant sources) were identified for the transport of sediment from the urban (developed) land surface, and they include streets, parking lots, and lawns.

Table 8-3. Sources of Sediment in Urban Areas

Source Area	Loading
Bank erosion	Up to 75 percent in California and Texas studies
Overland flow	Lawns - average value of geometric means from 4 studies: 201 mg/L
Runoff from areas with exposed soils	Average value: 3,640 mg/L
Blown-on material and organic matter	May account for as much as 35 to 50 percent in urban areas

Bannerman et al, 1993; Dartinguenave et al, 1997; Schueler, 1987; Steuer et al, 1997; Trimble, 1997; Waschbusch et al, 2000

Table 8-4. Source Area Concentrations for TSS in Urban Areas

Source Area	TSS (mg/L)[a]	TSS (mg/L)[b]	TSS (mg/L)[c]	
			Monroe Basin	Harper Basin
Commercial parking lot	110	58	51	
High-traffic street	226	232	65	
Medium-traffic street	305	326	51	
Low-traffic street	175	662	68	69
Commercial rooftop	24	15	18	
Residential rooftop	36	27	15	17
Residential driveway	157	173		34
Residential lawn	262	397	59	122

[a] Steuer et al, 1997.
[b] Bannerman et al, 1993.
[c] Waschbusch et al, 2000.

Parking lots and streets are responsible not only for high concentrations of sediment but also for high runoff volumes. Normally about 90 percent of the water that falls on pavement is converted to surface runoff, whereas roughly 5 to15 percent of the water that falls on lawns is converted to surface runoff (Schueler, 1987). The source load and management model (SLAMM; Pitt and Voorhes, 1989) evaluates runoff volume and concentrations of pollutants from different urban land uses and predicts loads to the stream. When used in the Wisconsin and Michigan subwatersheds, the model estimated that parking lots and streets were responsible for more than 70 percent of the TSS delivered to the stream (Steuer, 1997; Waschbusch et al, 2000). Because basin water quality measurements were taken at pipe outfalls, bank erosion was not accounted for in the studies.

Sediment load is due to erosion caused by an increased magnitude and frequency of flows brought on by urbanization (Allen and Narramore, 1985; Booth, 1990; Hammer, 1972; Leopold, 1968). Streambank studies by Dartinguenave et al (1997) and Trimble (1997) determined that streambanks

are large contributors of sediment in urban streams. Trimble (1997) used direct measurements of stream cross sections, sediment aggradation, and suspended sediment to determine that roughly 66.7 percent of the sediment load in San Diego Creek was a result of bank erosion. Dartiguenave et al (1997) used a GIS- based model developed in Austin, Texas, to determine the effects of stream channel erosion on sediment loads. By effectively modeling the pollutant loads on the land surface and by monitoring the actual in-stream loads at U. S. Geological Survey (USGS) gauging stations, they were able to determine that over 75 percent of the sediment load came from the streambanks.

Receiving Water Impacts

Sediment transport and turbidity can affect habitat, water quality, temperature, and pollutant transport, and can cause sedimentation in downstream receiving waters (Table 8-5). A large body of scientific literature addresses the question of how the health of aquatic resources is impacted by excess sediment loading in waterbodies. At least partly on the basis of the findings of this research, some states across the country have already set sediment targets for receiving waters to protect aquatic resources, and are developing and refining targets for geographically specific watersheds. Demarcation by waterbody type provides context and is an important theme in the literature for purposes of setting sediment targets. Differences among receiving waters are evident not only in the aquatic species that inhabit them, but also in terms of behavior of sediment within the waterbody and threshold levels of impacts. The biota or aquatic species that are the focus of the literature include aquatic vegetation, macroinvertebrates, eggs, fry, juvenile, and adult fish, shellfish and corals. Identified waterbody types in the literature include:

- lakes, reservoirs, ponds, and impoundments
- rivers and streams
- wetlands
- oceans, estuaries, and other coastal water ecosystems, including coral reefs

The impacts of excess sediment in the water include direct physical effects such as reducing visibility and light in the water column, physical abrasion of plant surfaces, clogging gill openings, and entombing of eggs and fry in redds. Impacts may also be indirect, as in changes to the chemical composition of the water, light penetration or turbidity, and/or temperature profile, which in turn affect primary productivity with repercussions in terms of fish behavior, and overall community profiles and trophic structure. Thus the aquatic resources may be directly affected in terms of aesthetics, physiology, and mortality, or affected indirectly via changes in the habitat structure of the waterbody. Bedded sediments, though they directly affect the survival of fish eggs and fry and other organisms, do so because they alter the habitat structure and are dealt with in Section 8.2.3 under Physical Impacts of Construction and Land Development Activities.

Table 8-5. Sediment Impacts on Receiving Waters

Resource Affected	Impacts of Sediment	References
Streams	• Loss of sensitive species and a decrease in fish and macroinvertebrate communities • Clogging of gills and loss of habitat • Decreased flow capacity in streams • Interference with water quality processes • Affects transport of contaminants	Kundell and Rasmussen, 1995 Leopold, 1973 Barrett and Molina, 1998 MacRae and Marsalek, 1992
Wetlands	• Deposition of sediment • Loss of sensitive species–amphibians, plants	Horner et al, 1997 Hilgartner, 1986 Pasternack, 1998
Reservoirs	• Turbidity results in increased costs of treatment for drinking water • Sedimentation results in decreased storage	Holmes, 1998
Beaches	• Turbidity reduces aesthetic value • Sedimentation can result in increased accretion rates in wetlands and change plant community structure	Kundell and Rasmussen, 1995
Estuaries	• Sedimentation • Turbidity accentuates eutrophication • Loss of submerged aquatic vegetation (SAV) • Reduced light attenuation	Pasternack, 1998 Livingston, 1996 Schiff, 1996 Mackiernan et al, 1996 Short and Wyllie-Echeverria, 1996 Orth and Moore, 1983 Stevenson et al, 1993 Hilgartner, 1986

Storm water discharges generated during construction activities cause a wide variety of physical, chemical, and biological water quality impacts. The interconnected process of erosion, sediment transport, and delivery is the primary pathway for introducing pollutants such as excess sedimentation, total suspended solids, nutrients, metals, and organic compounds to aquatic systems (Novotny and Chesters 1989) in USEPA (1999). USDA (1989) estimated that 80 percent of the phosphorus and 73 percent of the Kjeldahl nitrogen are directly associated with eroded sediment (cited in Fennessey and Jarrett (1994), in USEPA 1999). The 2000 National Water Quality Inventory (USEPA) states that siltation is one of the top causes of impairment of waters across the United States. The report also states that pollution from urban and agricultural land transported by precipitation and runoff, and which includes pollutants from construction and land development activities, is the leading sources of impairment.

Large amounts of fine sediment, or the introduction of coarse sediment is a also concern because of the of filling lakes and reservoirs and clogging of stream channels (Paterson et al, 1993, in USEPA, 1999).

The literature reviewed for this document focuses on study methodologies that describe quantitative effects of sediment imbalance in aquatic systems in a basic dose-response relationship and where aquatic organisms are exposed to suspended and/or bedded sediments. The review considered literature on each type of aquatic resource: aquatic vegetation and primary production, invertebrates, juvenile fish, fry, and eggs, and adult fish. These aquatic biota are considered within their geographical setting and waterbody type: rivers/streams, ponds/lakes, estuaries/coastal environments. Areas that are covered more extensively in the literature than other topics are the impacts of suspended sediment on adult fish and impacts of deposited or substrate sediment on juvenile fish, fry, and eggs. Cold-water salmonid fish, predominantly in a stream setting, dominates the literature on this sediment dose-response relationship. The literature is not as extensive or as rich, on estuaries, lakes, and coastal areas nor on macroinvertebrates and aquatic plants, in comparison to fish. Additional summary of biological impacts of sediment on aquatic ecosystems is available as part of the materials created as part of EPA's work on developing water quality criteria for sediments (USEPA, 2003).

Measures of suspended sediment include turbidity and total suspended solids, already covered in Section 8.2.2.1. With respect to reviewing these dose-response studies authors typically consider how either turbidity or TSS affects biota. However, the relationship between the two measures is often unclear and not explicitly defined. Turbidity is a measure of light dispersion whereas TSS measures the mass of particles in the water column. Larger particles contribute mass to a TSS measurement, but do not scatter light as much as a similar weight of smaller particles. Usually when the sediment particles are smaller, turbidity levels are higher. Suspended sediment and its resulting turbidity can reduce light for submerged aquatic vegetation. In addition, deposited sediment can cover and suffocate benthic organisms like clams and mussels, cover habitat for substrate-oriented species in urban streams, and reduce storage in reservoirs. Pollutants such as hydrocarbons and metals tend to bind to sediment and are transported with storm flow (Crunkilton et al, 1996; Novotny and Chesters, 1989). Increased turbidity also can cause stream warming by reflecting radiant energy (Kundell and Rasmussen, 1995).

Studies involving an analysis of the relationship between the two measures of suspended sediment include Packman et al (1999) who showed that TSS and turbidity have a strong positive relationship in nine urban/suburban Puget lowland streams. New Mexico TMDLs (NMED, 2002) converted a turbidity standard to TSS by calibrating with local data, so that the TSS values in units of mg/L could be converted to sediment loads in lbs/day. Keyes and Radcliff (2002) calibrated turbidity units (NTU) to approximate TSS measures using 40 mg/L kaolin clay set to a standard of 40 NTU. However, in natural streams the composition of suspended particles is not uniformly like that of kaolin clay.

The impact of suspended sediment depends on the type of particle sizes to some extent, and therefore TSS and turbidity measures should be considered together where the information is available. For example, Servizi and Martens (1992) reported that salmonids were relatively tolerant of elevated TSS levels when the particle sizes were larger. When the particles are smaller, turbidity is higher, which appears to make conditions more difficult for salmonids.

The effects of sediment deposition from construction activities are known to affect streams far downstream of construction sites. For example, Fox (1974), in USEPA (1999), found that streams between 4.8 and 5.6 miles downstream of construction sites in the Patuxent River watershed were impacted by sediment inputs. Erosion from construction sites can also generate the transport of pollutants associated with onsite wastes. The Storm Water Quality Task Force (1993), in USEPA (1999), states that rain splash, rills, and sheetwash encourage the detachment and transport of pollutants (including both sediments and pollutants associated with sediments) to waterbodies. Erosion from construction sites and runoff in developed areas can elevate pollutant loads well above those in undisturbed watersheds. Novotny and Olem (1994), in USEPA (1999), state that erosion rates from construction sites are much greater than from any other land use. The results from field studies and erosion models conducted by USDA (1970), in USEPA (1999), found that erosion rates from construction sites are usually an order or magnitude higher than row crops and several orders of magnitude higher than rates from well-vegetated areas such as forests or pastures. A review of the efficiency of sediment basins conducted by Brown (1997), in USEPA (1999), found that inflows from 12 construction sites had a mean TSS concentration of about 4,500 mg/L. Kuo (1976), in USEPA (1999), found that suspended sediment concentrations from housing construction sites in Virginia were measured at 500-3,000 mg/L, or about 40 times larger than the concentrations in runoff from already-developed urban areas. In Wisconsin, Daniel et al (1979) (in USEPA 1999) monitored storm water runoff from three residential construction sites and found that annual sediment yields were more than 19 times the yields from agricultural areas. Daniel et al identified total storm water runoff followed by peak storm water runoff as the most influential factors controlling the sediment loadings from residential construction sites, and also found that suspended sediment concentrations were 15,000-20,000 mg/L in moderate storm events and up to 60,000 mg/L in larger events. Lastly, Wolman and Schick (1967), in USEPA (1999), studied impacts of development on fluvial systems in Maryland, and found that sediment yields in areas undergoing construction were 1.5 to as much as 75 times greater than detected in natural or agricultural catchments.

The effects of road construction on erosion rates and sediment yields were also examined. In West Virginia, a road construction project studied by Downs and Appel (1986) disturbed only 4.2 percent of a 4.72 square mile basin, but it resulted in a three fold increase in suspended sediment yields. During the largest storm event, it was estimated that 80 percent of the sediment in the stream was attributed to the construction site. Hainly (1980) evaluated the effect of 290 acres of highway construction on watersheds which ranged in size from 5 to 38 square miles. He found that even in the smallest watershed, the estimated sediment yield from the construction area was 37 tons per acre during a two-year period. In Hawaii, Hill (1996) found that highway construction increased suspended sediment loads by 56 to 76 percent in basins of 1 to 4 square miles. Yorke and Herb (1978), in a long term study of subbasins in Maryland portions of the Anacostia River, found that average annual suspended sediment yields for construction sites ranged from 7 to 100 tons per acre.

Studies have indicated that the water quality impact from small construction sites may be the same or greater than large construction sites on a per acre basis. The concentration of pollutants in runoff from small sites is similar to those in large sites. In urban areas the proportion of sediment that makes it to surface waters may be the same because the runoff is delivered directly to storm drain

networks, with no opportunity for pollutants to be filtered out (USEPA, 1999). MacDonald (1997), in USEPA (1999), states that storm water regulations are more likely to require controls for large sites than smaller sites. The smaller sites that lack sediment and erosion controls would contribute a disproportionate amount of total sediment from construction activities.

To test the theory that small sites have sediment loads on a per acre basis similar to large sites, the EPA gave a grant to Dane County, Wisconsin Land Conservation Department, in cooperation with USGS, to evaluate sediment runoff. In this study by Owens et al (1999), in USEPA (1999), a 0.34 acre residential development and a 1.72 acre commercial office development were evaluated. At the residential site, total solids concentrations were 642 mg/L, 2,788 mg/L, and 132mg/L for preconstruction, active construction, and post-construction, respectively. This equaled 7.4 lbs preconstruction, 35 lbs during construction, and 0.6 lbs post-construction on a pollutant load basis. At the commercial site, Owens et al found that total solids during preconstruction were 138 mg/L and 200 mg/L during post-construction, but was 15,000 mg/l during the active construction period. This equaled 0.3 lbs preconstruction, 490 lbs during construction, and 13.4 lbs after construction on a pollutant load basis. The total solids from the commercial site were similar to those in a study by Downs and Appel (1986), who evaluated the effects of highway construction in West Virginia. They found that a small storm event yielded a sediment concentration of 7,520 mg/L.

Several studies have also evaluated the total amount of disturbed land for small and large construction sites. Brown and Caraco surveyed 219 jurisdictions to assess sediment and erosion control programs. They found that of the 70 respondents, in 27 cases more than three-fourths of the permits were for sites less than 5 acres, and in another 18 cases, more than half of the permits were for sites less than 5 acres. MacDonald (1997), in USEPA (1999), evaluated data on the 3,831 construction site permits for North Carolina from 1994 through 1996. He found that nearly 61 percent of the sites 1.0 acre or larger were between 1.0 and 4.9 acres in size. Given the high erosion rates, small construction sites can produce significant water quality impairment, particularly in small watersheds. Paterson (1994), in USEPA (1999), summarized that, given the critical importance of field implementation of erosion and sediment control programs, much more focus should be given to plan implementation.

8.2.2.2 Metals

Many toxic metals can be found in urban storm water, although only metals such as zinc, copper, lead, cadmium, and chromium have been indicated as being of primary concern because of their prevalence and potential for environmental harm. These metals are generated by motor vehicle exhaust, the weathering of buildings, the burning of fossil fuels, atmospheric deposition, and other common urban activities.

Metals can bioaccumulate in stream environments, resulting in plant growth inhibition and adverse health effects on bottom-dwelling organisms (Masterson and Bannerman, 1995). Generally the concentrations found in urban storm water are not high enough for acute toxicity (Field and Pitt, 1990). Rather, it is the cumulative effect of the concentration of these metals over time and the buildup in the sediment and animal tissue that are of greater concern.

Sources of Metal Runoff

Construction Sites

Construction sites are not thought to be important sources of metals contamination. Runoff from such sites could have high metals contents if the soil is already contaminated. Construction activities alone do not usually result in metals contamination, although there is little data available on this subject.

Postdevelopment Conditions

Postdevelopment conditions create significant sources of metal runoff in the urban environment, including streets, parking lots, and rooftops. Table 8-6 summarizes the major sources of metal runoff by metal type. Copper can be found in high concentrations on urban streets as a result of the wear of brake pads that contain copper. A study in Santa Clara, California, estimated that 50 percent of the copper released is from brake pads (Woodward-Clyde, 1992). Sources of lead include atmospheric deposition and diesel fuel, which are found consistently on streets and rooftops. Zinc in urban environments is a result of the wear of automobile tires (an estimated 60 percent of the total zinc in the Santa Clara study), paints, and the weathering of galvanized gutters and downspouts. Source area concentrations estimated by researchers in Wisconsin and Michigan are presented in Table 8-7. Actual concentrations vary considerably, and high-concentration source areas vary from study to study. A study using SLAMM for an urban watershed in Michigan estimated that most of the zinc, copper, and cadmium was a result of runoff from urban parking lots, driveways, and residential streets (Steuer, 1997).

Receiving Water Impacts of Metals

Downstream effects of metals transported to receiving waters, such as lakes and estuaries, have been studied extensively. Selected studies on metal impacts on receiving waters are summarized in Table 8-8. Although evidence exists for the buildup of metals in deposited sediments in receiving waters and for bioaccumulation in aquatic species (Bay et al, 2000; Livingston, 1996), specific effects of these concentrations on submerged aquatic vegetation and other biota are not well understood.

Table 8-6. Metal Sources and Hot Spots in Urban Areas

Metal	Sources	Hot Spots
Zinc	Tires, fuel combustion, galvanized pipes and gutters, road salts *Estimate of 60% from tires*[a]	Parking lots, rooftops, and streets
Copper	Auto brake linings, pipes and fittings, algacides, and electroplating *Estimate of 50% from brake pads*[a]	Parking lots, commercial roofs, and streets
Lead	Diesel fuel, paints, and stains	Parking lots, rooftops, and streets
Cadmium	Component of motor oil; corrodes from alloys and plated surfaces	Parking lots, rooftops, and streets
Chromium	Found in exterior paints; corrodes from alloys and plated surfaces	More frequently found in industrial and commercial runoff

[a] Woodward-Clyde, 1992 (Santa Clara, CA, study)
Sources: Barr, 1997; Bannerman, et al, 1993; Steuer, 1997

Table 8-7. Metal Source Area Concentrations in Urban Areas (in ug/L)

Source Area	Diss. Zinc	Total Zinc	Diss. Copper	Diss. Copper	Total Copper	Diss. Lead	Diss. Lead	Total Lead	Total Lead	Total Lead
Citation	(a)	(b)	(a)	(b)	(b)	(a)	(c)	(a)	(c)	(b)
Commercial parking lot	64	178	10.7	9	15			40		22
High-traffic street	73	508	11.2	18	46	2.1	1.7	37	25	50
Medium-traffic street	44	339	7.3	24	56	1.5	1.9	29	46	55
Low-traffic street	24	220	7.5	9	24	1.5	0.5	21	10	33
Commercial rooftop	263	330	17.8	6	9	20		48		9
Residential rooftop	188	149	6.6	10	15	4.4		25		21
Residential driveway	27	107	11.8	9	17	2.3		52		17
Residential lawn	na	59	na	13	13	na		na		na
Basin outlet	23	203	7.0	5	16	2.4		49		32

na : not available
Sources: (a) Steuer 1997; (b) Bannerman 1993; (c) Waschbusch, 1996, cited in Steuer, 1997

Table 8-8. Metals Impacts on Receiving Waters

Resource Affected	Impacts of Metals	Evidence and References
Streams	• Chronic toxicity due to in-stream concentrations and accumulation in sediment • Bioaccumulation in aquatic species • Acute toxicity at certain concentrations	• Chronic toxicity increased during longer-duration studies, i.e. 7/14/21-day studies (Crunkilton, 1996) • Delayed toxicity (Ellis, 1986/1987) • Baseflow toxicity (Mederios, 1983) • Resuspension of metals during storms accounting for some toxicological effects (Heaney and Huber, 1978) • Bioaccumulation in crayfish (Masterson & Bannerman, 1994)
Reservoirs/ Lakes	• Accumulation of metals in sediment	• Bioaccumulation levels in bottom-feeding fish were found to be influenced by the metal levels of the bottom sediments of storm water ponds (Campbell, 1995-CWP).
Estuaries	• Accumulation of metals in sediment • Loss of SAV	• Tampa Bay (Livingston, 1996) • San Diego (Schiff 1996) • SAV losses in northeast San Francisco Bay (Orth and Moore, 1983

8.2.2.3 PAHs, and Oil and Grease

Petroleum-based substances such as oil and grease and polycyclic aromatic hydrocarbons (PAHs) are found frequently in urban storm water. Many constituents of PAHs and oil and grease, such as pyrene and benzo[b]fluoranthene, are carcinogens and toxic to downstream biota (Menzie-Cura and Assoc., 1995). Oil and grease and PAHs normally travel attached to sediment and organic carbon. Downstream accumulation of these pollutants in the sediments of receiving waters such as streams, lakes, and estuaries is of concern.

Sources of PAHs, and Oil and Grease

Construction sites

Construction activities during site development are not believed to be major contributors of these contaminants to storm water runoff. Improper operation and maintenance of construction equipment at construction sites, as well as poor housekeeping practices (e.g., improper storage of oil and gasoline products), could lead to leakage or spillage of products that contain hydrocarbons, but these incidents would likely be small in magnitude and managed before off-site contamination could occur.

Postdevelopment Conditions

In most storm water runoff, concentrations of PAHs and oil and grease are typically below 5 mg/L, but concentrations tend to increase in commercial and industrial areas. Hot spots for these

pollutants in the urban environment include gas stations, commuter parking lots, convenience stores, residential parking areas, and streets (Schueler, 1994). Schueler and Shepp (1993) found concentrations of pollutants in oil/grit separators in the Washington Metropolitan area and determined that gas stations had significantly higher concentrations of hydrocarbons and a greater presence of toxic compounds than streets and residential parking lots. A study of source areas in an urban watershed in Michigan (which excluded gas stations) showed that high concentrations from commercial parking lots contributed 64 percent of the estimated hydrocarbon loads (Steuer et al, 1997).

Receiving Waters Impacts

Toxicological effects from PAHs and oil and grease are assumed to be reduced by their attachment to sediment (lessened availability) and by photodegradation (Schueler, 1994). Evidence of possible impacts on the metabolic health of organisms exposed to PAHs and of bioaccumulation in streams and other receiving waters does not exist (Masterson and Bannerman, 1994; MacCoy and Black, 1998); however, crayfish from Lincoln Creek, analyzed in the Masterson and Bannerman study, had a PAH concentration of 360 micrograms per kilogram–much higher than the concentration known to be carcinogenic. The crayfish in the control stream did not have detectable levels of PAHs. Known effects of PAHs on receiving waters are summarized in Table 8-9. Long-term effects of PAHs in sediments of receiving waters require additional study.

Table 8-9. Effects of PAHs and Oil and Grease on Receiving Waters

Resource Affected	Impacts of PAHs and Oil and Grease	Citations
Streams	• Possible chronic toxicity due to in-stream concentrations and accumulation in sediment • Bioaccumulation in aquatic species • Acute toxicity at certain concentrations	• Bioaccumulation in crayfish tissue studies (Masterson and Bannerman, 1994) • Potential metabolic costs to organisms (Crunkilton et al, 1996) • Delayed toxicity (Ellis, 1986/1987) • Baseflow toxicity (Mederios, 1983)
Reservoirs	• Accumulation of PAHs in sediment	• Sediment contamination may result in a decrease in benthic diversity and transfer of PAHs to fish tissue (Schueler, 2000) • Elevated levels of PAHs found in pond muck layer (Gavens et al, 1982-CWP)
Estuaries	• Accumulation of PAHs in sediment • Potential loss of SAV • Accumulation of PAHs in fish and shellfish tissue	• Tampa Bay (Livingston, 1996) • San Francisco Bay (Schiff, 1996)

8.2.2.4 Pathogens

Microbes are commonly found in urban storm water. Although not all microbes are harmful, several species such as the pathogens *Cryptosporidium* and *Giardia* can directly cause diseases in humans. The presence of bacteria such as fecal coliform bacteria, fecal streptococci, and *Escherichia coli*

indicates a potential health risk. High levels of these bacteria may result in beach closings, restrictions on shellfish harvest, and increased treatment for drinking water to decrease the risk of human health problems.

Sources of Pathogens

Construction sites

Construction site activities are not believed to be major contributors to pathogen contamination of surface waters. The only potential known source of pathogens from construction sites are portable septic tanks used by construction workers. These systems, however, are typically self-contained and are not connected to the land surface. Any leaks from them would likely be identified and addressed quickly.

Postdevelopment Conditions

Coliform sources include pets, humans, and wild animals. Source areas in the urban environment for direct runoff include lawns, driveways, and streets. Dogs have high concentrations of coliform bacteria in their feces and have a tendency to defecate in close proximity to impervious surfaces (Schueler, 1999). Many wildlife species also have been found to contribute to high fecal concentrations. Essentially, any species that is present in significant numbers in a watershed is a potential pathogen source. Source identification studies, using methods such as DNA fingerprinting, have attributed high coliform levels to such species as rats in urban areas, ducks and geese in storm water ponds, dogs, and even raccoons (Blankenship, 1996; Lim and Oliveri, 1982; Pitt et al, 1988; Samadapour and Checkowitz, 1998).

Indirect surface storm water runoff sources include leaking septic systems, illicit discharges, sanitary sewer overflows (SSOs), and combined sewer overflows (CSOs). These sources have the potential to deliver high concentrations of coliforms to receiving waters. Illicit connections from businesses and homes to the storm drainage system can discharge sewage or washwater into receiving waters. Leaking septic systems are estimated to constitute 10 to 40 percent of all systems. Inspection is the best way to determine whether a system is failing (Schueler, 1999).

There is also evidence that these bacteria can survive and reproduce in stream sediments and in storm sewers. During a storm event, they are resuspended and add to the in-stream bacteria load. Source area studies reported that end-of-pipe concentrations were an order of magnitude higher than any source area on the land surface; therefore, it is likely that the storm sewer system itself acts as a source (Bannerman, 1993; Steuer et al, 1997). Resuspension of fecal coliform bacteria from fine stream sediments during storm events has been reported in New Mexico (NMSWQB, 1999). The sediments in the storm sewer system and in streams may be significant contributors to the fecal coliform load. This area of research certainly warrants more attention to determine whether these sources can be quantified and remediated.

Giardia and *Cryptosporidium* in urban storm water are also a concern. There is evidence that urban watersheds and storm runoff might have higher concentrations of *Giardia* and *Cryptosporidium* than other surface waters (Stern, 1996). (See Table 8-10.) The primary sources of these pathogens are humans and wildlife. Although *Cryptosporidium* is found in less than 50 percent of storm water samples, data suggest that high *Cryptosporidium* values may be a concern for drinking water supplies. Both pathogens can cause serious gastrointestinal problems in humans (Bagley et al, 1998).

Table 8-10. Percentage Detection of *Giardia* Cysts and *Cryptosporidium* Oocysts in Subwatersheds and Wastewater Treatment Plant Effluent in the New York City Water Supply Watersheds

Source Water Sampled (No. of sources/ No. of samples)	Percent Detection			
	Total *Giardia*	Confirmed *Giardia*	Total *Cryptosporidium*	Confirmed *Cryptosporidium*
Wastewater effluent (8/147)	41.5	12.9	15.7	5.4
Urban subwatershed (5/78)	41.0	6.4	37.2	3.9
Agricultural subwatershed (5/56)	30.4	3.6	32.1	3.6
Undisturbed subwatershed (5/73)	26.0	0.0	9.6	1.4

Source: Stern et al, 1996.

Receiving Water Impacts

Fecal coliform bacteria, fecal streptococci, and *E. coli* are consistently found in urban storm water runoff. Their presence indicates that human or other animal waste is also present in the water and that other harmful bacteria, viruses, or protozoans might be present as well. Concentrations of these indicator organisms in urban storm water are highly variable even within a given monitoring site. Data for fecal coliform bacteria illustrate this variability: site concentrations range from 10 to 500,000 most probable number per 100 milliliters (MPN/100mL) (Schueler, 1999).

Concentrations in urban storm water typically far exceed the 200 MPN/100 mL threshold set for human contact recreation. The mean concentration of fecal coliform bacteria in urban storm water for 34 studies across the United States was 15,038 MPN/100mL (Schueler, 1999). Another national database of 1,600 samples (mostly Nationwide Urban Runoff Program data collected in the 1980s), estimates the mean concentration at 20,000 MPN/100 mL (Pitt, 1998). Fecal streptococci concentrations for 17 urban sites had a mean of 35,351 MPN/100 mL (Schueler, 1999). Transport occurs primarily as a result of direct surface runoff, failing septic systems, SSOs, CSOs, and illicit discharges.

Human health can be affected by bacterial impacts on receiving waters when bacteria standards for water contact recreation, shellfish consumption, or drinking water are violated. Epidemiological studies from Santa Monica Bay have documented frequent sickness in people who swim near outfalls (SMBRP, 1996). Documented illnesses include fever, ear infections, gastroenteritis, nausea, and flu-like symptoms. Table 8-11 describes the effects of bacteria and protozoan problems on different receiving waters.

Table 8-11. Effects of Bacteria on Receiving Waters

Resource Affected	Impacts and Citations
Streams	More than 80,000 miles of streams and rivers in non-attainment because of high fecal coliform levels (USEPA, 1998a)
Reservoirs	Increased treatment cost of drinking water due to bacteria contamination (USEPA, 1996)
Beaches	More than 4,000 beach closings or advisories (USEPA, 1998b)
Estuaries	Nearly 4% of all shellfish beds restricted or conditional harvest due to high bacteria levels (NOAA, 1992) and more than 4,000 beach closings or advisories (USEPA, 1998b)

8.2.3 PHYSICAL IMPACTS OF CONSTRUCTION AND LAND DEVELOPMENT ACTIVITIES

Construction and land development activities can have a number of impacts on stream systems, including impacts to stream hydrology, geomorphology, habitat structure, thermal regime, and direct channel impacts. These impacts are most visible on streams in urbanized areas. Construction and land development impacts on stream systems are described for each of these impact categories in Table 8-12. Because it is very difficult to differentiate between physical impacts that occur during construction and impacts that result from postdevelopment conditions, the discussion addresses physical impacts from a broader perspective. It does not differentiate between short-term effects arising and site construction activities from long-term impacts of postdevelopment conditions.

Physical changes are often precipitated by changes in hydrology that result when permeable rural and forest land is converted to impervious surfaces like pavement and rooftops and relatively impermeable urban soils. The conversion causes a fundamental change in the hydrologic cycle because a greater fraction of rainfall is converted to surface runoff. This change in the basic hydrologic cycle causes a series of other impacts (Table 8-12). The stream immediately begins to adjust its size, through channel erosion, to accommodate larger flows. Streams normally increase their cross-sectional area by incising, widening, or often both. This process of channel response to increases in impervious surfaces accelerates sediment transport and destroys habitat. In addition, urbanization frequently requires alteration of natural stream channels, such as straightening or

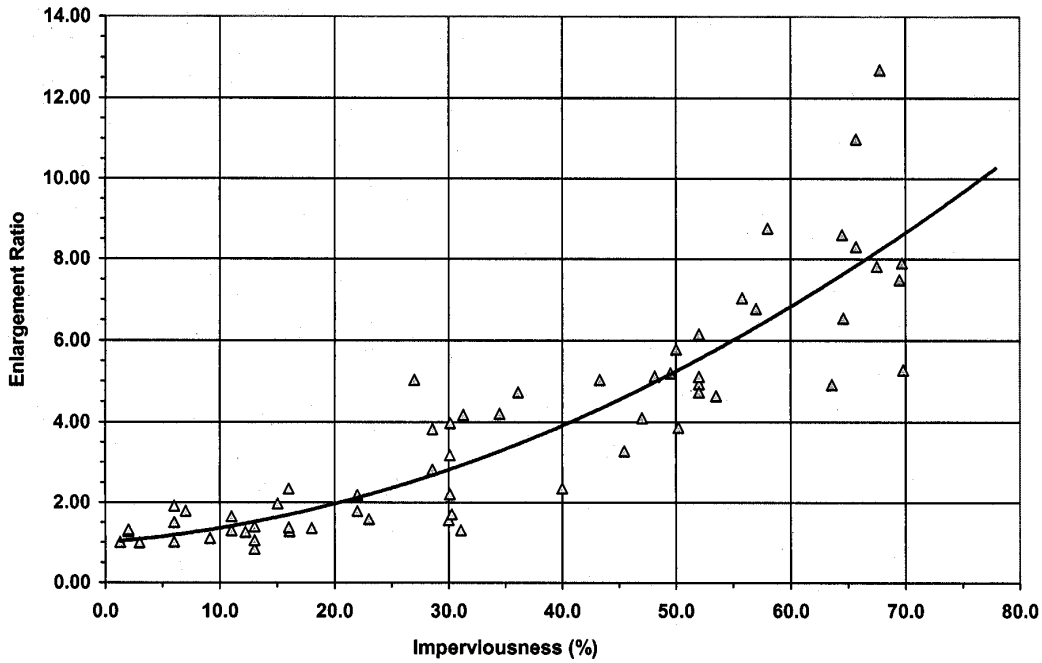
lining with concrete or rock to transport water away from developed areas more quickly. Finally, impervious surfaces also absorb heat, thereby increasing stream temperatures during runoff events.

Table 8-12. Physical Impacts of Urbanization on Streams

Impact Class	Specific Impacts	Cause(s)
Hydrologic	• Increased runoff volume • Increased peak flood flow • Increased frequency of "bankfull" event • Decreased baseflow	• Paving over natural surfaces • Compaction of urban soils
Geomorphic	• Sediment transport modified • Channel area increase to accommodate larger flows	• Modified flows • Channel modification • Construction
Habitat structure	• Stream embeddedness • Loss of large woody debris • Changes in pool/riffle structure	• Modified flows • Stream channel erosion • Loss of riparian area
Thermal	• Increased summer temperatures	• Heated pavement • Storm water ponds • Loss of riparian area
Channel modification	• Channel hardening • Fish blockages • Loss of first and second order streams through storm drain enclosure	• Direct modifications to the stream system.

Figure 8-2 (Claytor and Brown, 2000; MacRae and De Andrea, 1999) depicts the impacts of land development on the stream channel. At low levels of imperviousness, the stream has a stable channel, contains large woody debris, and has a complex habitat structure. As urbanization increases, the stream becomes increasingly unstable, increases its cross-sectional area to accommodate increased flows, and loses habitat structure. In highly urbanized areas, stream channels are often modified through channelization or channel hardening. These physical changes are often accompanied by decreased water quality.

Figure 8-2. Stream Channel Enlargement as a Function of Watershed Imperviousness



8.2.3.1 Hydrologic Impacts of Construction and Land Development Activities

The increased runoff volume that results from land development alters the hydrograph from its predeveloped condition. The resulting hydrograph accommodates larger flows with higher peak-flow rates. Because storm drain conveyance systems (e.g., curbs, gutters) improve the efficiency with which water is delivered to the stream, the hydrograph is also characterized by a more rapid time of concentration and peak discharge. Finally, the flow in the stream between events can actually decrease because less rainfall percolates into the soil surface to feed the stream as baseflow. The resulting hydrologic impacts include increased runoff volume, increased flood peaks, increased frequency and magnitude of bankfull storms, and decreased baseflow volumes.

Increased Runoff Volume

Impervious surfaces and urban land use changes alter infiltration rates and increase runoff volumes. Table 8-13 shows the difference in runoff volume between a meadow and a parking lot. The parking lot produces approximately 15 times more runoff than a meadow for the same storm event. Schueler (1987) demonstrated that runoff values increase significantly with the impervious surfaces

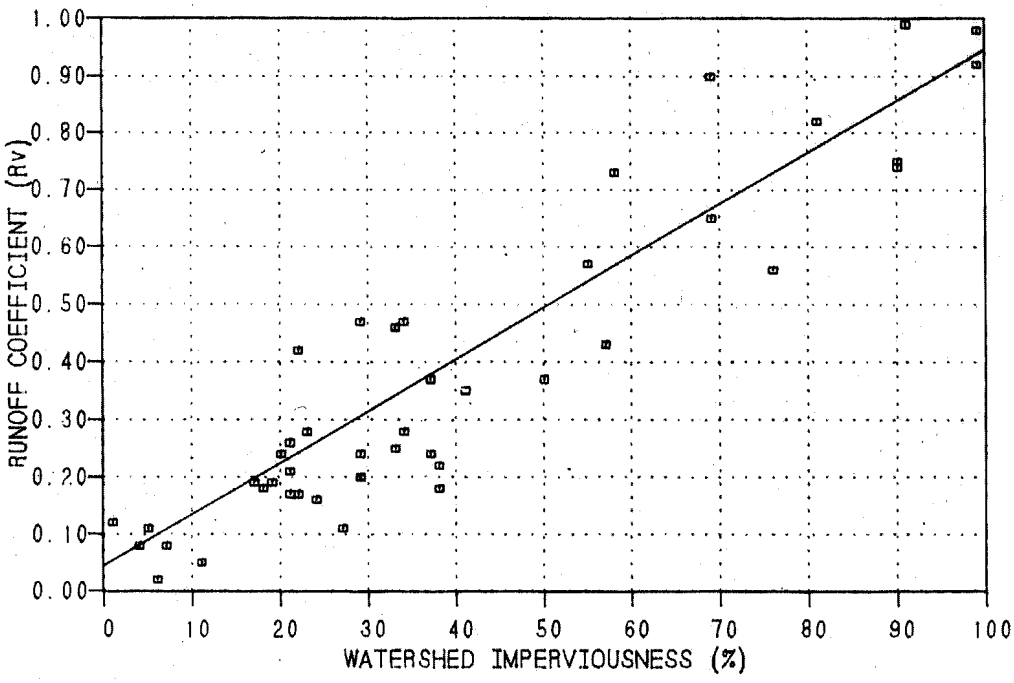
in a watershed (Figure 8-3). The increased volume of water from urban areas is likely the greatest single cause of the negative impacts of urban storm water on receiving waters. The volume causes channel erosion and loss of habitat stability, as well as an increase in the total load of many pollutants such as sediment and nutrients.

Table 8-13. Hydrologic Differences Between a Parking Lot and a Meadow

Hydrologic or Water Quality Parameter	Parking Lot	Meadow
Runoff coefficient	0.95	0.06
Time of concentration (minutes)	4.8	14.4
Peak discharge, 2-yr, 24-h storm (ft^3/s)	4.3	0.4
Peak discharge rate, 100-yr storm (ft^3/s)	12.6	3.1
Runoff volume from 1-in. storm (ft^3)	3,450	218
Runoff velocity @ 2-yr storm (ft/sec)	8	1.8

Key Assumptions: 2-yr, 24-hr storm = 3.1 in.; 100-yr storm = 8.9 in.
Parking Lot: 100% imperviousness; 3% slope; 200-ft flow length; hydraulic radius = 0.03; concrete channel; suburban Washington 'C' values
Meadow: 1% impervious; 3% slope; 200-ft flow length; good vegetative condition; B soils; earthen channel
Source: Schueler, 1987.

Figure 8-3. Runoff Coefficient as a Function of Impervious Cover



NOTE: 44 small urban catchments monitored during the national NURP study.

Construction activities also cause fundamental modifications in native soils. The compaction of urban soils and the removal of topsoil during construction decreases the infiltration capacity of the soil, resulting in a corresponding increase in runoff (Schueler, 2000). The bulk density is a measure of soil compaction, and Table 8-14 shows the values for different aspects of urbanization.

Table 8-14. Comparison of Bulk Density for Undisturbed Soils and Common Urban Conditions

Undisturbed Soil Type or Urban Condition	Surface Bulk Density (grams/cubic centimeter)
Peat	0.2 to 0.3
Compost	1.0
Sandy Soils	1.1 to 1.3
Silty Sands	1.4
Silt	1.3 to 1.4
Silt Loams	1.2 to 1.5
Organic Silts/Clays	1.0 to 1.2
Glacial Till	1.6 to 2.0
Urban Lawns	1.5 to 1.9
Crushed Rock Parking Lot	1.5 to 1.9
Urban Fill Soils	1.8 to 2.0
Athletic Fields	1.8 to 2.0
Rights of Way and Building Pads (85%)	1.5 to 1.8
Rights of Way and Building Pads (95%)	1.6 to 2.1
Concrete Pavement	2.2

Note: Shading indicates "urban" conditions.
Source: Schueler, 2000.

Increased Flood Peaks

Increased surface runoff following urbanization increases peak flows. Data from Sauer et al (1983) suggest that peak flow from large flood events (10-year to 100-year storm events) increases substantially with urbanization. The paper presents results of a survey of urban watersheds throughout the United States and predicts flood peaks based on watershed impervious cover and a "basin development factor" that reflects watershed characteristics such as the amount of curb and gutter, and channel modification. These data suggest that at 50 percent impervious cover, the peak flow for the 100-year event can be as much as twice that in an equivalent rural watershed. Data from Seneca Creek in Montgomery County, Maryland, suggest a similar trend. The watershed experienced significant growth during the 1950s and 1960s. Comparison of gauge records from 1961 to 1990 to those from 1931 to 1960 suggests that the peak 10-year flow event increased from 7,300 to 16,000 cfs, an increase of more than 100 percent (Leopold, 1994).

Increased Frequency and Volume of Bankfull Flows

Stream channel morphology is more influenced by frequent (1- to 2-year) storm events, or "bankfull" flows, than by large flood events. Hollis (1975) demonstrated that urbanization increased the frequency and magnitude of these smaller-sized runoff events much more than the larger events. Data from this study suggest that streams increase their 2-year bankfull discharge by two to five times after development takes place. Many other studies have documented the increase in flow associated with impervious cover. A study by Guay (1995) compared the 2-year flow events before and after development in an urban watershed in Parris Valley, California, in the 1970s and in the 1990s. The impervious level of 9 percent in the 1970s increased to 22.5 percent by the 1990s. The 2-year discharge more than doubled from 646 cfs to 1,348 cfs. A 13 percent change in impervious cover resulted in a doubling of the 2-year peak flow.

A significant impact of land development is the frequency with which the bankfull event occurs. Leopold (1994) observed a dramatic increase in the frequency of the bankfull event in Watts Branch, an urban subwatershed in Rockville, Maryland. This watershed also experienced significant development between the 1950s and 1960s. A comparison of gauge records indicated that the bankfull storm event frequency increased from two to seven times per year from 1958 to 1987.

Changes in Baseflow

Land development results in a smaller recharge to groundwater and a corresponding decrease in stream flow during dry periods (baseflow). Only a small amount of evidence, however, documents this decrease in baseflow. Spinello and Simmons (1992) demonstrated that baseflow in two urban Long Island streams went dry seasonally as a result of urbanization. Another study in North Carolina could not conclusively determine that urbanization reduced baseflow in some streams in that area (Evett et al, 1994). It is important to note, however, that groundwater flow paths are often complex. Water supplying baseflow feeding the stream can be from deeper aquifers or can originate in areas outside the surface watershed boundary. In arid and semiarid areas, watershed managers have reported that baseflow actually increases in urban areas. Increased infiltration from people watering their lawns and return flow from sewage treatment plants are two possible sources (Caraco, 2000). Recharge of clean groundwater is important in these communities, and managers would rather see clean water infiltrated than transported as surface water during storm events.

8.2.3.2 Impacts on Geomorphology/Sediment Transport

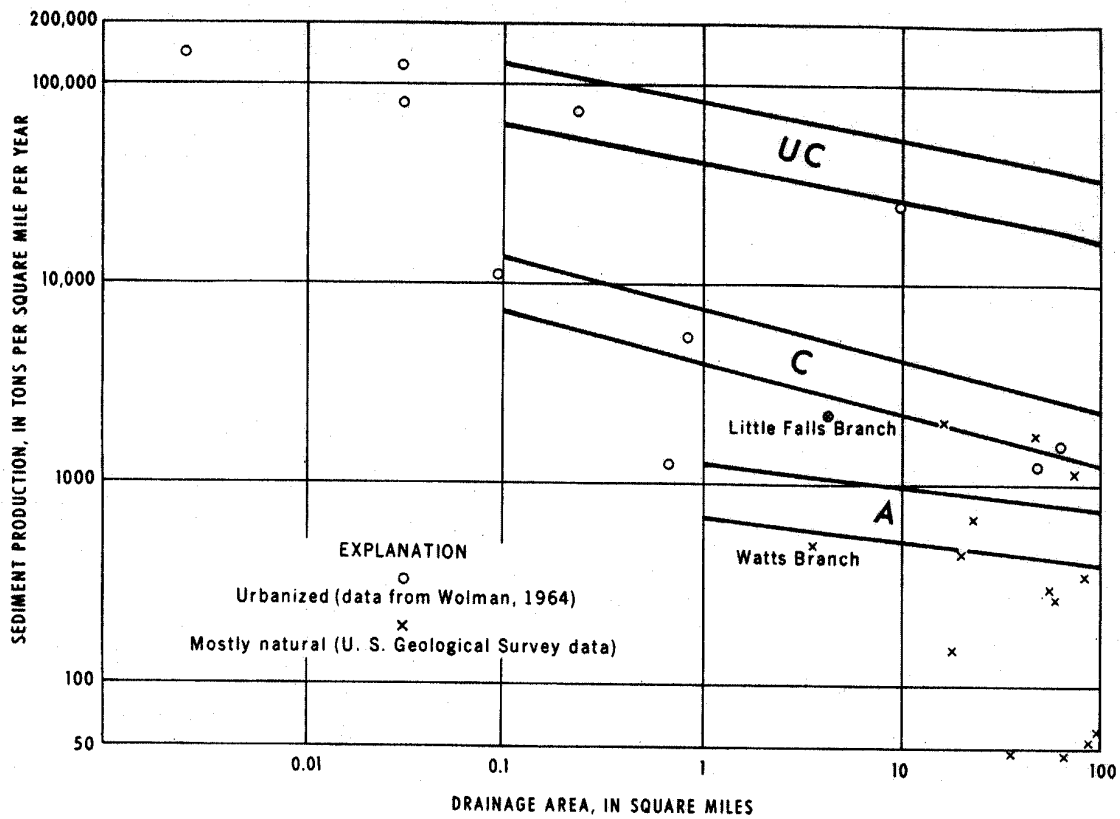
Changes in hydrology, combined with additional sediment sources from construction and modifications to the stream channel, result in changes to the geomorphology of stream systems. These impacts include increased, and sometimes decreased, sediment transport and channel enlargement to accommodate larger flows.

Increased Transport of Sediment

The increased frequency of bankfull (1- to 2-year) storms causes more "effective work" (as defined by Leopold), causing greater sediment transport and bank erosion to take place within the channel. For the same storm event, the increased volume results in a greater amount of total stress above the critical shear stress required to move bank sediment (Schueler, 1987). This effect is compounded by the fact that smaller, more frequent storm events also cause flows in excess of the stress required to move sediment.

The result of this change in effective work on streambanks is increased channel erosion. Studies in California (Trimble, 1997) and Austin, Texas (Dartinguenave et al, 1997) suggest that 60 to 75 percent of the sediment transport in urban watersheds is from channel erosion as compared to estimates of between 5 percent and 20 percent for rural streams (Collins et al, 1997; Walling and Woodward, 1995). If the sediment is not deposited in the channel at obstructions, it is transported downstream to receiving waters such as lakes, estuaries, or rivers. The result can be reduced storage and loss of habitat due to the filling of these water bodies. The clearing and grading of land for new construction at the outset of urbanization is another source of sediment in urban streams. Figure 8-4 (Leopold, 1968) illustrates the difference in sediment from uncontrolled and controlled construction sites.

Figure 8-4. Sediment Production from Construction Sites



Annual sediment production per square mile for urbanized and natural areas. Zones: *A*, agricultural; *C*, under construction; *UC*, under construction and undiluted.

Decreased Sediment Transport

Decreased sediment transport off the land surface itself can result after urbanization as natural drainage and first-order channels are replaced by storm drains and pipes (Dunne and Leopold, 1978). Channel erosion downstream might result when any export of sediment is not replaced by diminished upstream sediment supply. Ultimately, after significant erosion has taken place, the downstream channel will have adjusted to its postdevelopment flow regime and sediment transport will be reduced. Hence, the stability of the land surface and the piping of drainage channels limit storm water's exposure to sediment and reduce the sediment supply.

Increase in Size of Channel

Channels increase their cross-sectional area to respond to higher and more frequent urban flows. In postdevelopment urban watersheds, the increase in frequency of this channel-forming event normally causes sediment transport to be greater than sediment supply. The channel widens (and/or downcuts) in response to this change in sediment equilibrium (Allen and Narramore, 1985; Booth, 1990 Hammer, 1977; Morisawa and LaFlure, 1979;). Some research suggests that over time channels will reach an "ultimate enlargement," relative to a predeveloped condition, and that impervious cover can predict this enlargement ratio (MacRae and DeAndrea, 1999). This was shown in Figure 8-2, which depicted the relationship between ultimate stream channel enlargement and impervious cover for alluvial streams, based on data from Texas, Vermont, and Maryland.

Stream channels expand by incision, widening, or both. Incision occurs when the stream down-cuts and the channel expands in the vertical direction. Widening occurs when the sides of the channel erode and the channel expands horizontally. Either method results in increased transport of sediment downstream and degradation of habitat. Channel incision is often limited by grade control from bedrock, large substrate, bridges, or culverts. These structures impede the downward erosion of the stream channel and limit incision. In substrates such as sand, gravel, and clay, however, stream incision can be of greater concern (Booth, 1990).

Channel widening more frequently occurs when streams have grade control and the stream cuts into its banks to expand its cross-sectional area. Urban channels frequently have artificial grade control due to the frequent culverts and road crossings. These are often areas where sediment can accumulate as a result of undersized culverts and bridge crossings.

8.2.3.3 Changes in Habitat Structure

Land development results in many changes in habitat structure, including embeddedness, decreased riffle/pool quality, and loss of large woody debris (LWD). Increased sedimentation due to clearing and grading during construction as well as bank erosion can significantly reduce the amount of habitat for substrate-oriented species.

Increased sediment transport from construction and land development can fill the interstitial spaces between rocks and riffles, which are important habitat for macroinvertebrates and fish species, such as darters and sculpins. The stream bottom substratum is a critical habitat for trout and salmon egg incubation and embryo development (May et al, 1997).

The presence and stability of LWD is a fundamental habitat parameter. LWD can form dams and pools, trap sediment and detritus, provide stabilization to stream channels, dissipate flow energy, and promote habitat complexity (Booth et al, 1996). For example, depending on the size of the woody debris and the stream, the debris can create plunge, lateral, scour, and backwater pools, short riffles, undercut banks, side channels, and backwaters, and create different water depths (Spence et al, 1996). The runoff generated in urban watersheds from small storms can be enough to transport LWD. Maxted et al (1994) found that woody debris were typically buried under sand and silt in

urban streams. In addition, the clearing of riparian vegetation limits an important source of large woody debris. Horner et al (1997) present evidence from the Pacific Northwest that illustrates LWD in urban streams decreases with increased imperviousness.

Habitat diversity is a key factor in maintaining a diverse and well-functioning aquatic community. The complexity of the habitat results in increased niches for aquatic species. Sediment and increases in flow can reduce the residual depths in pools and decrease the diversity of habitat features such as pools, riffles, and runs. Richey (1982) and Scott et al (1986) reported an increase in the prevalence of glides and a corresponding altered pool/riffle sequence due to urbanization.

8.2.3.4 Thermal Impacts

Summer in-stream temperatures have been shown to increase significantly (5 to 12 degrees) in urban streams because of direct solar radiation, runoff from heat-absorbing pavement, and discharges from storm water ponds (Galli, 1991). Increased water temperatures can prevent temperature-sensitive species from surviving in urban streams.

Water temperature in headwater streams is strongly influenced by local air temperatures. Galli (1991) reported that stream temperatures throughout the summer are higher in urban watersheds, and the degree of warming appears to be directly related to the imperviousness of the contributing watershed. Over a 6-month period, five headwater streams in the Maryland Piedmont that have different levels of impervious cover were monitored. Each urban stream had mean temperatures that were consistently warmer than that of a forested reference stream, and the size of the increase appeared to be a direct function of watershed imperviousness. Other factors, such as a lack of riparian cover and ponds, were also shown to amplify stream warming, but the primary contributing factor appeared to be watershed impervious cover.

8.2.3.5 Direct Channel Impacts

Channel Straightening and Hardening/Reduction in First-Order Streams

Channel straightening and hardening includes the addition of riprap or concrete to the channel, the straightening of natural channels, and the piping of first-order and ephemeral streams. Although this conversion process is often done to control runoff from urbanized areas, adverse impacts often occur downstream. In a national study of urban watersheds in 269 gauged basins, Sauer et al (1983) determined that channel straightening and channel lining (hardening)–along with the percentage of curbs and gutters, streets, and storm sewers–were the dominant land use variables affecting storm flow. These variables all affect the efficiency with which water is transported to the stream channel. Maintaining this efficiency increases the velocities needed for storm water to exceed critical shear stress velocities, eroding the channel. These factors also considerably degrade any natural habitat for stream biota.

Embedded Sediment

Sediment embeddedness measures the degree to which cobbles and large gravels are buried and their interstitial spaces filled because of fine sediment deposition. In a study of habitat restoration in a highly sedimented Idaho stream, Hillman et al (1987) found that interstitial spaces among cobbles may be essential winter habitat for juvenile chinook salmon. When large cobble was added to an otherwise embedded stream, juvenile populations increased. When that same cobble became embedded, the population decreased.

Embeddedness blocks passages and removes small cover spaces for eggs, fry and juvenile fish. USEPA (2003) summarized that sediment deposition has caused a 94% reduction in numbers and standing crop biomass in large game fish due to increased vulnerability of their eggs to predation in gravel and small rubble, reductions in oxygen supply to eggs, and increased embryo mortality.

Weaver and Fraley (1993) (in USEPA 2003) reported that emergence success of cutthroat trout was reduced from 76% to 4% when fine sediment was added to redds. NAHB (2000) reported that as fry grow into juvenile fish they seek out the slow moving water at the channel edges for cover. These areas also are favored for deposition of suspended sediment. When these areas are filled with excess sediment, sheltered space is lost and the juveniles are forced out into the channel to compete at a disadvantage with the adult fish. Waters (1995) also found that juveniles face habitat degradation from the sedimentation of the pools. Information quantitatively relating embeddedness levels to effects on aquatic fauna is limited.

NAHB (2000) found that invertebrate study results are often complicated by the fact that the various invertebrate species in a community responds very differently to increased sediments. Aquatic insect densities may decline at embeddedness levels of approximately two-thirds to three-quarters.

Surface Sediment

Surface sediment describes the percentage of streambed area with exposed fine sediments. Targets are developed to describe thresholds of suitability of stream substrates for invertebrate and salmonid habitation. Using the Wolman pebble count method, percent surface fines may be calculated. The same method is also used to determine the median substrates size (d50). This is used as a sediment target. The percentage of area is one measure, but particle size distribution, geometric mean particle size, median particle size, or other indices like fredle index may be used to describe the streambed's exposed fine sediment area.

Salmonids prefer mid-sized substrates with interstitial cover to either fine sediment or boulders and bedrock. Ephemeroptera, Plecoptera, and Trichoptera (important fish-food organisms) also respond positively to gravel and cobble substrates (Waters 1995). However, the percent coverage of fine sediments by area and the effects on salmonids and invertebrates have not been extensively investigated.

NAHB (2000) found a notable absence of data regarding effects of suspended sediments on warmwater fish. They also found evidence that some warmwater fish may be able to spawn on muddy substrate. Studies on the effects of surface sediment from construction activities are limited. However, one study by Reed (1977) in Wheeler et al (2003) did reveal that sediment from road construction in Northern Virginia reduced aquatic insect and fish communities by up to 85 percent and 40 percent, respectively.

Subsurface Sediment

Surface fines and embeddedness are apparent to the human observer, and are thus relatively easy to measure, but subsurface or depth fines also have a major effect on the suitability of spawning habitats. The amount of subsurface fine sediments as measured at the head of riffles in likely spawning areas can be an indication of redd site suitability, conditions for egg survival and alevin emergence in the constructed redd, as well as habitat quality for fry and prey.

Information on the biological effects of subsurface sediment varies according to the size of sediment and geographic area of concern. Some of the variability is reduced by standardizing the habitat and stream types (e.g., Rosgen [1996] level II) sampled. Subsurface sediment targets can serve as a measure of suitability for fish spawning grounds, and they are most applicable in riffles and spawning areas in streams with gravel/cobble/boulder streambeds. If there are excessive subsurface fines they can have detrimental effects on salmonid and invertebrate habitat suitability and redd conditions. In the western U.S. redd construction is often upstream from riffles or at the tail end of pools where there is a net flow of stream water downward into the substrate. Where upwelling groundwater rather than surface irrigates the substrate, the fines are no longer in the position to block the flow of water into the redd, and therefore are a less important threat (Waters, 1995).

Riffle Stability

The Riffle Stability Index (RSI) indicates the relative percentage of the streambed that is mobile during channel forming flows. Bed mobility is related to pool quality and abundance. With lower RSI values, there is overall greater residual pool volume, because less of the streambed is susceptible to moving. Pool habitat provides critical refuge for juvenile and adult salmonids. The RSI has been used as an indicator of beneficial use, especially as related to cold water biota. The RSI is measured as the percentage of the substrate particles (from a Wolman pebble count) that are smaller than the largest particles that are moved in channel forming flows. Particles on point bars are measured to determine the largest mobile particles.

Intergravel Dissolved Oxygen

One effect of the accumulation of fine sediment in the aquatic environment is reduced permeability of the substrate resulting in less oxygen exchange to support fish embryos and macroinvertebrates. Salmonids excavate streambed substrate to deposit eggs then backfill the “egg pocket” to protect the eggs during the incubation period. The eggs are dependent on the flow of

oxygen-rich water through the substrate to survive. The accumulation of fines in the redd restricts water flow and reduces oxygen to the eggs which results in decreasing survival (Shapovalov and Berrian, 1939; Wickett, 1954; Shelton and Pollock, 1966).

Several studies have related intergravel dissolved oxygen to egg/fry survival. Survival of embryos has been positively correlated with intergravel dissolved oxygen in the redds for steelhead (Coble, 1961) and brown trout (Maret et al, 2003). Silver et al (1963) found that embryos incubated at low and intermediate DO concentrations produced smaller and weaker alevins than embryos incubated at higher concentrations. Weak sac fry cannot be expected to survive rigorous natural conditions. In a review of embryo development studies, Chapman (1988) noted several examples of developmental impairment at lower DO concentrations, but did not recommend a single threshold. Bjornn and Reiser (1991) recommended that intergravel DO concentrations should be at or near saturation, and that temporary reductions should drop to no lower that 5.0 mg/L.

Observations of the effects of intergravel flow on macroinvertebrates are much less extensive than those for fish. Excessive sediment affects macroinvertebrates by accumulating on the body surfaces and reducing the effective area of the respiratory structures (Lemly, 1982) or by covering pupae cases and reducing the flow of oxygenated water to the metamorphosing insect (Rutherford and Mackay, 1986).

Fish Blockages

Infrastructure associated with urbanization–such as bridges, dams, and culverts–can have a considerable effect on the ability of fish to move freely upstream and downstream in the watershed. This in turn can have localized effects on small streams, where nonmigratory fish species can be inhibited by the blockage from recolonizing areas after acutely toxic events. Anadromous fish species such as shad, herring, salmon, and steelhead also can be blocked from making the upstream passage that is critical for their reproduction.

8.2.3.6 Site Differences in Physical Impacts

Site differences that can affect physical impacts include location of the impervious surfaces, presence of vegetation, and soil type within the watershed. Location of the impervious development can be instrumental in the timing of runoff in a watershed. If the development is at the bottom of the watershed, peak flow from the urbanized area will likely have passed downstream before the flow peaks from the upper watersheds reach the urbanized area (Sauer et al, 1983). Vegetation can reduce channel erosion from storm flows. A study in British Columbia showed that meander bends with vegetation were five times less likely to experience significant erosion from a major flood than similar nonvegetated meander bends (Beeson and Doyle, 1995). The types and porosity of soils are also important in determining runoff characteristics from the land surface and erosion potential of the channels. Allen and Narramore (1985) showed that channel enlargement in chalk channels was from 12 to 67 percent greater than in shale channels near Dallas, Texas. They attributed the differences to greater velocities and shear stress in the chalk channels.

8.3 ANALYSIS OF SOIL TEXTURE BY REGION

EPA used surface soil texture as the primary indicator of soil nature for the 48 contiguous states. The USDA GIS coverage of surface soil texture (the top six inches of soil) was developed primarily to characterize agricultural areas. NRI (USDA, 2000) data indicates that agricultural land (crop land, pasture land and range land) makes up a large fraction of the land area converted to urbanized areas annually. The bulk of the remaining converted acreage is from areas characterized as forested. EPA used the agriculture-based USDA soil characterization data as a reasonable approximation of the soil texture that would be encountered on all new construction sites.

The USDA coverage also allowed for the identification of the three dominant soils for each ecoregion, listed in Table 8-15. Where more than three soils were present, only the top three textures were selected and the percentage of each prorated so that the total percentage equaled 100%. In each ecoregion the three dominant surface soil textures comprised at least 65 percent of the total surface area in each ecoregion when considering all soils present. This was judged to provide a reasonable approximation of the geographic distribution of construction site soils for each ecoregion. The per-ecoregion soil texture information was then subdivided into the state-ecoregion area basis for later use in computing erosion rates. In summary, the analysis identified seven different soil textures that dominate the surface soil coverage within the 48 contiguous states.

8.4 ESTIMATION OF SOIL EROSION RATES

The evaluation of soil erosion rates was based on previous procedures used by EPA to assess the environmental benefits of the Phase II Storm Water Rule (EPA, 1999), which utilized the Revised Universal Soil Loss Equation (RUSLE) (USDA, 1997). The pollutant of primary interest in storm water discharges from construction sites is sediment that results from eroded soil. This sediment is composed of both suspended solids (fine-grained material) and bedload (large-grained material). The analysis entailed evaluation of up to three dominant soils in each ecoregion (see Table 8-15), for three slopes (3, 7, and 12 percent). In this assessment, EPA assumed that construction sites were evenly divided among these three slopes. For all slope and soil combinations, the RUSLE equation was used to estimate the ambient annual erosion rate or yield (natural), and the erosion rate with construction activity occurring without any BMPs. These two erosion rates provide the basis for the estimate of loadings reductions related to implementation of construction site BMPs.

Table 8-15. Ecoregion Surface Soil Texture Characterization

Ecoregion	Soil #1 Texture	Percent Coverage	Soil #2 Texture	Percent Coverage	Soil #3 Texture	Percent Coverage
1	Sand	18.5%	Sandy Loam	34.2%	Loam	47.3%
2	Sand	11.3%	Sandy Loam	41.8%	Loam	46.9%
3	Sandy Loam	36.9%	Loam	63.1%		
4	Loamy Sand	29.0%	Sandy Loam	71.0%		
5	Sand	31.8%	Sandy Loam	51.2%	Loamy Sand	17.0%
6	Sand	78.2%	Loamy Sand	9.9%	Sandy Loam	11.8%
7	Sand	100.0%				
8	Sandy Loam	46.5%	Silt Loam	53.5%		
9	Silt Loam	62.6%	Sandy Loam	18.1%	Loam	19.4%
10	Silt Loam	54.0%	Sandy Loam	18.3%	Loam	27.7%
11	Silt Loam	59.7%	Sandy Loam	18.0%	Clay	22.3%
12	Silt Loam	54.0%	Sandy Loam	25.6%	Loam	20.4%
13	Silt Loam	31.5%	Loam	68.5%		
14	Sandy Loam	39.5%	Loam	60.5%		
15	Silt Loam	38.9%	Loam	61.1%		
16	Sandy Loam	52.4%	Loam	47.6%		
17	Silt Loam	37.5%	Loam	34.0%	Silty Clay	28.5%
18	Silt Loam	100.0%				
19	Sandy Loam	37.4%	Loam	43.2%	Loamy sand	19.4%

Within each of the 19 ecoregions, specific urban areas were selected as the areas where new construction is most likely to occur. Selecting specific urban areas was necessary in order to determine the appropriate rainfall characteristics and to set RUSLE equation parameters related to rainfall and soil cover. The erosion rates for these urban areas were assumed to be representative of the ecoregion as a whole. The specific urban areas analyzed within each ecoregion are presented in Table 8-16. This table also presents the range of sediment yields for the three slopes and dominant soils in each ecoregion. When computing the values in Table 8-16, the role of construction site BMPs were not considered–the estimates are solely ambient conditions and disturbed (denuded) conditions. BMP removal rates are discussed in Section 8.5.

As shown in Table 7-4, it was assumed that some portion of each construction site will remain undisturbed, depending on site size and ultimate land use. This is due to a certain percentage of each site comprising features such as open space, natural area set-asides, stream buffers, and forested buffers. For the estimated fraction of each construction site expected to be undisturbed, EPA set the rate of eroded material to ambient levels. For example, disturbed sand soils in

ecoregion 1 produce a maximum construction site yield of 2.71 tons per acre, and undisturbed sand soils on construction sites will produce 0.69 tons per acre.

The duration of construction site activities and timing of these activities are variables that affect how much eroded soil is generated. Several factors are simplified in this assessment in order to avoid complexity and the use of excessive analytical resources. First, the assumed length of the construction period spans a calender year, regardless of construction site size, meaning there is no "wintering over" of partially constructed areas. Since the estimates of construction acreage are based on annual values obtained from NRI, this is a reasonable assumptions. Although large construction projects will likely span several years, the basis of the analysis is the amount of acreage actually being developed in any given year.

The timing of construction activities (e.g., clearing and grubbing) are assumed to occur in ways that minimize soil erosion. Instead of denuding an entire large site at a single time, construction operators are assumed to used a phased approach to land disturbance, where only portions of each construction site are cleared and graded before moving on to other portions. EPA acknowledges this assumption will likely result in underestimating the actual loadings, as it neglects the fact that large portions of the site may be disturbed for a considerable period of time.

Table 8-16. Range of Annual Erosion Estimates by Dominant Soil Type in Each Ecoregion (tons/acre/year)

Soil Type	Minimum Ambient Yield	Maximum Ambient Yield	Minimum Construction Site Yield	Maximum Construction Site Yield
Ecoregion 1, Indicator City Denver, Co				
Sand	0.19	0.69	0.73	2.71
Sandy Loam	1.01	3.73	3.96	14.63
Loam	1.42	5.25	5.58	20.59
Ecoregion 2, Indicator City Salt Lake, Ut				
Sand	0.07	0.26	0.36	1.33
Sandy Loam	0.38	1.39	1.95	7.20
Loam	0.53	1.96	2.74	10.13
Ecoregion 3, Indicator City Austin, Tx				
Sandy Loam	12.13	44.76	29.46	108.73
Loam	17.07	63.00	41.46	153.03
Ecoregion 4, Indicator City Atlanta, Ga				
Loamy Sand	5.26	19.41	13.87	51.20
Sandy Loam	11.83	43.67	31.21	115.20
Ecoregion 5, Indicator City Charleston, SC				
Sand	3.13	11.57	8.00	29.54
Sandy Loam	16.92	62.46	43.22	159.51
Loamy Sand	7.52	27.76	19.21	70.89
Ecoregion 6, Indicator City Jacksonville, Fl				
Sand	3.92	14.46	10.00	36.92
Loamy Sand	9.40	34.70	24.01	88.62
Sandy Loam	21.15	78.08	54.02	199.39
Ecoregion 7, Indicator City Miami, Fl				
Sand	5.22	19.28	13.34	49.23
Ecoregion 8, Indicator City Albany, NY				
Sandy Loam	3.33	12.30	10.35	38.21
Silt Loam	5.93	21.87	18.40	67.92
Ecoregion 9, Indicator City Pittsburgh, Pa				
Silt Loam	9.18	33.90	28.53	105.28
Sandy Loam	5.17	19.07	16.05	59.22
Loam	7.27	26.83	22.58	83.35

Soil Type	Minimum Ambient Yield	Maximum Ambient Yield	Minimum Construction Site Yield	Maximum Construction Site Yield
Ecoregion 10, Indicator City St. Paul/Minneapolis				
Silt Loam	5.4	20.01	21.03	77.62
Sandy Loam	3.05	11.25	11.83	43.66
Loam	4.29	15.84	16.65	61.45
Ecoregion 11, Indicator City Houston, Tx				
Silt Loam	35.94	132.63	87.29	322.17
Sandy Loam	20.21	74.61	49.10	181.22
Clay	9.73	35.92	23.64	87.25
Ecoregion 12, Indicator City Kansas City, Mo				
Silt Loam	12.61	46.55	36.15	133.40
Sandy Loam	7.09	26.18	20.33	75.04
Loam	9.98	36.85	28.62	105.61
Ecoregion 13, Indicator City Rapid City, SD				
Silt Loam	2.02	7.46	7.93	29.26
Loam	1.60	5.91	6.28	23.16
Ecoregion 14, Indicator City Boise, Id				
Sandy Loam	0.20	0.75	1.16	4.27
Loam	0.29	1.05	1.63	6.01
Ecoregion 15, Indicator City Eureka, Ca				
Silt Loam	4.55	16.78	17.20	63.49
Loam	3.60	13.28	13.62	50.27
Ecoregion 16, Indicator City San Francisco, Ca				
Sandy Loam	1.21	4.47	4.58	16.92
Loam	1.70	6.29	6.45	23.81
Ecoregion 17, Indicator City: Olympia/Seattle, Wa				
Silt Loam	3.35	12.36	12.68	46.78
Loam	2.65	9.79	10.04	37.04
Silty Clay Loam	2.58	9.53	9.77	36.06
Ecoregion 18, Indicator City: Spokane/Highland, Wa				
Silt Loam	0.30	1.11	1.71	6.32

Soil Type	Minimum Ambient Yield	Maximum Ambient Yield	Minimum Construction Site Yield	Maximum Construction Site Yield
Ecoregion 19, Indicator City: Stampede Pass/Mount Hood, Wa				
Sandy Loam	1.35	4.97	5.09	18.80
Loam	1.89	6.99	7.17	26.46
Loamy sand	0.60	2.21	2.26	8.35

Another assumption made in the analysis is that the size distribution of eroded material matches the native (dominant) soils. Table 8-17 indicates the grain size distribution of seven common soil textures believed to be present at a majority of construction sites.

Table 8-17. Estimated Soil Grain Size Distribution

Gross Soil Texture Classification	Clay Fraction, %	Fine Silt Fraction, %	Silt Fraction, %	Fine Sand Fraction, %	Sand Fraction, %
Clay	45	20	10	10	15
Loam	15	15	20	20	30
Loamy Sand	5.25	4.25	5	23.25	62.25
Sand	3.75	2.5	2.5	23.75	67.5
Sandy Loam	7.5	7.5	10	22.5	52.5
Silt Loam	11.25	18.75	30	21.25	18.75
Silty Clay Loam	18.75	22.5	32.5	18.75	7.5

Adapted from Foth, 1978

8.5 ESTIMATION OF BMP REMOVAL EFFICIENCIES

8.5.1 APPLICATION OF SEDCAD

BMP performance is dependent on many factors related to soil nature, hydrology, and engineering practice (see Section 5). A commercially available software package (SEDCAD) was used to model BMP removal efficiencies for a series of site conditions. These reference values were then used to estimate performance for each combination of soil, slope, location, and model construction site size, and reflecting the influence of the regulatory options considered on sediment discharges. Surface soil texture was the key feature used to adjust for the varying effects of soil nature on BMP removal efficiency.

BMPs were selected and sized for a subset of the model sites developed in Sections 4 and 7 reflecting the area draining to each BMP through the appropriate drainage pathway and following industry standard design practices. Table 8-18 provides an overview of the analysis performed, and detailed documentation of the specific design criteria and assumptions made can be found in the public record.

Table 8-18. Description of EPA Construction Site Analysis for BMP Removal Estimation

Item	BMP	Analysis Performed	Comments
Erosion Control	Seed and Mulch	No SEDCAD simulation	Estimation of removals was conducted in two phases. The first phase assumed that soils were exposed and unmanaged for varying periods of time to account for the active construction phase. In the second phase, soils were assumed to be stabilized with seed and mulch (see Table F-4). The total duration of each project was assumed to be 1 year.
Sediment Controls	Silt Fence	SEDCAD analysis generic to all model sites	
	Rock Check Dam	SEDCAD analysis generic to all model site sizes	
	Inlet Protection	SEDCAD analysis generic to all model site sizes	
	Sediment Trap	SEDCAD analysis of 3 acres of centralized drainage on a 7.5 acre model site	
	Sediment Basin	SEDCAD analysis of 10 acres of centralized drainage on a 25 acre model site	

For each BMP, performance was evaluated individually for 10 soil grain size groups under five different rainfall events ranging from 0.5 to 3.6 inches in depth. All NRCS or Soil Conservation Service (SCS) Type rainfall distributions (Type I, II, and III) were individually evaluated so that BMP performance would be customized to the climate on an ecoregion basis. For example, the estimated BMP performance within the relatively dry Ecoregion 1 is based on a range of rainfall events that are shaped according to the NRCS Type II distribution, or the rainfall distribution expected in the region.

The wide range in grain size groups was intended to improve the representativeness of the SEDCAD simulation of BMP performance to all of the likely conditions present across the country. This acknowledges that construction site BMPs have higher removal efficiencies for larger grained particles (such as sand) than for smaller grained particles (clays). By analyzing soil grain size groups individually, a reasonable basis for compositing an estimated removal rate was established for any of the common surface soil textures discussed in Section 8.3. BMPs are assumed to provide consistent performance for all sites that employ them in a single state-ecoregion area. For example, two sedimentation basins employed on a single 25 acre construction site were assumed to provide

the same performance as four sedimentation basins employed on a 70 acre construction site. This simplification was necessary in order to limit the total analytical time and resources required to conduct the analysis.

8.5.2 CUSTOMIZING BMP REMOVALS FOR STATE-ECOREGIONS

The results of the basic SEDCAD analysis were used to develop BMP removal rates customized to each state-ecoregion area that reflect the role of:

- Dominant soils;
- Climate;
- Regulatory conditions (e.g,. baseline state regulations); and
- BMP combinations.

The suite of potential regulatory requirements includes stabilization of exposed soil areas within 14 days following the end of land disturbance. Because seeding (e.g., hydroseeding) and seeding with mulching for soil stabilization are common practices within the industry, it was assumed that this requirement would not increase the application rates of stabilization measures, but would rather only change the timing of stabilization. This was judged to be a reasonable assumption because existing state requirements include stabilization of exposed soils (although the time allotted may be 28 or 30 days instead or 14 days) or developers elect to stabilize exposed soils to prevent the need for subsequent re-grading.

EPA acknowledges there are difficulties involved in analyzing the effect of the shortened time period allowed for stabilization. Inherent to any analysis is uncertainty associated with the timing of land disturbing activities on various portions of a construction site, and further uncertainty related to seasonal variation in rainfall conditions across the country. So when developing its standardized approach within limits of its resources, EPA elected to focus on site physical features for a suite of model sites (e.g., site size, local soils texture) and the “typical” performance of seed/mulch as reported in the literature (derived from a range of soils and rainfall events).

To calculate the effects of seeding and mulching, EPA’s model assumed that well applied mulch provides the same sediment control effectiveness as grass. So, denuded construction surfaces are immediately stabilized as soon as the seed/mulch combination is applied. The idea behind this assumption is that as the mulch degrades, the grass germinates and grows, which then compensates for the loss of mulch. To estimate the sediments generated and released to the environment, the first step was to assign to each model site size category the period in the construction year that the site has bare soils or is covered by either mulch or grass (both for the baseline and regulatory conditions) (See Appendix F). For larger site sizes (larger than 1 acre), eroded site sediment generally goes through additional sediment control devices (e.g., sedimentation basins), whether site soils are bare or are stabilized with seed/mulch. So, for part of the construction year, seeding/mulching provides additional in-series control with downstream sediment controls within EPA’s suite of site models. The overall capture of eroded material for a construction year was set equal to the sum of the sediment captured in sediment control for the period without seed/mulch,

plus the sediment captured by combined seed/mulch/sediment controls for the period following seed/mulch application. In this calculation, EPA's suite of site models estimates the generation of sediments on a per particle size basis (e.g., clay, silt, sand), based on local rainfall information and local (common) soils derived from national databases.

EPA acknowledges that this approach to estimating the influence of seeding and mulching on sediment discharges from construction sites likely underestimates the actual sediment discharges that will occur over the life of construction projects. Similarly, it also likely underestimates the reductions that will result from implementing soil stabilization within 14 days instead of 28 days since it ignores a number of important real-world factors. In addition, on residential projects individual lots are often sold off to a number of builders, and exposed soil areas are likely to persist for long periods of time in these areas. In addition, the analysis uses average or typical rainfall conditions. It ignores the influence of short-duration, high intensity storm events that could potentially occur throughout the construction project. However, despite its drawbacks, the analysis is reasonable given the analytical resources available in this case.

As shown in Table 8-17, each of the seven dominant surface soil textures can be characterized by the percent found in various grain size groups. The 10 soil grain size groups analyzed individually with SEDCAD provide key data for creating composited BMP removal rates for each dominant soil texture. Computing the amount of soil removed for a particular BMP is done by combining size-specific removals in proportion to the grain-size distribution of each soil. Step 1 in Table 8-19 presents the scale and purpose of the assessment of dominant soil grain size distributions.

The method for estimating construction site BMP removal rates in this analysis is probability-based, where the rainfall probability (i.e., the total rainfall depth occurring during an event) in each ecoregion is used to composite a probable annual performance for the model construction sites. Single-event BMP removal rates from SEDCAD were combined for each ecoregion to compute an "expected annual" removal rate. SEDCAD simulation of six individual rainfall events ranging from 0.5 to 5 inches in rainfall demonstrate how individual BMPs perform for various storm events. For each ecoregion, EPA analyzed ten years of precipitation records to categorize local rainfall patterns and estimate the probability that a storm of a given size will occur within a 1-year period (the assumed duration of construction projects). The expected annual removal value was then calculated for each BMP within each ecoregion from the cross-product of the BMP removal rate array with the ecoregion distribution of rainfall.

The expected value approach accounts for the fact that large but relatively infrequent events will have low removal rates (due to flows exceeding BMP design capacities and leading to bypasses, shorter detention times, or overtopping), while more frequent but smaller rainfall events will have higher removal rates. Step 2 in Table 8-19 indicates the scale and purpose of the probability-based assessment of ecoregion hydrologic characteristics. Table 8-20 indicates the range in soil-specific BMP removal rates for eroded construction site soils in the nineteen ecoregions.

The assessment of current state regulations (see Table 3-1) provides the basis for characterizing which of the seven model construction site sizes will employ a particular mix of BMPs under

baseline conditions. The best example of this is a sediment trap for sites with between 5 and 10 acres of drainage area. Many states do not have this requirement as part of their existing program, but it is a requirement under Options 2 and 4. When calculating removal rates under baseline conditions for states without this requirement, removal rates were calculated for the 7.5 acre site group using BMP removal rates for rock check dams. For the analysis of BMP removals under Option 2 and 4, the removal rates were calculated using the more effective sediment trap.

Options 2 and 4 also affect construction site BMPs by way of setting minimum design requirements. The design basis for sediment basins under these options would increase from 1,800 to 3,600 cubic feet per acre of drainage for the 25 acre site size group in states that do not have this requirement under baseline conditions. The change in basin sizing would be reflected in the associated removal rate for those sites. Although many states do not specifically indicate minimum sediment basin requirements, EPA assumed that all construction sites of greater than 10 acres would implement sediment basins with at least 1,800 cubic feet per acre of storage, as basins are common practice in the industry. Step 3 in Table 8-19 indicates the scale and purpose of these considerations of current state regulations.

The combined performance of BMPs in series was assessed individually for each grain size group. An assumption was made that total BMP removal was equal to the removal from an erosion control BMP (i.e., seed and mulch), followed by the removal from a sediment control BMP (e.g, sediment trap). So, for 7.5 acre construction sites under Options 2 and 4, the total removal of clay-sized particles would be equal to the load of eroded clay-sized particles from the site, less the reduction of seed and mulch, and then less the estimated reduction of clay-sized particles provided by a silt trap. Step 4 in Table 8-19 indicates the scale and purpose of the BMP groupings used in this analysis.

Table 8-19. Methodology for Estimating BMP Removal Rates

SEDCAD Analysis	Other EPA Analysis	Examples
Step 1 - Soils Processing		
10 grain size groups covering from large sand to clay are individually analyzed, then combined to estimate individual removals for 3 major size groups; sand, silt, and clay	7 soil textures containing different amounts of sand, silt and clay were found to be common in the nation. SEDCAD output is used to estimate soil texture-specific removals, based on sand, silt, and clay fractions.	Loam texture soil contains 40, 40, and 20 percent sand, silt, and clay particles, respectively. SEDCAD lumped removals for these grain sizes in a sediment basin are 90, 40 and 10 percent, respectively, for a single rainfall event. The composited removal rate for the silt texture soils is calculated as 54 percent for the event.

SEDCAD Analysis	Other EPA Analysis	Examples
Step 2 - Precipitation Processing		
No direct role	For each size fraction, BMP removals are estimated for 6 rainfall events of increasing depth (0.5, 0.7, 1.2, 2.4, 3.6, and 5.0 inches of total precipitation) and then composited into a single expected removal rate.*	For the NRCS Type II rainfall distribution, SEDCAD sediment basin removal rates for the silt size fraction range from 100 (a 0.7-inch event) to 21 percent (a 5-inch event). The probability of the six rainfall events for Ecoregion 1 are used to composite an expected annual silt fraction removal rate of 98 percent for sediment basins. (Note, most rainfall events in the semi-arid Ecoregion I are small and fully retained within the wet storage portion of sediment basins with 3,600 cubic feet per acre of storage)
Step 3 - State Regulation Processing		
No direct role	For each area defined by the intersection of state and ecoregion boundaries, a decision is made on the presence or absence of BMPs under each option evaluated	A state found in Ecoregion 1 does not have a sediment basin requirement under baseline conditions. In this case, baseline reductions are based on removal rates of sediment basins with 1,800 cubic feet per acre of storage. Under Option 4, all sites would be required to install sediment basins with 3,600 cf/ac for large sites, so removal rates will range from 39% to 94% depending on the soils present.
Step 4 - BMP Combination		
No direct role	For centralized drainage and perimeter drainage (each), one erosion prevention BMP (e.g., seed/mulch) is followed by a single sediment control BMP (e.g,. sediment basin). The combined efficiency of the two BMPs is calculated individually for each land use and site size combination, which indicates the total removal.	For a loam soil, seed/mulch is 95 percent effective on all grain sizes. The remaining 5 percent enters a sediment basin where sand, silt, and clay size particles are individually assessed to determine the additional removal of each fraction. As a result, the combined removal of seed/mulch and sediment basins in a state in Ecoregion 1 is 98.5 percent (accounts for the probability of various rainfall events and the full capture with no discharge condition that occurs for frequent small events)

* Expected performance was based on all rainfall events encountered in 10 years of records for indicator cities selected for each ecoregion

Table 8-20. Range of BMP Percent Removals (Weighted by Grain Size Distribution)

Soil Texture	Silt Fence	Inlet Protection	Rock Check Dam	Silt Trap	Sediment Basin
Clay	34.5 / 40.4	17.3 / 20.8	17.3 / 20.8	30.9 / 39.8	38.8 / 62.2
Loam	67.4 / 73.3	34.2 / 39.4	34.2 / 39.4	59.9 / 70.8	64.2 / 79.7
Loamy Sand	89.9 / 91.5	67.1 / 72.2	67.1 / 72.2	88.0 / 90.9	89.3 / 93.8
Sand	93.5 / 94.3	72.4 / 77.5	72.4 / 77.5	92.5 / 94.1	93.4 / 96.1
Sandy Loam	83.7 / 86.6	57.2 / 62.4	57.2 / 62.4	80.0 / 85.4	82.1 / 89.8
Silt Loam	65.8 / 73.9	23.3 / 28.9	23.3 / 28.9	54.6 / 69.9	59.2 / 78.1
Silty Clay Loam	54.4 / 63.3	11.5 / 16.9	11.5 / 16.9	42.3 / 59.4	48.2 / 71.1
Range shows values across nineteen ecoregions					

8.6 CALCULATION OF NATIONAL LOADINGS AND REMOVALS BY REGULATORY OPTION

This assessment of model construction sites is intended to acknowledge major influences on national loadings, including site size, current state BMP requirements, soil nature, slopes and flow lengths of construction sites, and climate. Ultimately, the assessment resulted in 276 individual loadings estimates, which were combined with 9,000 individual estimates of BMP removal rates for various settings. For each state-ecoregion area, the analysis:

- Generated "whole site" estimates of the population of construction sites reflecting up to three dominant soils and three slopes (i.e, at no time were fractions of model construction sites analyzed);

- Estimated the amount of eroded soil produced due to construction activities on the basis of site size and land use type;

- Estimated BMP removal rates for the regulatory options;

Using the population of construction sites by land use and size (see Section 4.2.2), state-ecoregion area load totals based on the estimated load discharged from each model site were computed for baseline conditions and for each regulatory option. State-ecoregion area load totals were then summed to produce state and national total loads for each regulatory option (see Table 8-21). Tables F-1, F-2 and F-3 in Appendix F provide detailed information on loadings, including loadings to individual HUCs. Table 8-22 indicates estimated per-state loadings for each alternative. Note that the state-level loads in Table 8-22 do not sum to the national loads in Table 8-21 or 8-1 due to rounding.

Table 8-21. National Annual Construction Load Estimates

Site Size, acres	Single Family (tons)	Multi-family (tons)	Commercial (tons)	Industrial (tons)	Total (tons)
Baseline					
0.5	96,735	31,105	888,510	38,268	1,054,618
3	89,368	66,771	929,412	46,473	1,131,964
7.5	129,814	97,290	540,091	18,237	785,432
25	392,563	268,202	1,319,539	34,323	2,014,627
70	220,234	112,214	859,721	30,127	122,296
200	291,595	2,742	0	0	294,337
Total Load (tons)	1,220,308	578,325	4,537,274	167,428	6,503,334
Options 2 and 4					
0.5	96,735	31,105	888,510	38,268	1,054,618
3	89,368	66,771	929,412	46,473	1,132,024
7.5	73,781	55,356	306,504	10,608	446,249
25	315,661	215,635	1,061,546	28,068	1,620,910
70	183,283	94,895	716,892	26,102	1,021,172
200	246,314	2,151	0	0	248,465
Total Load (tons)	1,005,142	465,913	3,902,864	149,519	5,523,438
Option 2/4 Incremental Loading Reduction Estimate (tons)	215,166	112,412	634,410	17,909	979,896

Table 8-22. State Annual Construction Load Estimates (Tons)

State	Baseline	Options 2 and 4
AL	287,073	209,759
AR	170,647	170,647
AZ	31,901	31,901
CA	137,654	101,464
CO	10,713	6,882
CT	26,680	17,834
DE	13,992	12,789
FL	165,065	165,065
GA	402,299	346,641
IA	55,537	55,537
ID	4,988	4,988
IL	120,331	103,157
IN	109,407	93,942
KS	91,805	67,129
KY	164,311	152,279
LA	276,932	216,048
MA	58,414	58,414
MD	116,981	79,118
ME	34,821	34,821
MI	233,685	170,917
MN	157,401	115,099
MO	277,848	188,674
MS	295,241	216,221
MT	17,343	11,416
NC	358,486	263,116
ND	11,326	7,709
NE	38,323	28,211
NH	25,857	25,857
NJ	131,874	90,000
NM	32,418	32,418
NV	747	747
NY	118,749	118,749
OH	212,799	181,410
OK	134,039	134,039
OR	37,690	25,820
PA	346,182	273,585
RI	9,311	6,337
SC	146,239	146,239
SD	14,761	13,729
TN	323,505	323,505
TX	787,982	787,982
UT	4,258	4,258
VA	159,707	159,707
VT	8,113	5,561
WA	69,782	47,035
WI	158,684	106,885
WV	99,719	99,719
WY	3,251	2,338

8.7 INTEGRATION OF NATIONAL LOADINGS INTO NWPCAM

As described in Section 8.5, the analysis generated loadings for 146 state-ecoregion areas. State-ecoregion areas were created by overlaying state boundaries with the boundaries of the 19 EPA ecroegions. In order to determine HUC-level loadings, GIS processing was used to convert state-ecoregion loadings into loadings for the approximately 2,000 HUCs that span the 48 contiguous states. Individual HUCs were apportioned loads by overlaying state-ecoregion areas based on the development rate in the HUC obtained from NRI. For example, when two HUCs collectively cover a single state-ecoregion area the HUC with the highest rate of development is assumed to have a proportionately greater fraction of the state-ecoregion loadings than the neighboring lower-rate HUC.

Estimates of the number of construction sites within each HUC were based on the acreage developed within each HUC along with the distribution of construction sites by site size in Table 4-10. Numbers were rounded to whole numbers in order to prevent analytical problems associated with analyzing fractional sites. The per-site load within each HUC was calculated by dividing the total load for a site size group (i.e., 25 acres) by the number of sites in that site size category. The per-HUC construction site population and loadings were converted from GIS into a spreadsheet for subsequent analysis of benefits in NWPCAM. The HUC-level number of sites and associated loads are contained in Table F-3 of Appendix F. Note that due to rounding, the total number of sites and loads presented in Table F-3 do not match the national totals in Table F-1.

8.8 NWPCAM ASSESSMENT OF IN-STREAM SEDIMENT CONCENTRATIONS

8.8.1 NWPCAM SYSTEM OVERVIEW

The National Water Pollution Control Assessment Model (NWPCAM) is a national surface water quality model that simulates water quality improvements and economic benefits that result from water pollution control policies. NWPCAM is designed to characterize water quality for the nation's network of rivers, streams, and lakes. NWPCAM incorporates a water quality model into a system designed for conducting national policy simulations and benefits assessments. NWPCAM is able to translate spatially varying water quality changes into willingness-to-pay values that reflect the value that individuals place on water quality improvements. In this way, NWPCAM is capable of deriving economic benefits estimates for a wide variety of water pollution control policies.

NWPCAM's water quality modeling system is suitable for developing water quality estimates for virtually the entire inland portion of the country. Its national-scale framework allows hydraulic transport, routing, and connectivity of surface waters to be simulated in the 48 conterminous states. The model can be used to characterize source loadings (e.g., point sources) under a number of alternative policy scenarios (e.g., loadings with controls). These loadings are processed through the NWPCAM water quality modeling system to estimate in-stream pollutant concentrations on a detailed spatial scale and to provide estimates of policy-induced changes in water quality. The model incorporates routines to translate estimated concentrations into a six-parameter water quality index (WQI6) that provides a composite measure of overall water quality. The WQI6 allows for the

calculation of economic benefits associated with the estimated water quality improvements. NWPCAM can be used to assess both the water quality impacts and the social welfare implications of alternative policy scenarios.

NWPCAM is an evolving system developed for EPA's Office of Water (OW) by RTI and has been used in several applications to estimate the benefits of pollution control policies. An adaptation of version 1.0 was used by OW's Office of Waste Management (OWM) to evaluate the potential benefits of the Stormwater Phase II rulemaking (Bondelid et al, 1999). Version 1.1 (RTI, 2000b), developed in response to external peer review on version 1.0, was oriented toward evaluating the effects of point source controls. NWPCAM version 1.1 was used in the proposed Meat Processing Effluent Guidelines rulemaking (EPA, 2003a). Version 1.5 was used in the proposed Animal Feed Operation/Confined Animal Feed Operation (AFO/CAFO) rulemaking (RTI, 2000a). Version 1.6 was used in developing the final AFO/CAFO rulemaking process (RTI, 2002). Version 2.1 with the Eutro-WASP kinetics model was used for analysis of the options for the construction and development final action. Complete documentation on NWPCAM and the modeling process used in this analysis can be found in RTI, 2004.

8.8.2 CONSTRUCTION AND LAND DEVELOPMENT MODELING PROCESS

8.8.2.1 Construction and Development Loads

The loads developed (see Tables 8-21, 8-22 and Tables F-1 and F-2 of Appendix F) for the options evaluated were distributed to the 8-digit hydrologic unit (HUC) level and broken out by site size. All loads were assumed to be TSS. These HUC-level loads are presented in Table F-3 in Appendix F. Loadings were developed for 1,717 HUCs for baseline conditions and the four regulatory options considered. Of the 1,717 HUCs, 57 (3%) were immediately excluded from the modeling analysis because they did not have an associated stream network in NWPCAM.

8.8.2.2 Distribution of Construction Sites and Loads

The methodology developed for distributing loads called for:

(1) Randomly distributing construction sites onto agricultural and forest land cover cells;

(2) Assigning loads to land cover cells based on the number and size of sites assigned to each land cover cell; and

(3) Removing background NPS TSS loads from land cover cells that were assigned construction sites based on the fraction of the cell that was covered by sites.

A total of 6,894,140 land cover cells were in the NWPCAM 2.1 database. Each land cover cell was assigned to one of eight general categories: agriculture, agriculture/herbaceous, agriculture/woodland, herbaceous, forest, water bodies/barren, tundra, and urban. Of the total land cover cells, 6,557,224 (95%) were assigned one of the first five land cover categories, and were

classified as forest or agriculture. All of the forest and agricultural cells used during the site distribution process. Each agricultural and forest cell was assigned a random number.

An analysis was conducted to compare the construction site area against the available forest and agricultural land within each HUC. Of the 1,660 HUCs that had an associated stream network, 1,638 (95%) had at least as many agriculture/forested land cover cells as number of sites, indicating that no land cover cell would be assigned multiple construction sites. Six (<1%) had fewer agriculture/forest land cover cells than sites but had enough area to accommodate all sites. This indicated that some land cover cells were assigned multiple sites. Sixteen HUCs (1%) were excluded from the modeling analysis because they lacked land cover data.

Of the original 1,717 HUCs supplied in the loadings file, 1,644 HUCs were included in the final modeling analysis. Table 8-23 shows the total TSS loadings by loading option (i.e. mode run) for the 1,644 HUCs included in the modeling analysis. Of the 979,896 tons/year of loadings reductions estimated for Option 2/4, 941,108 tons/year, or 96%, were incorporated into the NWPCAM modeling.

Table 8-23. Summary of Construction and Development Loadings

Option	TSS Loading (ton/yr)
Baseline	6,288,751
Options 2 and 4	5,347,643

A computer module was used to distribute construction sites onto land cover cells. For each HUC, the module selected its associated land cover cells, ordered by the random identification numbers. Sites were distributed by assigning each land cover cell one site before moving on to the next land cover cell. When there were more sites than land cover cells, the code went back to the first land cover cell on the list and continued looping until all sites were distributed. The sites were distributed in order of decreasing size: 200 acres, 70 acres, 25 acres, 7.5 acres, 3 acres, and 0.5 acres. Since the land cover cells were randomly ordered, this did not introduce bias but had the advantage that each successive land cover cell had greater than or equal area available for sites.

Each agriculture and forest cell started with its total area available for construction sites. Each time a site was assigned to a land cover cell, the cells's available area was reduced by the site are. In one HUC (4090001), a point was reached where no land cover cell had enough area to contain the entire construction site. In that case, the code distributed portions of the site onto two different land cover cells. After distributing the sites to land cover cells, quality assurance measures were taken to ensure that:

- The total number of sites distributed in each HUC was equal to the starting value.
- The number of sites in each size category that were distributed in each HUC was equal to the starting values.

- The total site area distributed was equal to the starting site area.
- No land cover cell was assigned more construction site area than was available in the land cover cell.
- The number of land cover cells with sites was close to (or equal, in most cases) to the number of sites in the HUC.

Once construction sites were distributed to the land cover cells, TSS loads were distributed using the HUC, site size, and fraction of site assigned to the land cover cells. The loading file contained total TSS loadings by HUC and site size category, so loadings for each site were calculated by dividing the total load in the size category by the number of sites in that size category. The TSS load distribution process involved several quality assurance measures to ensure that:

- Total TSS loads distributed matched the total loads shown in Table 8-23.
- Total TSS loads within each HUC were the same as in the load file.
- TSS loads by HUC, site size category, and regulatory option were the same as in the load file.

The output of the computer module was a table with the format shown in Table 8-24.

Table 8-24. Example of Output from Site and Load Distribution Process

HUC8	Cell ID	RF3RCHID	Site Size	Fraction of Site	Baseline Load	Opt 2/4 Load
3010102	1	3010102 1 0.00	200	1	30.2	28.7

8.8.2.3 Removal of Background NPS TSS Loads

For each land cover cell that was assigned a construction site, a portion of its background NPS TSS was removed to avoid double-counting. The NPS TSS load on each cell was reduced by the fraction of the land cover cell occupied by construction sites. For example, if a land cover cell was originally assigned 100 ton/yr of TSS, but was assigned a 200 acre (0.81 km^2) construction site, the new NPS TSS load for that cell was calculated as 100 ton/yr * (1-0.81) = 19 ton/yr. This removal process had a negligible impact on NPS TSS loads. Originally, total NPS TSS loads were 5.226×10^8 ton/yr. Approximately 7.126×10^5 ton/yr were removed through this process, leaving a total NPS TSS load of 5.218×10^8 ton/yr. The modified NPS loads underwent an overland transport module that delivered the loads to the RF3 network, and an in-stream delivery module that routed the loads down to the RF3Lite network. For both modeling components, TSS settling was modeled using a net settling velocity approach, as shown in Equation 1.

$$k_{sed} = \frac{v_{sed}}{depth} \qquad (1)$$
$$C(x_2) = C(x_1)e^{-k_{sed}t}$$

where

k_{sed} = First-order TSS settling rate (1/day)
v_{sed} = Net settling velocity (0.3 m/d; Chapra 1997)
depth = Channel depth (m)
$C(x_2)$ = TSS concentration at x_2 (mg/L)
$C(x_1)$ = TSS concentration at x_1 (mg/L)
t = Time-of-travel from x_1 to x_2 (d)

Table 8-25 presents a summary of these modified NPS TSS loads.

Table 8-25. NPS TSS Loads Modified for Construction and Development Analysis

Scale	TSS Load (ton/yr)	Delivery Ratio
Land Cover Cell	5.22×10^8	N/A
RF3 Network	3.24×10^8	0.62
RF3Lite Network	1.99×10^8	0.38

8.8.2.4 Routing Construction and Development Loads to the RF3Lite Network

The overland transport step was eliminated, which is the same as assuming that all loads from land cover cells entered the RF3 network. This assumption was made because the load development process accounted for the loss of large particles. Construction loads were routed from the RF3 network to the RF3Lite network using the first-order loss approach described in Equation 1. Table 8-26 summarizes the delivery of construction and development TSS loads to the RF3Lite network. TSS loads from construction sites accounted for approximately 1% of the total TSS loads entering the RF3Lite network.

Table 8-26. Summary of Construction and Development TSS Loads

Option	LCC Load (ton/yr)	RF3 Load (ton/yr)	RF3 Delivery Ratio	RF3Lite Load (ton/yr)	RF3Lite Delivery Ratio
Baseline	6,288,751	6,288,751	100%	3,806,800	61%
2/4	5,347,643	5,347,643	100%	3,238,926	61%

8.8.2.5 Water Quality Modeling and Economic Benefits Analysis

After the construction and development and modified background NPS loads were routed to the RF3Lite network, the next step in each model run consisted of water quality modeling in the RF3Lite network using Eutro-WASP and the mean annual flow condition. After in-stream modeling with Eutro-WASP, the WQI6 and WQL values were calculated in each RF3Lite reach. Economic benefits associated with the regulatory options were calculated for RF3Lite reaches that showed a change in WQI6 or WQL.

8.9 RESULTS OF CONSTRUCTION AND DEVELOPMENT MODELING ANALYSIS

Table 8-27 lists the number of improved reaches and the length of the improved reaches for Option 2/4 over baseline conditions. Option 2/4 loads also caused water quality degradation in a number of reaches. This degradation was likely due to effects of algal growth on modeled TSS concentrations.

Tables 8-28 and 8-29 list the economic benefits estimates using both the WQL approach and the WQI6 approach, respectively. The sum of local and nonlocal annual benefits for Option 2/4 ranged from $15,203,000 to $28,357,000 (year $2002). EPA was not able to ascribe any benefits to Option 1.

Table 8-27. Summary of Waters Affected (Option 2/4)

Method	Number of Improved Reaches	Improved Segment Length (miles)	Number of Degraded Reaches	Degraded Segment Length (miles)
WQI6	7,446	9,303	38	78
WQL	583	803.3	26	55.8

Table 8-28. Economic Benefits Using the WQL Approach (Option 2/4)

Use Support Category	WQL Benefit (2002$)*
Boat	$8,461,000
Fish	$15,580,000
Swim	$4,316,000
Total	**$28,357,000**

* Note: numbers may not add due to rounding

Table 8-29. Economic Benefits Using the WQI Approach (Option 2/4)

WQI Category	WQI6 Benefit (2002$)*
WQI<26	$27,000
26 < WQI < 70	$7,714,000
WQI > 70	$7,462,000
Total	**$15,203,000**

*Numbers may not add due to rounding

8.10 REFERENCES

Ambrose, R.B., T.A. Wool, and J.L. Martin. 1993. *The Water Quality Analysis Simulation Program, WASP5, Parts A and B, Version 5.10.* Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Barfield, B.J., and Clar, M. 1985. *Development of new design criteria for sediment traps and basins*. Prepared for the Maryland Resource Administration. Annapolis, MD, pp. 33.

Barrett, M. and J. Molina. 1998. Comparison of Filtration Systems and Vegetated Controls for Stormwater Treatment. 3rd International Conference on Diffuse Pollution. August 31 - September 4, 1998. Scottish Environment Protection Agency, Edinburg Scotland.

Beaulac, M.N. and K.H. Rechkow. 1982. An examination of land use-nutrient export relationships. *Water Res. Bulletin*. 18:(6)1013-1024

Bondelid, T.R., G. Ali, and G. Van Houtven. *The National Water Pollution Control Assessment Model Benefits Assessment of Stormwater Phase II Program*. Draft. Prepared for the United States Environmental Protection Agency, Office of Water, Washington, DC. Research Triangle Institute. Research Triangle Park, NC. June 1999.

Bondelid, T., R. Dodd, C. Spoerri, and A. Stoddard. 1999. *The Nutrients Version of the National Water Pollution Control Assessment Model*. Draft. Prepared for the U.S. Environmental Protection Agency, Office of Water, Washington, DC. Research Triangle Institute. Research Triangle Park, NC. December.

Brown, L., and T. Barnwell. 1987. *The Enhanced Stream Water Quality Model Qual2E and Qual2e-UNCAS: Documentation and User's Manual*. Athens, GA: U.S. Environmental Protection Agency, Environmental Research Laboratory. EPA/600/3-87/007.

Carson, R.T., and R.C. Mitchell. 1993. The Value of Clean Water: The Public's Willingness to Pay for Boatable, Fishable, and Swimmable Quality Water. *Water Resources Research* 29(7): 2445-2454. July.

Chapra, S.C. 1997. *Surface Water Quality Modeling*. New York: McGraw Hill Publishing.

Covar, A.P. 1976. *Selecting the proper reaeration coefficient for use in water quality models.* Presented at U.S. Environmental Protection Agency Conference on Environmental Simulation and Modeling, April 19-22, Cincinnati, OH. EPA-600/9-76-016.

Crunkilton, R. et al. 1996. Assessment of the response of aquatic organisms to long-term insitu exposures of urban runoff. In: Effects of Watershed Development and Management on Aquatic Ecosystems: Proceedings of an Engineering Foundation Conference. Snowbird, UT.

Dartiguenave, C.M., I. ECLille, and D.R. Maidment. 1997. *Water Quality Master Planning for Austin*. CRWR Online Report. 97-6.

Di Toro, D.M., P.R. Paquin, K. Subburamu, and D.A. Gruber. 1990. Sediment Oxygen Demand Model: Methane and Ammonia Oxidation. *Jour. EED, ASCE*, 116(5):945-987.

Eidenshink, J.E. 1992. The 1990 conterminous United States AVHRR data set. In *Photogrammetric Engineering and Remote Sensing* 58(6): p. 809-813.

ESRI (Environmental Systems Research Institute). 2000a. Data & Maps Media Kit, CD 6: North America Digital Elevation Model (grid).

ESRI (Environmental Systems Research Institute). 2000b. Data Maps Media Kit, CD5: Zip Code and Population Data.

Fennessey, L.A.J., A.R. Jarrett. 1994. *The Dirt in a Hole: A Review of Sedimentation Basins for Urban Areas and Construction Sites*. Journal of Soil and Water Conservation, July-August 1994, p 317-323.

Harding, M.V. 1990. *Erosion control effectiveness: comparative studies of alternative mulching techniques.* Environmental Restoration, pp. 149-156.

Holmes, Thomas P. 1988. The Offsite Impacts of Soil Erosion on the Water Treatment Industry. Land Economics 64 (4):3356-3366.

Horner, R.R., J. Guedry, and M.J. Kortenhoff. 1990. Improving the Cost Effectiveness of Highway Construction Site Erosion and Pollution Control. Washington State Transportation Center and the Federal Highway Administration. Seattle, WA, 79pp.

Horner, R.R., D.B. Booth, A. Azous, and C.W. May. 1997. Watershed Determinants of Ecosystem Functioning. In Effects of Watershed Development and Management on Aquatic Ecosystems, L.A. Roesner (ed.), American Society of Civil Engineers, New York, pp. 251-274.

Islam, M.M., D. Taphorn, and H. Utrata-Halcomb. 1998. Current Performance of Sediment Basins & Sediment Yield Measurement of Construction Sites in Unincorporated Hamilton County, Ohio. Prepared for Hamilton County Soil and Water Conservation District.

Jarrett, A. 1996. Sediment Basin Evaluation and Design Improvements. Pennsylvania State University. Prepared for Orange County Board of Commissioners, 11pp.

Keup, L.E. 1985. Flowing Water Resources. Prepared for *Water Resources Bulletin* 21(2), American Water Resources Association. April.

Kundell, J. and T. Rasmussen. 1995. Recommendations of the Georgia Board of Regent's scientific panel on evaluating the erosion measurement standard defined by the Georgia erosion and sedimentation act. In Proceedings of the 1995 Georgia Water Resources Conference. Athens, Georgia.

Leopold, L.B., and T. Maddock, Jr. 1953. The Hydraulic Geometry of Stream Channels and Some Physiographic Implications. USGS Geological Survey Professional Paper 252.

Leopold, L. 1973. River change with time: an example. Geological Society of America Bulletin. 84: 1845-1860.

Livingston, E. 1996. *Florida's Evolving Stormwater/Watershed Management Program*. Proceedings of an Engineering Foundation Conference, August 4-9, 1996, Snowbird, UT. American Society of Civil Engineers.

Mackiernan, G., M. Leffler and T. Malone. 1996. Scientific consensus and public policy: dissolved oxygen in the Chesapeake Bay. In Watershed '96 Proceedings. Baltimore, Maryland.

MacRae, C.R., J. Marsalek. 1992. *The Roll of Stormwater in Sustainable Urban Development*. Proceedings of the Canadian Hydrology Sumposium, No. 19-1992, Hydrology: Its Contribution to Sustainable Development, Winnipeg, Manitoba, June 15-17, 1992, pp. 372-389.

McClelland, Nina I. 1974. *Water Quality Index Application in the Kansas River Basin.* Prepared for the U.S. Environmental Protection Agency - Region 7. EPA-907/9-74-001.

Mederios, C., R. LeBlanc, and R. A. Coler. 1983. An In situ Assessment of the Acute toxicity of Urban Runoff to Benthic Macroinvertebrates. Environmental Toxicity and Chemistry (2):119-126.

Metcalf & Eddy, Inc., G.T. Tchobanoglous, and F.L. Burton. 1991. *Wastewater Engineering: Treatment, Disposal, and Reuse (Third Edition)*. Boston, MA: Irwin McGraw-Hill (Series in Water Resources and Environmental Engineering).

Mitchell, R.C., and R.T. Carson. 1986. The Use of Contingent Valuation Data for Benefit/Cost Analysis in Water Pollution Control. CR-810224-02. Prepared for U.S. EPA, Office of Policy Planning and Evaluation. Washington, DC.

NAHB (National Assoc. of Home Builders). 2000. *Small Businesses in the Construction Industry*. 1997 Economic Census Data.

Novotny, V., and H. Olem. 1994. *Water Quality Prevention, Identification and Management of Diffuse Pollution*. New York: Van Nostrand Reinhold.

Omernik, James M. 1987. *Ecoregions of the Conterminous United States.* Annals of the Association of American Geographers. 77(1): 118-125.

Orth, R. and K. Moore. 1983. *Chesapeake Bay: An unprecedented decline in submerged aquatic vegetation*. Science 22:51-52.

Owens, et al. 1999.

Pasternack, G. 1998. Physical dynamics of tidal freshwater delta evolution. PhD Dissertation. Johns Hopkins University, Baltimore, Maryland.

Reckhow, K.H., M.N. Beaulac, and J.T. Simpson. 1980. *Modeling Phosphorus Loading and Lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients*. U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Criteria and Standards Division, Washington, DC. EPA 440/5-80-011.

RTI (Research Triangle Institute). 2000a. *Estimation of National Surface Water Quality Benefits of Regulating Concentrated Animal Feeding Operations (CAFOs) Using the National Water Pollution Control Assessment Model (NWPCAM)*. Prepared for the United States Environmental Protection Agency, Office of Water, Washington, DC. Research Triangle Institute. Research Triangle Park, NC. August.

RTI (Research Triangle Institute). 2000b. *National Water Pollution Control Assessment Model (NWPCAM) Version 1.1*. Prepared for the United States Environmental Protection Agency, Office of Water, Washington, DC. Research Triangle Institute. Research Triangle Park, NC. November.

RTI (Research Triangle Institute). 2001. The National Water Pollution Control Assessment Model (NWPCAM v2): Quality Review Process Report for NWPCAM2 RF3 - Reach Routing, Hydrology, and Hydraulics Datasets. Draft Report.

RTI (Research Triangle Institute). 2002. *A Review of Changes and Advances Related to the National Water Pollution Control Assessment Model Since the Proposed AFO/CAFO Rulemaking Process*. Prepared for the U.S. Environmental Protection Agency. Research Triangle Park, NC: Research Triangle Institute. April.

RTI (Research Triangle Institute). 2004. *Estimation of National Economic Benefits Using the National Water Pollution Control Assessment Model to Evaluate Regulatory Options for the Construction and Land Development Industry*. Prepared for the U.S. Environmental Protection Agency. Research Triangle Park, NC: Research Triangle Institute. March.

Rosgen, D. L. 1996. Applied River Morphology, Wildland Hydrology, Pagosa Springs, CO.

Sauer V. et al. 1983. Flood Characteristics of Urban Watersheds in the United States. US Geological Survey Water Supply Paper 2207.

Schiff, K. 1996. Review of existing stormwater monitoring programs for estimating bight-wide mass emissions from urban runoff. SCCWRP Annual Report 1996.

Schueler, T., and J. Lugbill. 1990. *Performance of Current Sediment Control Measures at Maryland Construction Sites*. Metropolitan Washington Council of Governments. Washington, DC. 90pp.

Short, F., S. Wyllie-Escheverria. 1996. *Natural and Human-Induced Disturbance of Seagrasses*. Environmental Conservation 23(1).

Smith, R.A, G.E. Schwarz, and R.B. Alexander. 1997. Regional Interpretation of Water Quality Monitoring Data. *Water Resources Research* 33(12):2781-2798. December.

Stevenson, J., L. Staver and K. Staver. 1993. Water quality associated with submersed aquatic vegetation along an estuarine gradient. Estuaries 16(2): 346-361.

Sturm, T.W., and R.E. Kirby. 1991. Sediment Reduction in Urban Stormwater Runoff From Construction Sites. Environmental Resources Center, Georgia Institute of Technology. Altanta. 104pp.

U.S. ACE (Army Corp of Engineers). 1998. Analysis of Best Management Practices for Small Construction Sites. Work performed for the U.S. Environmental Protection Agency, Office of Wastewater Management. June.

U.S. EPA (Environmental Protection Agency). 1985. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling (Second Edition). Environmental Research Laboratory, Office of Research and Development, Athens, GA.

U.S. EPA (Environmental Protection Agency). 1986. *Quality Criteria for Water*. U.S. Environmental Protection Agency, Office of Water Regulations and Standards, Criteria and Standards Division, Washington, DC. EPA 440/5-86/001.

USEPA. 1998. *Reissuance of NPDES General Permits for Storm Water Discharges from Construction Activities.* ("Construction General Permit.") Federal Register, Vo. 63, No. 31, p. 7858. February 17, 1998. Washington, DC.

US. EPA, 1999. *Economic Analysis of the Final Phase II Storm Water Rule*. U.S. Environmental Protection Agency, Office of Wastewater Management. Washington D.C. (Web site: http://cfpub.epa.gov/npdes/pubs.cfm?program_id=0)

USDA, 1995. State Soil Geographic (STATSGO) Database, Miscellaneous Publication 1492 Revised 1994. (Web site: http://water.usgs.gov/GIS/metadata/usgswrd/ussoils.html)

USDA (Department of Agriculture). 1997. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*. Agricultural Handbook No. 703.

USDA. 2000. *1997 National Resources Inventory*. U.S. Department of Agriculture, National Resources Conservation Service, Washington, DC.

U.S. EPA (Environmental Protection Agency). 2003. *Developing Water Quality Criteria for Suspended and Bedded Sediments (SABs); Potential Approaches* (includes appendices). Draft. A USEPA Science Advisory Board Consultation. August.

Vaughan, William J. 1986. *The Water Quality Ladder*. Included as Appendix B in Mitchell, R.C., and R.T. Carson. 1986. *The Use of Contingent Valuation Data for Benefit/Cost Analysis in Water Pollution Control*. CR-810224-02. Prepared for the U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation. Washington, DC.

Warner, R.C. and P.J. Schwab. 1998. SEDCAD 4 for Windows 95 & NT-Design Manual and User's Guide. Civil Software Design, Ames, IA.

Wheeler, A.P., A.E. Keiter Rosenberger,, and P.L. Angermeier. 2003. Potential Impacts of I-73 on Stream Habitat and Biota, with Emphasis on the Federally Endangered Roanoke Logperch. Department of Fisheries and Wildlife Sciences. Virginia Polytechnic Institute and State University. Blacksburg, VA. (Web site: http://filebox.vt.edu/users/awheeler/var/final_I-73.pdf on 4/14/04.)

York, J.H., and W.J. Herb. 1978. Effects of Urbanization and Streamflow Sediment Transport in Rock Creek and Anacostia River Basins, Montgomery County, MD, 1972-1974. U.S. Geological Survey Professional Paper No. 1003. 72pp.