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Agency

DEVELOPMENT DOCUMENT FOR FINAL EFFLUENT GUIDELINES AND STANDARDS FOR THE CONSTRUCTION & DEVELOPMENT CATEGORY

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Acronyms and Abbreviations

ASCE	American Society of Civil Engineers
ATS	Active Treatment System
AWWA	American Water Works Association
BAER	Burned Area Emergency Response
BAT	Best Available Technology Economically Achievable
BCT	Best Conventional Pollutant Control Technology
BMP	best management practice
BOD	biochemical oxygen demand
BPJ	best professional judgment
BPT	Best Practicable Control Technology
C&D	Construction and Development
CAA	Clean Air Act
CCI	Construction Cost Index
CFR	*Code of Federal Regulations*
CGP	Construction General Permit
CHIA	Cumulative Hydrologic Impact Analysis
CONUS	conterminous United States
CSTR	continuously stirred tank reactor
CTAPE	Chemical Technology Assessment Protocol—Ecology
CUD	conditional use designation
CWA	Clean Water Act
DADMAC	Diallydimethyl-ammonium chloride
DCN	Document Control Number
ECRMs	erosion control and revegetation mats
ELG	Effluent Limitations Guidelines
ENR	*Engineering News-Record*
EPA	U.S. Environmental Protection Agency
ERF1	Enhanced River Reach File 1.2
ERF1_2	Enhanced River Reach File 2.0
ESC	erosion and sediment control
GIS	geographic information system
gpm	gallons per minute
GULD	general use level designation
HDSC	Hydrometeorological Design Studies Center
HSG	hydrologic soil group
LEW	Low Erosivity Waiver
MRLC	Multi-Resolution Land Characteristics Consortium
MS4	municipal separate storm sewer system
MUID	Map Unit Identifiers
NAICS	North American Industry Classification System

NEL	numeric effluent limit
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intent
NOT	Notice of Termination
NOx	nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NRDC	Natural Resources Defense Council
NSPS	New Source Performance Standards
NTU	nephelometric turbidity units
NWS	National Weather Service
OCPSF	organic chemicals, plastics, and synthetic fibers
PAH	polycyclic aromatic hydrocarbon
PAM	polyacrylamide
PFDS	Precipitation Frequency Data Server
POTW	publicly owned treatment works
PPA	Pollution Prevention Act of 1990
PRISM	Parameter Elevation Regressions on Independent Slopes Model
RCRA	Resource Conservation and Recovery Act
RF1	Reach File Version 1.0
RUSLE	Revised Universal Soil Loss Equation
SC AQMD	South Coast Air Quality Management District
SCS	Soil Conservation Service
SIC	Standard Industrial Classification
SIP	state implementation plan
SMRCA	Surface Mining, Reclamation, and Control Act
SPARROW	Spatially Referenced Regressions on Watersheds
SSC	suspended sediment concentration
STATSGO	State Soil Geographic Database
SWPPP	stormwater pollution prevention plan
SWRPC	Southeastern Wisconsin Regional Planning Commission
TP	total phosphorus
TRM	turf reinforcement mats
TSS	total suspended solids
TSS	total suspended solids
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
VOCs	volatile organic compounds
WDEC	Washington Department of Ecology
WSDOT	Washington Department of Transportation

1. OVERVIEW

1.1. INTRODUCTION

This document presents technical information to support the U.S. Environmental Protection Agency's (EPA's) decision and complements the Agency's *Economic Analysis for Final Effluent Guidelines and Standards for the Construction and Development Category* (EPA-821-R-09-011), and the *Environmental Impact and Benefits Assessment for Final Effluent Guidelines and Standards for the Construction and Development Category* (EPA-821-R-09-0012).

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 stormwater 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 a description of pollutants in stormwater runoff known to be the most prevalent and of greatest concern to the environment. It also presents the selection of pollutants for the final regulation.
- Section 6 presents the method and data used to establish limitations and standards.
- Section 7 presents information and data on erosion and sediment control (ESC) strategies used by the construction and development industry, including applicability, costs, and efficiencies of various technologies.
- Section 8 presents a description of the regulatory options EPA considered when developing the final rule.
- Section 9 presents a description of the approach EPA used in developing costs for the regulatory options.
- Section 10 summarizes the approach EPA used to estimate the pollutant loads and load reductions for the regulatory options EPA considered.
- Section 11 summarizes the non-water quality environmental impacts, including the energy requirements, air emissions impacts, and solid waste generation of each regulatory option.

1.2. SUMMARY AND SCOPE OF THE FINAL RULE

EPA has established effluent limitations guidelines and new source performance standards for stormwater discharges from the construction and development industry. The guidelines and standards require discharges from certain construction sites to meet a numeric turbidity limit. The guidelines and standards also require all construction sites that are now required to obtain a National Pollutant Discharge Elimination System permit to implement a variety of best management practices designed to limit erosion and control sediment discharges from construction sites. EPA evaluated four options in developing the final rule. Those options are described below:

- Option 1 establishes minimum requirements for implementing a variety of ESCs and pollution prevention measures on all construction sites that are required to obtain a permit.
- Option 2 contains the same requirements as Option 1. In addition, construction sites of 30 or more disturbed acres would be required to meet a numeric turbidity limit in stormwater discharges from the site. The technology basis for the numeric limit is active treatment systems (ATS). The numeric turbidity standard would be applicable to stormwater discharges for all storm events up to the local 2-year, 24-hour event.
- Option 3 contains the same requirements as Option 1. Option 3 also requires all sites with 10 or more acres of disturbed land to meet a numeric turbidity standard that is based on the application of ATS. The turbidity standard would apply to all stormwater discharges for all storm events up to the local 2-year, 24-hour event.
- Option 4 contains the same requirements as Option 1. Option 4 also requires all sites with 10 or more acres of disturbed land to meet a numeric turbidity standard that is based on the application of passive treatment systems. The turbidity standard would apply to all stormwater discharges for all storm events up to the local 2-year, 24-hour event; although, only certain types of discharges would require monitoring.

The costs and economic impacts of the Options are presented in the Preamble to the Final Rule and in the Economic Analysis.

2. BACKGROUND

2.1. LEGAL AUTHORITY

The U.S. Environmental Protection Agency (EPA) is promulgating Effluent Limitations Guidelines (ELGs) for discharges associated with construction and development activities under the authority of the Clean Water Act (CWA) sections 301, 304, 306, 308, 402, and 501 (the Federal Water Pollution Control Act), Title 33 of the *United States Code* (U.S.C.) sections 1311, 1314, 1316, 1318, 1342, and 1361. This Background section describes EPA's legal authority for issuing the regulation, existing state regulations, and other federal regulations associated with construction and development activities.

2.2. CLEAN WATER ACT

Congress adopted the 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 section 402 requires *point source* discharges to obtain a permit under the National Pollutant Discharge Elimination System (NPDES). Those 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 ELGs and standards for many industrial categories, and those 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 stormwater discharges as point sources. Industrial stormwater dischargers, municipal separate storm sewer systems (MS4s) and other stormwater 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, and nonconventional 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 control technologies, non-water quality environmental impacts (including energy requirements), and such other factors as the Agency deems appropriate (CWA section 304(b)(1)(B)). Traditionally, EPA establishes BPT effluent limitations on the basis of 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 ELGs 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 require 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 Economically Achievable (BAT) for control of conventional pollutants. In addition to other factors specified in section 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 developing BCT limitations in July 1986 (51 *Federal Register* [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, BAT effluent guidelines (CWA section 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 on 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 on technology transferred from a different subcategory or from another category. In addition, the Agency may base BAT on manufacturing process changes or internal controls, even when such technologies are not common industry practice.

2.2.4. NEW SOURCE PERFORMANCE STANDARDS

New Source Performance Standards (NSPS) reflect effluent reductions that are achievable on the basis of 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, nonconventional, and priority pollutants). In establishing NSPS, CWA section 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. Such standards are Pretreatment Standards for Existing Sources and Pretreatment Standards for New Sources under section 307(b).

2.2.6. EFFLUENT GUIDELINES SCHEDULE AND PREVIOUS ACTIONS RELATED TO CONSTRUCTION AND DEVELOPMENT

CWA section 304(m) requires EPA to publish a plan every 2 years that consists of three elements. First, under section 304(m)(1)(A), EPA is required to establish a schedule for the annual review and revision of existing effluent guidelines in accordance with section 304(b). Section 304(b) applies to ELGs for direct dischargers and requires EPA to revise such regulations as appropriate. Second, under section 304(m)(1)(B), EPA must identify categories of sources discharging toxic or nonconventional pollutants for which EPA has not published BAT ELGs under section 304(b)(2) or NSPS under section 306. Finally, under section 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 3 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 CWA sections 307(b) and 307(c).

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 section 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 11 point source categories identified by name in the decree and for 8 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 stormwater rules (i.e., 1 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); best management practices (BMPs) for controlling post-construction runoff; BMPs for construction sites; and requirements to design stormwater controls to maintain predevelopment runoff conditions where practicable.

On June 24, 2002, EPA published a proposed rule for the C&D category that contained several options for the control of stormwater discharges from construction sites, including ELGs and NSPS. (67 FR 42644; June 24, 2002). In a final action published on April 26, 2004, EPA determined that national ELGs would not be the most effective way to control discharges from construction sites and, instead, chose to rely on the range of existing programs, regulations, and initiatives that already existed at the federal, state, and local level. (69 FR 22472).

The June 28, 2000, settlement agreement also required EPA to issue guidance to MS4s and other permittees on maintenance of post-construction BMPs identified in the proposed ELGs. Because EPA's proposal or final action does not contain requirements for post-construction BMPs, that guidance was considered 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 in the public docket for the previous rulemaking.

On October 6, 2004, NRDC and Waterkeeper Alliance, as well as New York and Connecticut filed a motion against EPA alleging that EPA failed to promulgate ELGs and NSPS as required by the CWA. On December 1, 2006, the district court—in *Natural Resources Defense Council, et al. v U.S. Environmental Protection Agency, et al.,* 437 F.Supp.2d 1137, 1139 (C.D. Cal.2006)—held that CWA section 304(m), read together with CWA section 304(b), imposes on EPA a mandatory duty to promulgate ELGs and NSPS for industrial point source categories named in a CWA section 304(m) plan. The court ordered EPA to publish proposed regulations in the FR by December 1, 2008, and to promulgate ELGs and NSPS for the C&D category as soon as practicable, but no later than December 1, 2009.

2.2.7. NPDES PHASE I AND II STORMWATER RULES

As authorized by the CWA, the NPDES permit program was established to control water pollution by regulating point sources that discharge pollutants into waters of the United States. Stormwater runoff from construction activities can have a significant effect on water quality. The NPDES stormwater program requires operators of construction sites to apply for either a general permit or an individual permit under the NPDES Phase I and II stormwater rules. Phase I of EPA's stormwater program was promulgated in 1990 under the CWA and addresses, among other discharges, discharges from construction activities disturbing 5 acres or more of land. Phase II of the NPDES stormwater program, promulgated in 1999, expands the Phase I Rule by addressing stormwater discharges from small construction sites disturbing between 1 and 5 acres. In addition, operators of small construction sites are also required to develop and implement a stormwater pollution prevention plan (SWPPP), which includes implementing the appropriate ESC BMPs. The BMP selection and design are at the discretion of permittees (in conformance with applicable state or local requirements). Moreover, construction activities disturbing less than 1 acre are also included in Phase II of the NPDES stormwater program if they are part of a larger, common plan of development or sale with a planned disturbance of equal to or greater than 1 acre and less than 5 acres, or if they are designated by the NPDES permitting authority.

Most states are authorized to implement the stormwater NPDES permitting program. However, EPA remains the permitting authority in a few states, territories, and on most Indian country lands. For construction (and other land disturbing activities) in areas where EPA is the permitting authority, operators must meet the requirements of the EPA Construction General Permit (CGP).

The current CGP became effective on June 30, 2008 (as modified effective September 29, 2008) and expires on June 30, 2010. That permit contains substantially the same terms and conditions as the 2003 CGP. In response to comments on the proposal, EPA has reorganized the content of the 2003 permit to better clarify existing requirements. The 2008 CGP applies only to new discharges. Construction site operators with permit coverage under the 2003 CGP may continue to operate under the terms of conditions of that permit and need not file a new Notice of Intent for coverage under the 2008 CGP. Permit coverage is now available for eligible construction activities in New Hampshire, Oklahoma, Texas, Puerto Rico, federal facilities, and Indian country lands in Colorado and Montana.

The 2003 permit expanded coverage from the 1998 CGP, which provided coverage for large construction sites (i.e., those disturbing greater than 5 acres) to include both small and large construction activities (i.e., any project disturbing greater than 1 acre). Small construction activity was added to the 2003 CGP in response to the promulgation of the NPDES Phase II Rule.

A major provision required by the CGP is preparation of a SWPPP. The SWPPP focuses on two major requirements: (1) Providing a site description that identifies sources of pollution to stormwater discharges associated with industrial activity on-site; and (2) identifying and implementing appropriate measures to reduce pollutants in stormwater discharges to ensure compliance with the terms and conditions of the permit. All SWPPPs must be developed in accordance with sound engineering practices and must be developed specific to the site. For coverage under the permit, the SWPPP must be prepared before commencement of construction and then updated as appropriate. Commencement of construction activities is defined as the initial disturbance of soils associated with clearing, grading, or excavating activities or other construction-related activities (e.g., stockpiling of fill material).

The permit also clarifies that once a definable area of the site has been finally stabilized, no further SWPPP requirements apply to that portion of the site as long as the SWPPP has been updated accordingly to identify that portion of the site as complete. The SWPPP must be implemented as written from the beginning of construction activity until final stabilization is complete. Stabilization practices include seeding of temporary vegetation, seeding of permanent vegetation, mulching, geotextiles, sod stabilization, vegetative buffer strips, preservation of trees and mature vegetative buffer strips, and other appropriate measures. For a detailed description of all permit requirements and conditions, see the CGP.

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 [that] 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 wastestream or that is otherwise released into the environment before out-of-process recycling, treatment, or disposal.

Although the PPA does not explicitly address stormwater 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. Such controls and practices are described in Section 7 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 CGPs and regulations was prepared to help establish the baseline for national and regional levels of control. Data were collected by reviewing state CGPs, Web sites, summary references, and state ESC or stormwater management guidance manuals. The state regulatory data are discussed in Sections 3.4 and 9.2 of this document, and the complete data sheets are included in Appendix A.

3. DATA COLLECTION

3.1. INTRODUCTION

As part of the regulatory efforts to develop the proposed Construction and Development (C&D) regulations in 2002 and the related final action in 2004, the U.S. Environmental Protection Agency (EPA) gathered and evaluated an extensive amount of technical and economic data from various sources. EPA used much of the data collected for the previous rulemaking effort in support of this effort. EPA also collected additional data and information to support the technical analyses used in developing this final rule. This section summarizes EPA's data collection efforts.

3.2. LITERATURE SEARCH

A literature search was performed to obtain additional information on various erosion and sediment control (ESC) technologies that pertain to the C&D industry. Journal articles and professional conference proceedings were reviewed to collect recent data and information related to ESC design and installation criteria, performance, and related costs. Annotated bibliographies for the journal articles and professional conference proceedings that EPA reviewed for possible use in developing this final rule are in Appendix B (costs), Document Control Number (DCN) 44321 (sediment basin performance), and DCN 43114 (passive treatment).

3.3. DATA AND INFORMATION PROVIDED IN RESPONSE TO THE 2002 REGULATORY ACTION AND THE 2008 PROPOSAL

In response to the previous rulemaking efforts for the C&D industry, EPA received numerous public comments on most aspects of the 2002 proposed rule. EPA considered those comments in developing this final rule. EPA also considered public comments received on the 2008 proposal.

3.4. COMPILATION OF STATE CONTROL STRATEGIES, CRITERIA, AND STANDARDS

EPA compiled and evaluated existing state program information for the control of construction site stormwater. The data were collected by reviewing state construction general permits (CGPs), Web sites, summary references, state regulations, and ESC design and guidance manuals. A summary of criteria and standards for construction site stormwater ESC that are implemented by states is presented in Appendix A. More information on this analysis is in Section 9.2, Analysis of State Equivalency. Appendix A also includes updated state information that EPA obtained in early 2007, state-level data sheets and information originally presented in Section 7 and Appendix D of the 2004 *Development Document for Final Action for Effluent Guidelines and Standards for the Construction and Development Category* (EPA-821-B-04-001), and information originally presented in Appendix A of the June 2002 *Development Document for Proposed Effluent Guidelines and Standards for the Construction and Development Category* (EPA-821-R-02-007).

3.5. OTHER DATA SOURCES

3.5.1. LAND USE DATA

EPA accessed a number of sources of land cover information at a national scale for use in estimating the potential number of acres subject to C&D activities.

3.5.1.1. National Land Cover Dataset

The National Land Cover Database (NLCD) provides a national source of data on land cover change. The Multi-Resolution Land Characteristics Consortium (MRLC) has produced the NLCD data sets that created a 30-meter resolution land cover data layer over the conterminous United States (CONUS) from Landsat Thematic Mapper satellite imagery. NLCD data are publicly available for the years 1992 and 2001 (see http://www.epa.gov/mrlc/ and http://www.mrlc.gov/).

Because new developments in mapping methodology, new sources of input data, and changes in the mapping legend for the 2001 NLCD confound direct comparison between 2001 NLCD and the 1992 NLCD (MRLC 1992 and 2001), the U.S. Geological Survey (USGS) prepared and released the NLCD 1992/2001 Retrofit Land Cover Change Product. The NLCD 1992/2001 Retrofit Land Cover Change Product was developed to offer more accurate direct change analysis between the two products.

The NLCD 1992/2001 Retrofit Land Cover Change Product uses a specially developed methodology to provide land cover change information at the Anderson Level I classification scale, relying on decision tree classification of Landsat imagery from 1992 and 2001. While NLCD 1992 reported on developed land in the categories of low-residential intensity, high-residential intensity, commercial/industrial/transportation, and urban/recreational grasses, NLCD 2001 reported categories of developed low, medium, high, and open space. To compare change between the two data sets, the developed categories were merged into one overall urban class. Unchanged pixels between the two dates are coded with the NLCD 2001 Anderson Level I class code, while changed pixels are labeled with a *from-to* land cover change value. Modified Anderson Level 1 Classifications include the following:

- Open water
- Urban
- Barren
- Forest
- Grassland/Shrub
- Agriculture
- Wetlands Ice/Snow

The NLCD 1992/2001 Retrofit Land Cover Change Product was intended to provide a current, consistent, and seamless data set for the United States at medium spatial resolution for Anderson Level 1 classes. This land cover change map and all documents pertaining to it are considered *provisional* until a formal accuracy assessment can be conducted.

EPA used the NLCD to estimate the annual number of acres of land converted to urban land uses in the United States during the period between 1992 and 2001. At proposal, EPA used the NCLD results to estimate acres of construction activities subject to the national effluent guidelines regulations because no national database of the number and size of construction activities exists. For the final rule analysis, the NLCD data was not used to estimate the amount of construction activity occurring. EPA used economic data to estimate expected levels of construction activity (for more information, see the Economic Analysis). EPA used the NCLD to apportion consruction activity to watersheds as a basis for estimating baseline loadings and loadings reductions of the regulatory options. Figure 3-1 illustrates an example of the Reach File Version 1.0 (RF1)-level analysis of the NLCD data. EPA used the RF1 watershed cataloging system (described below) because the SPARROW model (which is the model EPA used to estimate water quality improvements) operates at the RF1 scale.

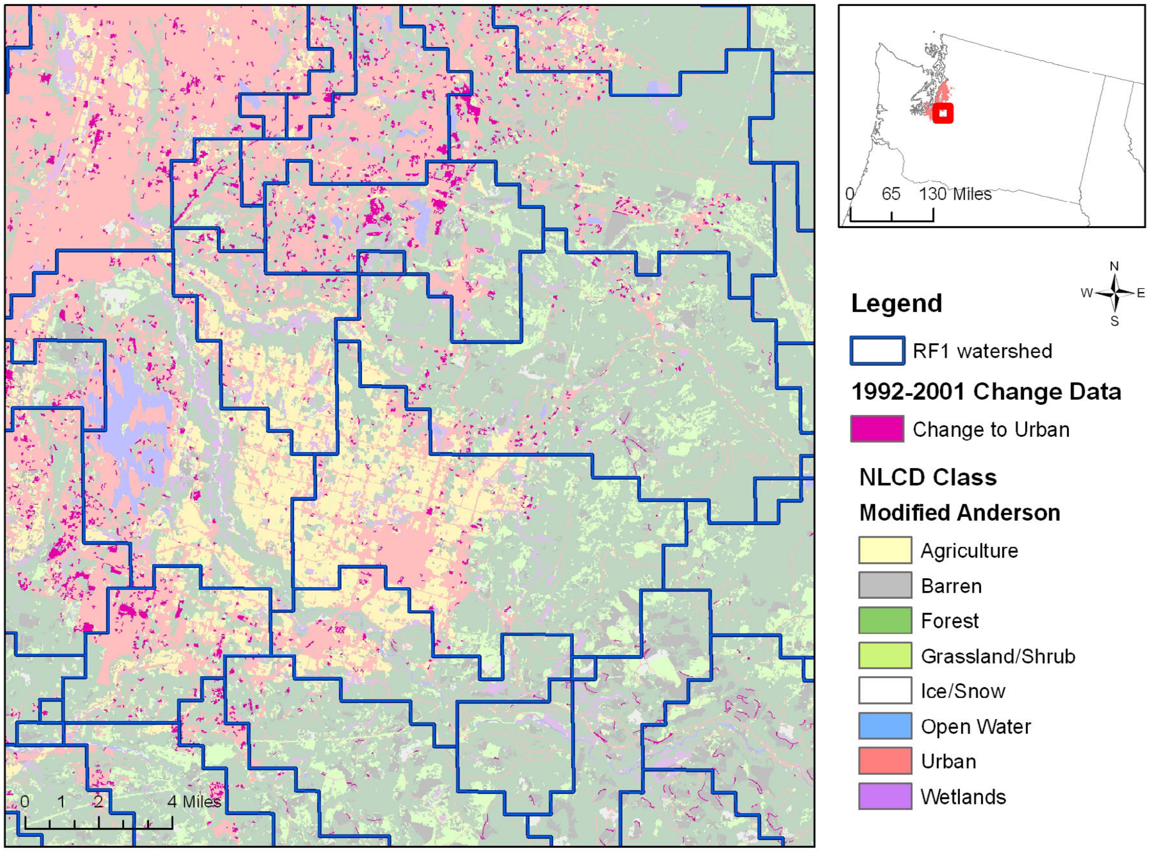

Figure 3-1. NLCD 1992/2001 land cover change product near Seattle, Washington.

Table 3-1 summarizes the national- and state-level estimates obtained from the NLCD analysis. Figures 3-2 through 3-11 graphically present the results of the NLCD land use change analysis at the RF1 level for each EPA Region. Results are presented as percent urban change between 1992 and 2001. (For an index of the NLCD-related analyses conducted for the rule, see DCN 43097 in the Administrative Record.)

Table 3-1. State and national estimates of urban land from NLCD

	1992 Urban acres	2001 Urban acres	% of state that is developed (1992)	% of state that is developed (2001)	Annual rate of development, 1992–2001 (acres)
Alabama	2,066,843	2,197,496	6.40%	6.80%	14,517
Alaska	NO DATA				
Arizona	1,285,258	1,408,765	1.80%	1.97%	13,723
Arkansas	1,836,496	1,912,492	5.50%	5.73%	8,444
California	6,278,143	6,524,815	6.20%	6.44%	27,408
Colorado	1,609,387	1,751,902	2.40%	2.61%	15,835
Connecticut	727,078	736,015	23.40%	23.69%	993
Delaware	113,052	120,720	9.40%	10.04%	852
Florida	4,526,626	4,870,084	13.00%	13.99%	38,162
Georgia	3,026,921	3,319,772	8.20%	8.99%	32,539
Hawaii	NO DATA				
Idaho	847,520	898,118	1.60%	1.70%	5,622
Illinois	4,014,480	4,197,711	11.30%	11.82%	20,359
Indiana	2,238,170	2,353,388	9.90%	10.41%	12,802
Iowa	2,527,225	2,621,239	7.10%	7.36%	10,446
Kansas	2,463,194	2,666,459	4.70%	5.09%	22,585
Kentucky	1,740,669	1,830,327	6.80%	7.15%	9,962
Louisiana	1,788,423	1,903,893	6.60%	7.03%	12,830
Maine	653,697	695,682	3.30%	3.51%	4,665
Maryland	698,386	754,384	11.30%	12.21%	6,222
Massachusetts	1,174,234	1,203,889	23.90%	24.50%	3,295
Michigan	3,746,569	3,946,405	10.30%	10.85%	22,204
Minnesota	2,648,001	2,731,809	5.20%	5.36%	9,312
Mississippi	1,721,138	1,827,869	5.70%	6.05%	11,859
Missouri	2,845,661	2,967,035	6.50%	6.78%	13,486
Montana	1,187,901	1,246,068	1.30%	1.36%	6,463
Nebraska	1,699,570	1,752,634	3.50%	3.61%	5,896
Nevada	572,706	646,794	0.80%	0.90%	8,232
New Hampshire	426,786	443,382	7.50%	7.79%	1,844
New Jersey	1,124,705	1,162,613	23.70%	24.50%	4,212
New Mexico	799,207	838,609	1.00%	1.05%	4,378
New York	2,682,301	2,752,573	8.90%	9.13%	7,808
North Carolina	2,816,229	2,984,988	9.10%	9.65%	18,751
North Dakota	1,667,029	1,727,113	3.90%	4.04%	6,676
Ohio	3,549,025	3,705,445	13.60%	14.20%	17,380
Oklahoma	2,387,508	2,537,439	5.40%	5.74%	16,659
Oregon	1,552,824	1,617,957	2.50%	2.60%	7,237
Pennsylvania	3,006,384	3,149,538	10.40%	10.90%	15,906
Rhode Island	173,764	177,085	27.00%	27.52%	369
South Carolina	1,487,194	1,632,427	7.70%	8.45%	16,137
South Dakota	1,315,111	1,388,776	2.70%	2.85%	8,185
Tennessee	2,189,700	2,307,879	8.30%	8.75%	13,131
Texas	8,229,892	8,791,816	5.00%	5.34%	62,436
Utah	758,031	831,309	1.40%	1.54%	8,142
Vermont	304,570	309,628	5.40%	5.49%	562
Virginia	1,818,500	1,954,409	7.20%	7.74%	15,101

	1992 Urban acres	2001 Urban acres	% of state that is developed (1992)	% of state that is developed (2001)	Annual rate of development, 1992–2001 (acres)
Washington	2,286,574	2,402,332	5.40%	5.67%	12,862
West Virginia	1,016,805	1,049,133	6.70%	6.91%	3,592
Wisconsin	2,345,956	2,411,998	6.70%	6.89%	7,338
Wyoming	491,168	516,818	0.80%	0.84%	2,850
District of Columbia	26,381	28,865	82.80%	90.60%	276
Nation	**96,492,992**	**101,807,897**			**590,545**

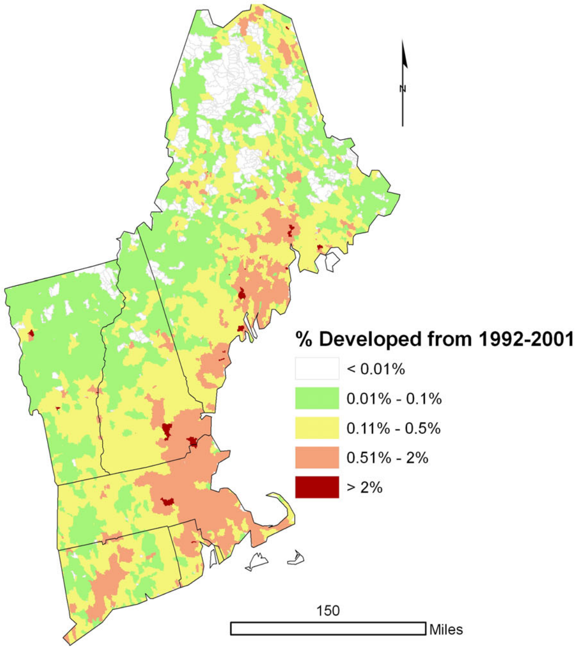

Figure 3-2. EPA Region 1: Percent urban change 1992–2001 by ERF1_2 watershed.

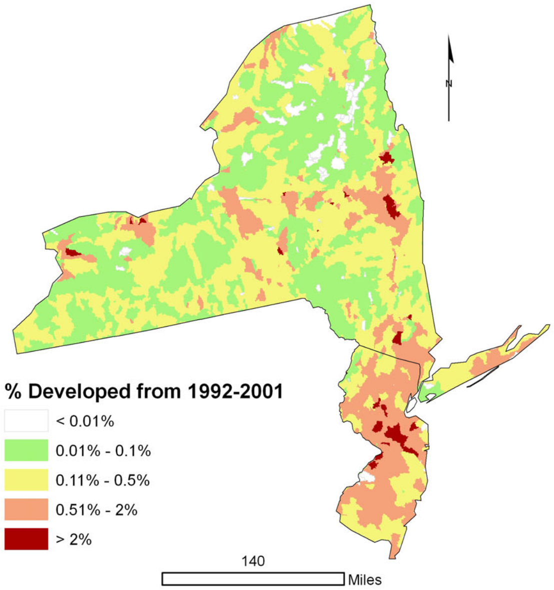

Figure 3-3. EPA Region 2: Percent urban change 1992–2001 by ERF1_2 watershed.

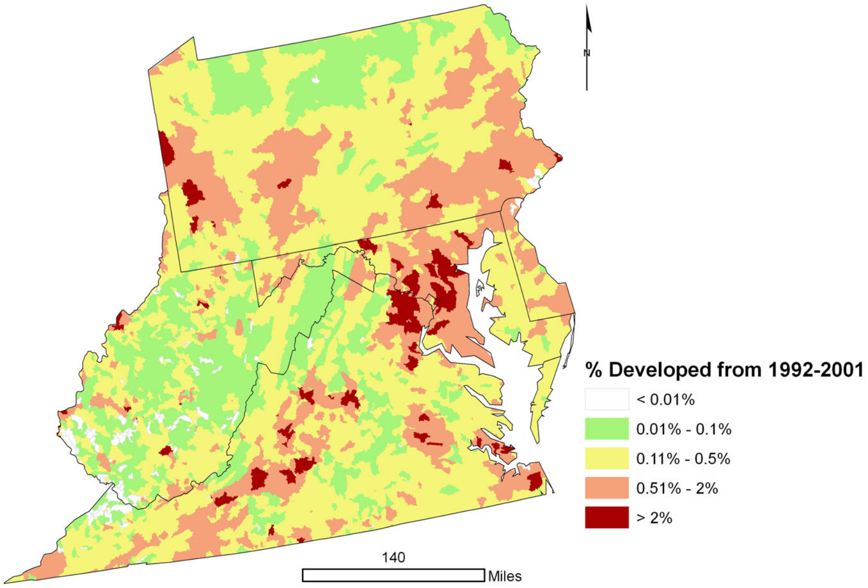

Figure 3-4. EPA Region 3: Percent urban change 1992–2001 by ERF1_2 watershed.

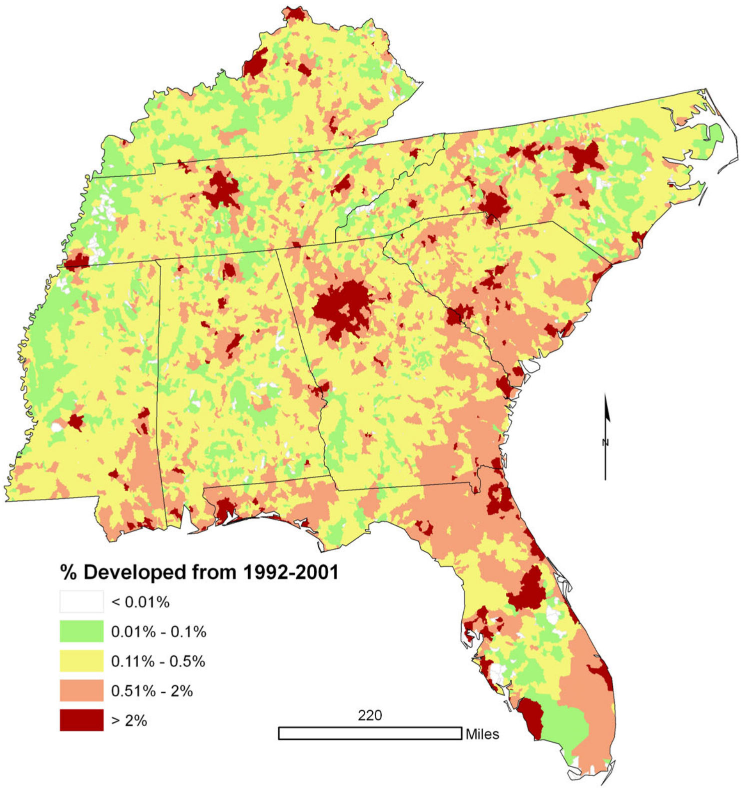

Figure 3-5. EPA Region 4: Percent urban change 1992–2001 by ERF1_2 watershed.

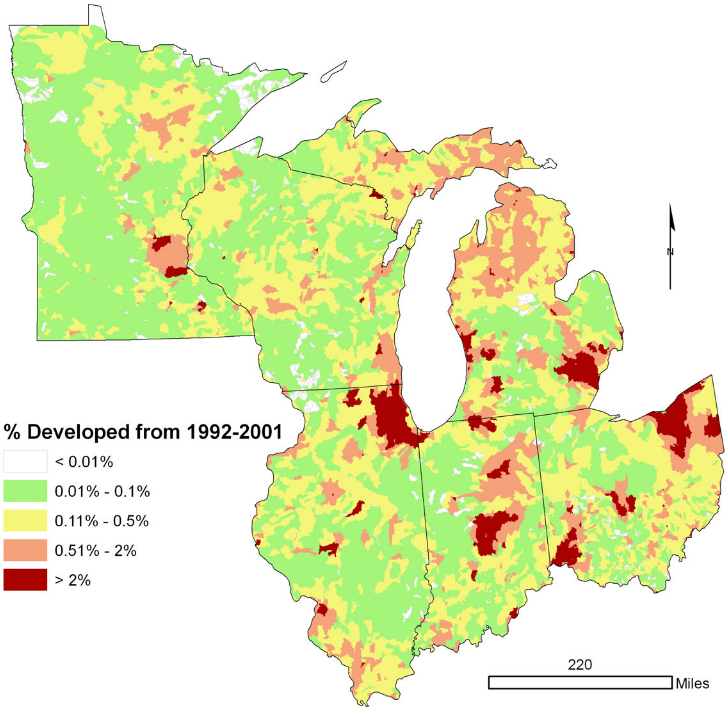

Figure 3-6. EPA Region 5: Percent urban change 1992–2001 by ERF1_2 watershed.

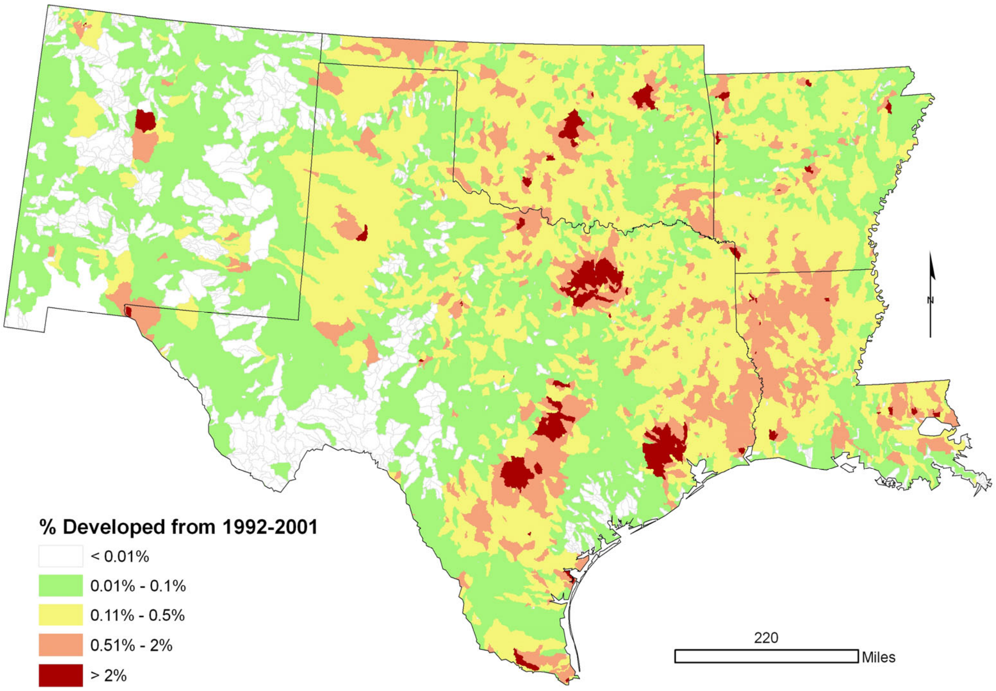

Figure 3-7. EPA Region 6: Percent urban change 1992–2001 by ERF1_2 watershed.

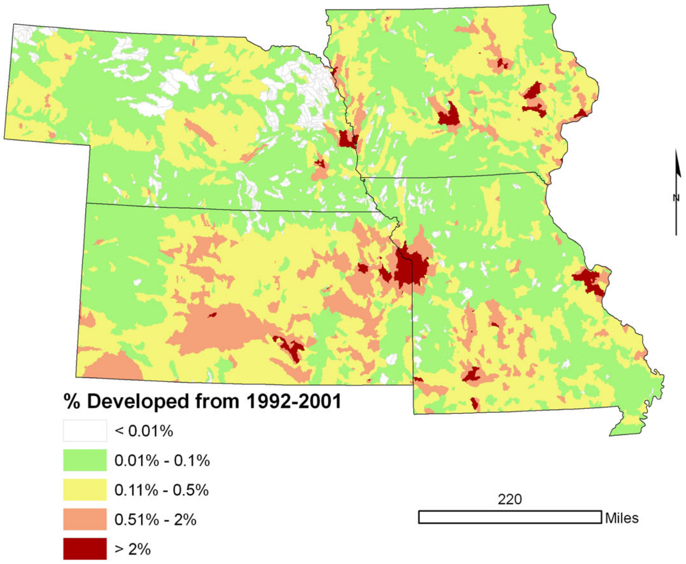

Figure 3-8. EPA Region 7: Percent urban change 1992–2001 by ERF1_2 Watershed.

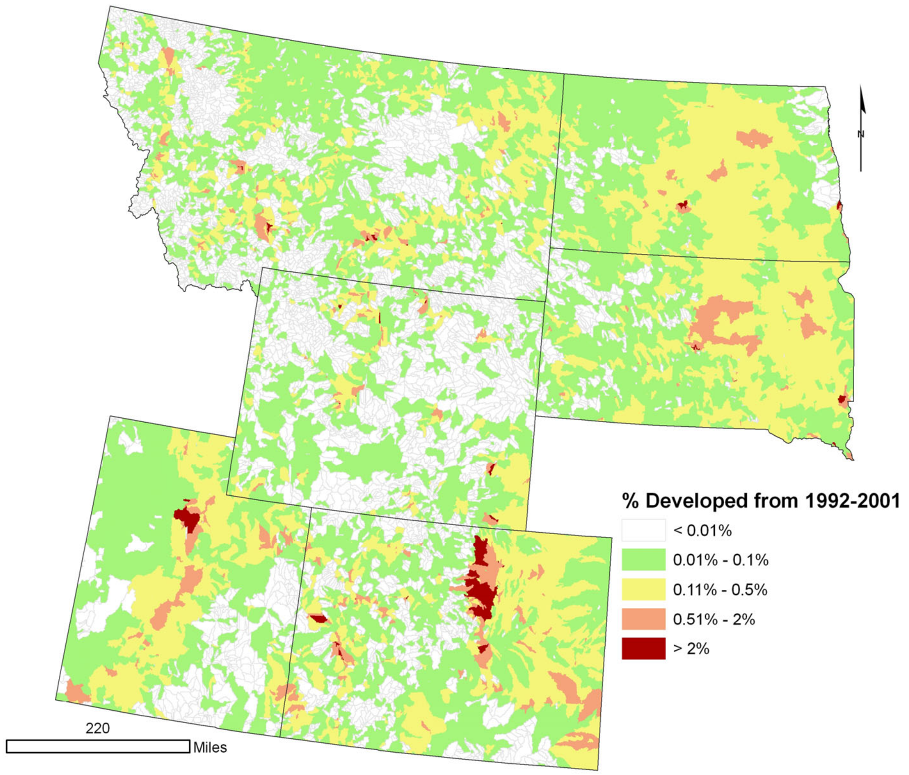

Figure 3-9. EPA Region 8: Percent urban change 1992–2001 by ERF1_2 watershed.

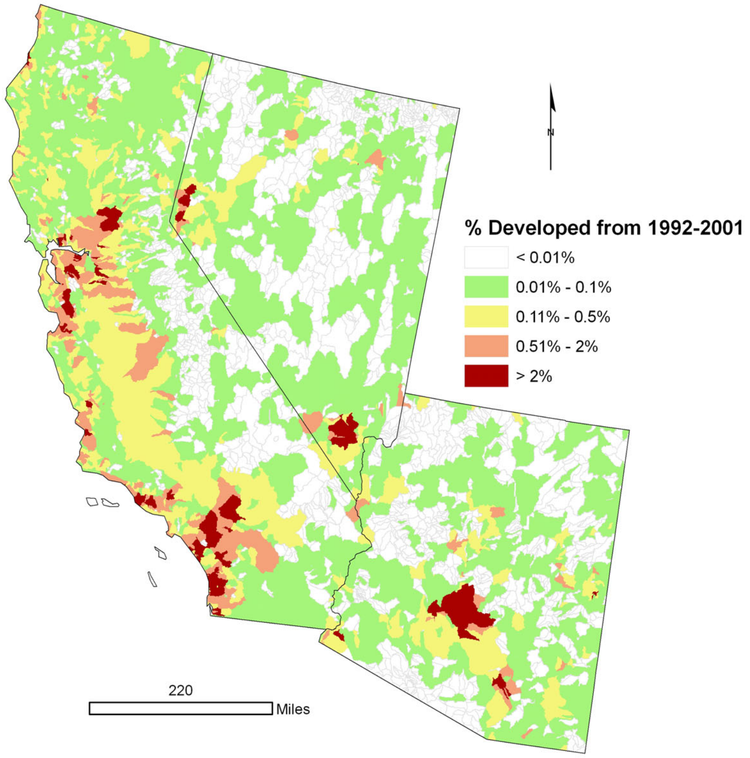

Figure 3-10. EPA Region 9: Percent urban change 1992–2001 by ERF1_2 watershed.

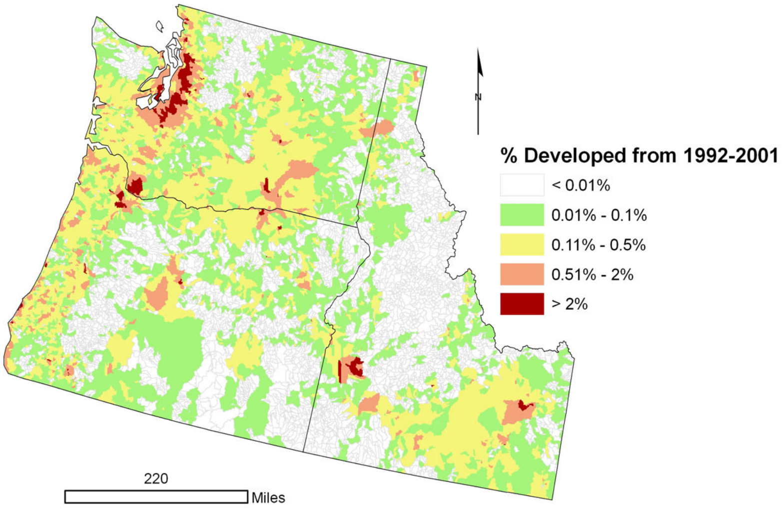

Figure 3-11. EPA Region 10: Percent urban change 1992–2001 by ERF1_2 watershed.

Because NLCD data does not exist for Alaska, Hawaii, or the U.S. territories, EPA's analysis does not consider pollutant loading reductions for those areas. Detailed definitions and discussion of the NLCD 1992/2001 Retrofit Product is presented in Appendix E. DCN 43097 in the Administrative Record provides an index to the NLCD-related analyses conducted for the rulemaking.

3.5.1.2. River Reach File Data

An option for summarizing national land cover change in drainage area units is to use EPA's RF1 for the CONUS. RF1 is a vector database of approximately 700,000 miles of streams and open waters in the CONUS. EPA and states use it extensively, and the U.S. Fish and Wildlife Service and the National Weather Service (NWS) have used it for many years. EPA prepared RF1 in 1982 from National Oceanic and Atmospheric Administration (NOAA) aeronautical charts having a scale of 1:500,000. Those charts provided the best nationwide hydrographic coverage available on a single scale at that time. They include all hydrography shown on USGS maps having a scale of 1:250,000 with extensive additions, corrections, and improvements in detail made by NOAA from aerial photography and satellite imagery. In the 1980s, EPA used RF1 for performing water quality modeling on whole river basins for all the hydrologic regions in the CONUS. In that role, it was used to provide national assessments and overviews of water quality and to provide the foundation for a nationwide, stratified, sampling frame for performing statistical summaries of modeled and measured water quality on all surface waters of the CONUS.

A consistent, national-scale watershed data set was prepared to enhance the RF1 hydrology data set. That watershed data set, the Enhanced River Reach File 1.2 (ERF1), was designed to be a digital database of river reaches capable of supporting regional and national water-quality and river-flow modeling and transport investigations in the water-resources community. USGS has used ERF1 to support interpretations of stream water-quality monitoring network data. In such analyses, the reach network has been used to determine flow pathways between the sources of point and nonpoint pollutants and downstream water-quality monitoring locations in support of predictive water-quality models of stream nutrient transport.

The Enhanced River Reach File 2.0 (ERF1_2) expands on ERF1 and includes the incremental and total drainage area founded on the 1-kilometer (km) elevation data for North America (Nolan et al. 2002). Previous estimates of the water time-of-travel were recomputed for reaches with water quality monitoring sites that included two reaches. The mean flow and velocity estimates for the split reaches are based on previous estimation methods (Alexander et al. 1999) and are unchanged in ERF1_2. Drainage area calculations provide data used to estimate the contribution of a given nutrient to the outflow. ERF1_2 contains 67,171 watersheds with a minimum size of 247 acres (1 square km [km^2]) and an average size of 30,182 acres (122 km^2).

EPA used the ERF1_2 as the foundation for summarizing land cover change and in drainage area units (or watersheds) and for SPARROW (Spatially Referenced Regressions [of nutrient transport] on Watershed) modeling. Within the context of a geographic information system (GIS), SPARROW estimates the proportion of watersheds in the CONUS with outflow flux of several nutrients, including total nitrogen and total phosphorus, (Smith et al. 1997). EPA modified SPARROW to model changes in sediment flux in the RF1 network to evaluate potential benefits of regulatory options. Sediment and nutrient flux were converted to concentrations using estimates of reach flow for each RF1.

3.5.2. NPDES PERMIT NOTICE OF INTENT DATA

EPA used CGP Notice of Intent (NOI) records to characterize construction activity by project type and project size for subsequent analysis of costs and pollutant loading reductions. Using NOI data, EPA broadly characterized the construction industry into three land use types (residential construction, nonresidential construction, and road/highway construction). EPA has NOI data for approximately 22,000 permit applications, containing data from four states for construction activities occurring primarily between 2003 and 2009. While the NOI data are useful for characterizing construction activities into different project types and project sizes, as well as for estimating the duration of projects, EPA did not find the NOI data useful as a national data set to estimate the amount of construction occurring. That is because the NOI data obtained by EPA are not national in coverage. EPA’s analysis of the NOI data are in Appendix C.

3.5.3. CLIMATIC/RAINFALL DATA

3.5.3.1. NOAA National Weather Service Precipitation Frequency Data Server

Variations in rainfall depth and intensity are important factors in determining erosion rates, sediment discharges, pollutant load reductions, and control technology costs for construction sites. EPA used a combination case study approach of 11 indicator cities as well as national data sets for different components of the analysis. Indicator cities were used for certain components of the cost analysis, such as estimating design storm depths. EPA also used indicator cities in the loadings analysis to develop runoff coefficients. However, national data coverages were used for other components of the loads analysis, such as estimating average annual precipitation values for RF1s.

For the indicator city analysis, EPA selected representative areas in each of the 10 EPA Regions to be used as a point estimate for the entire region. EPA generally selected the urban area in each region with the greatest rate of development on the basis of EPA's analysis of land use change from the NLCD analysis. EPA selected one metropolitan area in each of the 10 EPA Regions, with the exception of Region 10. In Region 10, EPA selected two indicator cities because the two areas with the greatest rate of development (Boise City, Idaho, and Seattle, Washington) have very different rainfall patterns. For each of the 11 indicator cities, EPA obtained detailed rainfall data and rainfall summaries. EPA also obtained detailed soils data for each of the 11 areas. The 11 indicator cities are identified in Table 3-2.

Table 3-2. EPA Region indicator cities

EPA Region	Indicator city
1	Manchester, New Hampshire
2	Albany, New York
3	Washington, DC, Virginia, and Maryland
4	Atlanta, Georgia
5	Chicago, Illinois—Indiana
6	Dallas, Fort Worth, and Arlington, Texas
7	Kansas City, MIssouri and Kansas
8	Denver and Aurora, Colorado
9	Las Vegas, Nevada
10	Boise City, Idaho, and Seattle, Washington

EPA's costing analysis used state-specific design storms for determining stormwater runoff rates and volumes and for determining storage volumes and treatment system sizing. EPA identified one major city within each state to serve as an indicator for the entire state. EPA obtained rainfall summary data for each of these cities for using as a basis for determining expected runoff rates and rainfall volumes for costing of technologies.

Precipitation data was gathered and analyzed using the NOAA NWS Precipitation Frequency Data Server (PFDS). The Hydrometeorological Design Studies Center (HDSC) in the Office of Hydrologic Development of the NWS is in an ongoing process of updating its precipitation frequency estimates, which are available in NOAA Atlas 14 format. At the time of this writing, only a portion of the United States had been updated into this format (NWS 2008). Atlas 14 supersedes precipitation frequency estimates contained in previous NWS publications. The updates are based on more recent and extended data sets, currently accepted statistical approaches, and improved spatial interpolation and mapping techniques. A complete list of NWS publications is at http://www.nws.noaa.gov/ohd/hdsc/currentpf.htm.

NOAA Atlas 14 contains precipitation frequency estimates with associated confidence limits for the United States for 5-minute through 60-day durations at average recurrence intervals of 1-year through 1,000-year. The estimates are based on the analysis of annual maximum series and then converted to partial duration series results. The Atlas 14 rainfall data results used in this study are shown in Appendix D, Table D-3.

For the states not currently updated by NOAA Atlas 14, the rainfall-frequency values for selected durations were estimated using a series of maps presented in the older NWS publications. The data for the remainder of the western United States were estimated by using NOAA Atlas 2, *Precipitation Frequency Atlas of the Western United States* (NOAA 1973), which are generalized maps presented for 6- and 24-hour point precipitation for the return periods of 2, 5, 10, 25, 50, and 100 years. Atlas 2 is published in separate volumes for each of the states. Similarly, the maps presented in the corresponding technical paper were used for the remainder of the eastern United States and Hawaii. (Alaska was not included in this study because EPA lacked sufficient data on the annual amount of construction activities in Alaska).

Precipitation frequency results generated by Atlas 2 or technical paper maps are presented in Appendix D, Table D-4. The rainfall depths were estimated by identifying the target city on the Atlas 2 or technical paper map and linearly approximating the rainfall value. For example, if a city fell between a depth of 4.5 and 5 inches, and the city was approximately 20 percent of the map distance from the 5-inch line, a rainfall depth of 4.9 inches was estimated. Note that the maps provide data for depth only. Intensity estimates were calculated by dividing the duration (e.g., 6- or 24-hour) by the depth. Additionally, Atlas 2 depths were converted from tenths of an inch to inches.

To analyze the percent of total construction site runoff captured and treated for various regulatory options, EPA obtained hourly precipitation data for each indicator city. EPA obtained 30 years of hourly rainfall data from EarthInfo Version 2.31 (www.earthinfo.com). EarthInfo provides National Climatic Data Center meteorological data in an easy-to-use format from which precipitation data can be extracted. From the 7,000 National Climatic Data Center gages available, EPA generally used data collected at an airport in or adjacent to each indicator city. In general, EPA analyzed data for the period between the mid-1970s and mid-2000s. EPA also used the hourly precipitation data in EarthInfo to evaluate the number and size of rainfall events that discharge from construction sites. Appendix H details this evaluation that focuses on the 11 indicator cities.

Table 3-3 summarizes the state-specific rainfall data EPA used in its analyses.

3.5.3.2. Parameter Elevation Regressions on Independent Slopes Model (PRISM)

EPA's analyses of the regulatory options used estimates of the average annual precipitation for each RF1 watershed. Annual precipitation was used to estimate runoff volumes and baseline sediment concentrations as well as to evaluate removals under regulatory options that incorporated a numeric limit. For each RF1 watershed, the average annual precipitation amount was obtained from the 1-km resolution United States Average Monthly or Annual Precipitation (1971–2000) PRISM Group raster data coverage (PRISM Group 2006). RF1 watershed boundaries were used to summarize the PRISM Group average annual rainfall values, and each RF1 was assigned a value by spatially averaging contributing raster data. Figure 3-12 shows average annual precipitation for the CONUS from the PRISM data. Additional information on the PRISM data is in Appendix D.

Table 3-3. Rainfall summary data for indicator cities

State	City	Average annual precipitation (inches)	2-year, 24-hour storm depth (inches)	10-year, 24-hour storm depth (inches)	25-year, 24-hour storm depth (inches)	10-year, 6 hour storm depth (inches)
Alabama	Montgomery	49	4.50	6.5	7.6	4.60
Arizona	Phoenix	8	1.40	2.14	2.59	1.57
Arkansas	Little Rock	48	4.10	6.05	7	4.35
California	Sacramento	18	2.00	3	3.5	1.70
Colorado	Denver	13	2.00	3	3.8	2.30
Connecticut	Hartford	44	3.10	4.8	5.5	3.25
Delaware	Dover	43	3.26	5.08	6.36	3.44
Florida	Tallahassee	62	4.75	7.4	8.5	5.25
Georgia	Atlanta	51	3.70	5.5	6.5	4.20
Hawaii	Honolulu	18	4.25	7.8	8.9	4.80
Idaho	Boise	11	1.20	1.8	2.2	1.20
Illinois	Chicago	33	2.85	4.29	5.25	3.30
Indiana	Indianapolis	40	2.95	4.13	4.83	3.12
Iowa	Des Moines	32	3.25	4.7	5.5	3.54
Kansas	Kansas City	37	3.50	5.2	6.1	3.90
Kentucky	Frankfort	45	3.00	4.34	5.23	3.09
Louisiana	Baton Rouge	59	5.25	8.2	9.1	5.75
Maine	Augusta	42	2.80	4.25	4.9	2.90
Maryland	Baltimore	42	3.16	4.85	6.08	3.32
Massachusetts	Boston	42	3.10	4.5	5.5	3.30
Michigan	Lansing	30	2.40	3.6	4.2	2.70
Minnesota	St. Paul	29	2.75	4.2	4.7	3.10
Mississippi	Jackson	52	4.45	6.7	7.8	4.70
Missouri	Kansas City	37	3.45	5.3	6	3.85
Montana	Helena	12	1.30	2.1	2.4	1.10
Nebraska	Lincoln	28	3.00	4.8	5.4	3.52
Nevada	Las Vegas	4	1.00	1.62	1.96	1.29
New Hampshire	Manchester	40	2.80	4.3	5	3.20
New Jersey	Hightstown	47	3.31	5.07	6.3	3.55
New Mexico	Santa Fe	15	1.54	2.22	2.62	1.77

State	City	Average annual precipitation (inches)	2-year, 24-hour storm depth (inches)	10-year, 24-hour storm depth (inches)	25-year, 24-hour storm depth (inches)	10-year, 6 hour storm depth (inches)
New York	Albany	37	2.90	4	5.9	3.10
North Carolina	Charlotte	43	3.34	4.86	5.76	3.54
North Dakota	Bismarck	16	1.90	3.25	3.75	2.50
Ohio	Columbus	38	2.62	3.73	4.44	2.80
Oklahoma	Oklahoma City	33	3.70	5.8	6.9	4.25
Oregon	Salem	41	2.50	3.5	4	2.90
Pennsylvania	Philadelphia	42	3.23	4.8	5.85	3.38
Rhode Island	Providence	45	3.20	4.8	5.7	3.40
South Carolina	Columbia	45	3.62	5.28	6.39	3.85
South Dakota	Pierre	16	2.25	3.5	4.1	2.75
Tennessee	Nashville	46	3.37	4.7	5.53	3.31
Texas	Fort Worth	33	3.90	6.3	7.4	4.55
Utah	Salt Lake City	15	1.40	1.9	2.21	1.27
Vermont	Montpelier	34	2.40	3.7	4.25	2.70
Virginia	Arlington	40	3.11	4.78	5.98	3.29
Washington	Seattle	35	2.00	3	3.4	1.40
West Virginia	Charleston	43	2.56	3.55	4.16	2.56
Wisconsin	Madison	31	2.80	4.1	4.75	3.15
Wyoming	Cheyenne	15	1.60	2.4	2.8	1.90
Puerto Rico	San Juan	51	4.26	6.76	8.29	4.42
District of Columbia	Washington	42	3.16	4.85	6.07	3.32

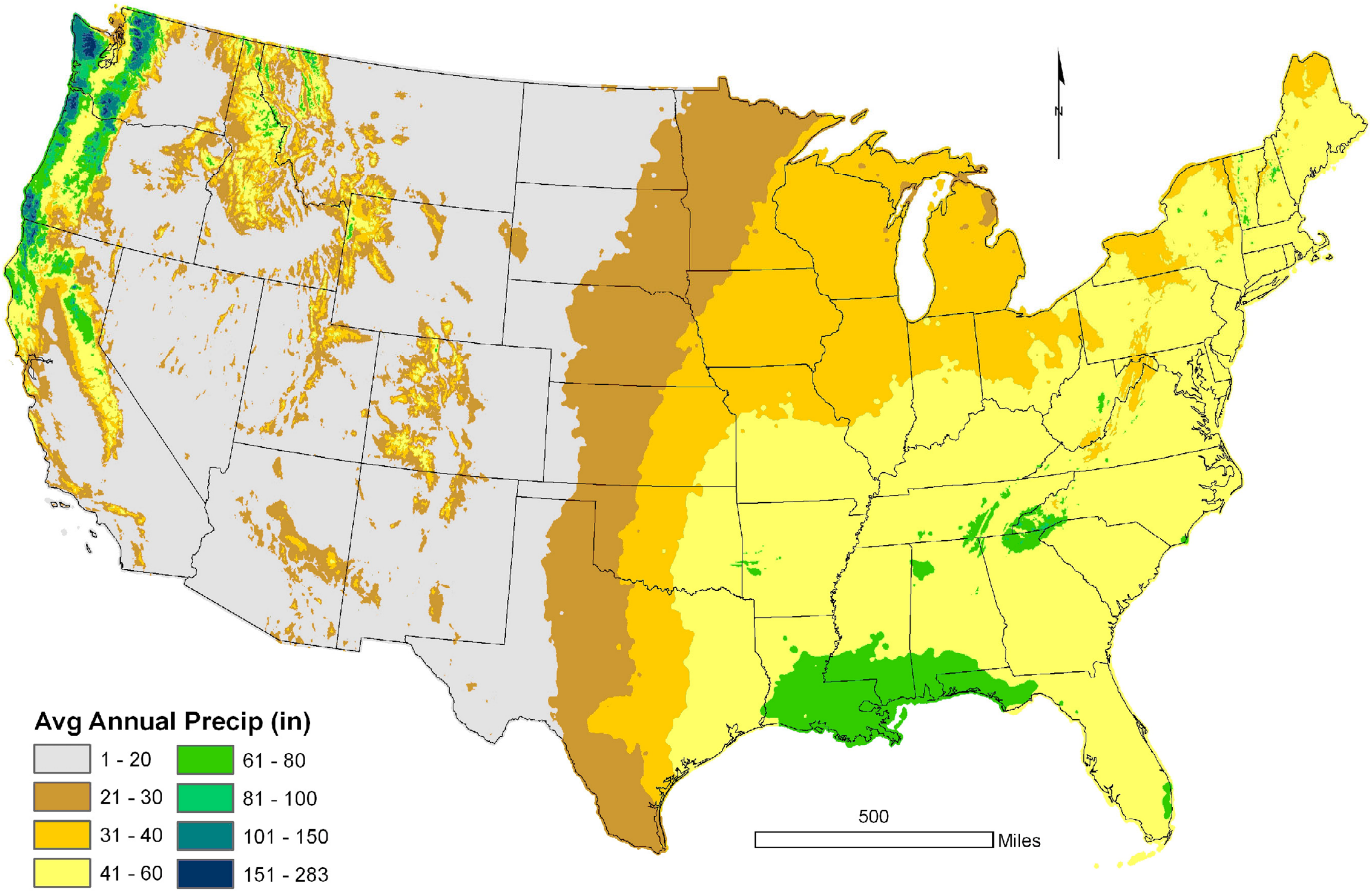

Figure 3-12. Average annual precipitation in the CONUS from PRISM.

3.5.4. SOILS DATA

The variation in soil types found in the United States is a significant factor in estimating sediment discharges. EPA used soil coverage data provided in the State Soil Geographic Database (STATSGO) (Wolock 1997; USDA 2007) and the CONUS-SOIL data layers (Miller and White 1998) for the loadings analysis. STATSGO component and layer tables were accessed through the Pennsylvania State University's active archive (http://www.soilinfo.psu.edu/index.cgi?soil_data&index.html). EPA extracted data for only the portions of RF1 watersheds where development change has been documented by NLCD. This *urban masking* approach was implemented using a binary raster grid of NLCD 1992/2001 Retrofit Land Cover Change Product representing urbanization to weight RF1 values for STATSGO data layers. EPA used the mask of urbanization change to create RF1 watershed parameter values. Essentially, the individual spatial units of the soil coverage—Map Unit Identifiers (MUIDs)—were summarized by urbanizing area weights into RF1 average values, instead of using proportional weight based on land area (Figure 3-13). The geographic limits of the soil coverage evaluated were determined by superimposing indicator city urban area boundaries—from the U.S. Census Bureau's 2000 Urbanized Areas Cartographic Boundary Files (U.S. Census Bureau 2000)—on intersecting RF1 watersheds. The resulting list of RF1 watersheds intersecting the rapidly developing indicator city urban areas was used to spatially identify underlying STATSGO soil coverage MUIDs. Last, soil data associated with the surface soil layer within the selected MUIDs were extracted from STATSGO to produce the suite of data evaluated for each indicator city.

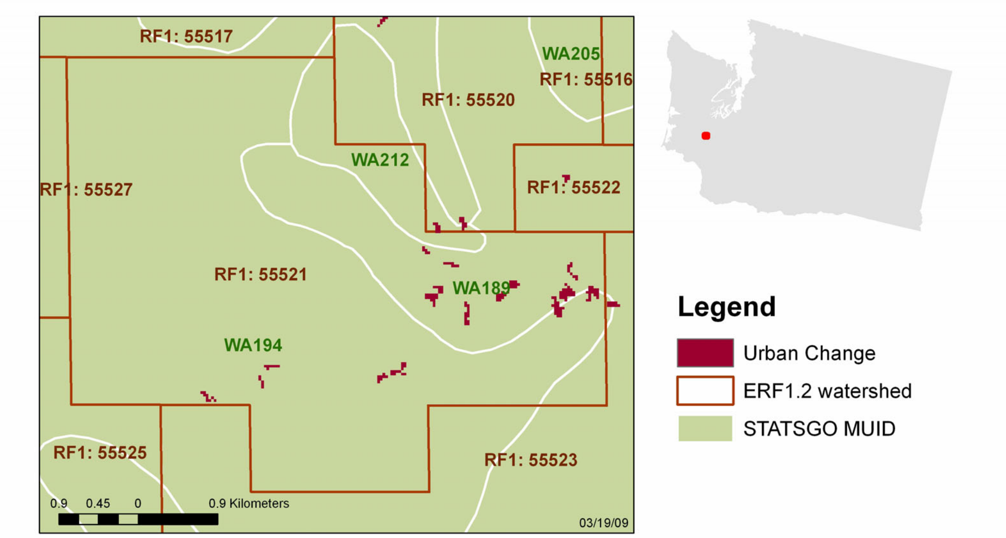

Figure 3-13. An example of Washington State RF1 watershed showing urban weighting emphasizes MUID: WA189, while area-weighting would have enhanced MUID WA194.

3.5.5. VENDOR DATA FOR ACTIVE TREATMENT SYSTEMS

EPA compiled and evaluated information from vendors on treatment technologies that could be used in setting numeric standard discharge limits for stormwater runoff from construction sites. EPA conducted an Internet-based search and placed telephone calls to several vendors to gather data on available treatment technologies, costs, and performance (for vendor-specific information and fact sheets, see DCNs 43000 through 43011 and DCN 43081 in the Administrative Record). EPA also received unsolicited e-mails with data from vendors. After publishing the November 2008 proposed rule, EPA received additional data from vendors (see DCN 43125).

3.5.6. RAINFALL AND RUNOFF EROSIVITY FACTOR

EPA used a GIS data layer for the RUSLE R factor to determine average R factors for RF1 as a component of the loadings analysis. The R factor (USDA 1997) is an indicator of rainfall energy and intensity and varies seasonally across the United States. EPA uses this data for determining whether small construction sites can qualify for the Low Erosivity Waiver (LEW) that is in the NPDES Phase II stormwater regulations. EPA has an online tool that can be used to determine if sites qualify for the LEW (see http://cfpub.epa.gov/npdes/stormwater/lew/lewcalculator.cfm). Figure 3-14 shows annual R factor values for the CONUS. Again using an urban masking approach, EPA derived the R factor values for RF1 watersheds on the basis of averaging values underlying land undergoing development according to the NLCD 1992/2001 Retrofit Land Cover Change Product.

3.5.7. HYDROLOGIC SOIL GROUPS

EPA used GIS data to determine the percent of each hydrologic soil group (HSG) for each RF1 watershed using the urban masking approach. The per RF1 HSG percentages were then used to estimate runoff coefficients for each RF1. As described in Section 10.3, EPA first determined the hydrologic response of indicator cities independently for each soil class, i.e., A soil, B soil, C soil, and D soil. Next, the effective per RF1 runoff coefficient was determined by prorating the hydrologic response of the adjacent indicator city using the RF1 HSG percentages. That resulted in a customized runoff coefficient for each RF1. To provide insight into the variability of the HSG within CONUS, Table 3-4 shows the percent of each HSG by state.

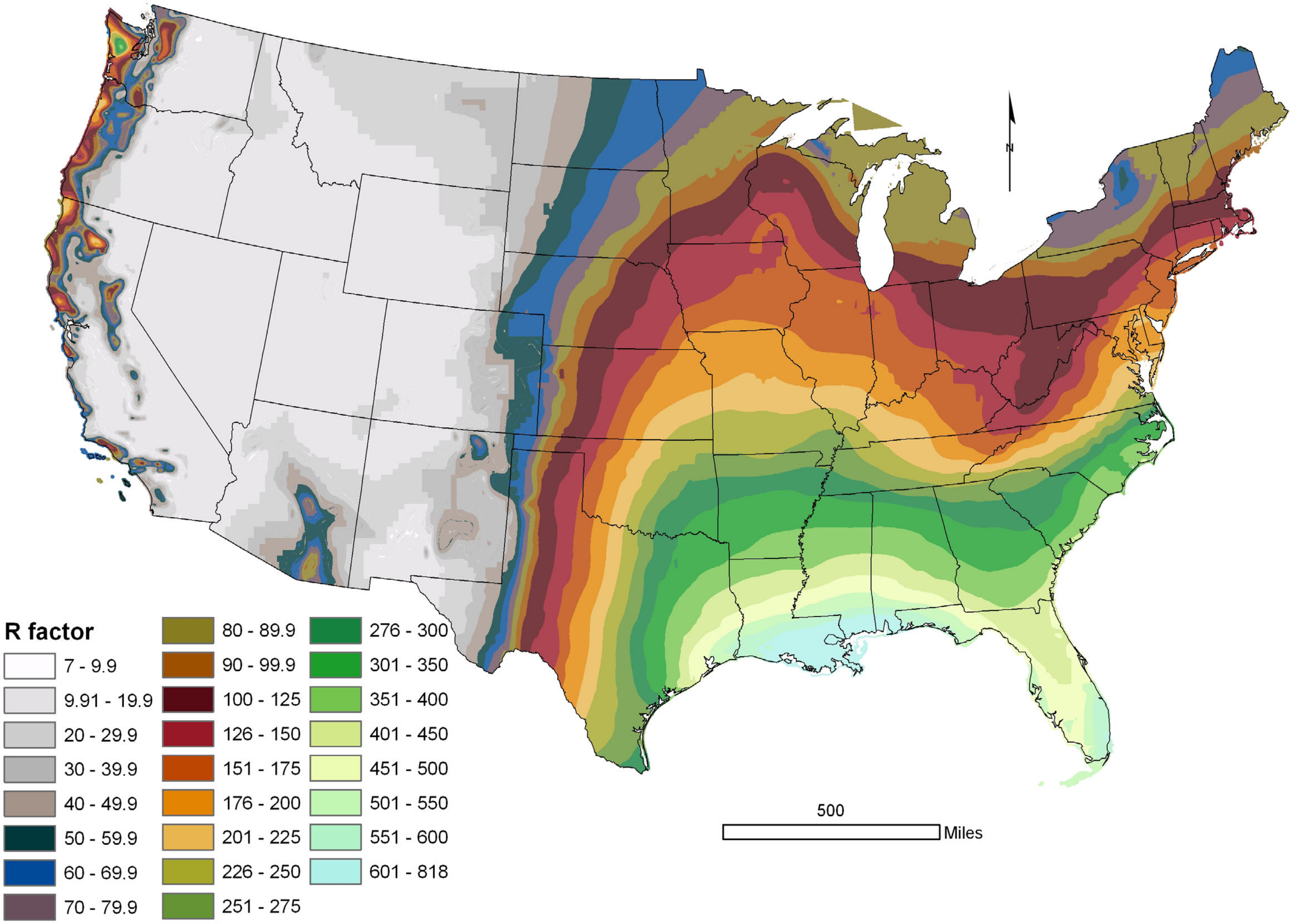

Figure 3-14. Annual R factor values for CONUS.

Table 3-4. HSGs by state

	HSG					HSG			
	A	B	C	D		A	B	C	D
Alabama	8.7%	41.2%	28.8%	21.3%	Nebraska	31.9%	53.6%	3.0%	11.5%
Arizona	4.7%	38.6%	17.2%	39.5%	Nevada	5.6%	26.4%	17.7%	50.3%
Arkansas	0.6%	28.3%	35.9%	35.1%	New Hampshire	17.1%	24.8%	41.4%	16.6%
California	10.9%	32.2%	18.4%	38.5%	New Jersey	12.5%	32.8%	25.1%	29.6%
Colorado	7.2%	46.7%	24.6%	21.4%	New Mexico	5.6%	41.9%	16.5%	36.0%
Connecticut	9.1%	41.1%	35.9%	13.9%	New York	9.6%	18.5%	51.1%	20.7%
Delaware	20.8%	30.9%	13.4%	34.9%	North Carolina	7.9%	48.8%	16.5%	26.8%
Florida	18.1%	6.3%	8.6%	67.0%	North Dakota	4.7%	56.1%	16.6%	22.6%
Georgia	6.6%	53.1%	16.9%	23.5%	Ohio	0.6%	16.8%	54.6%	28.0%
Idaho	4.4%	46.8%	23.1%	25.7%	Oklahoma	6.8%	44.5%	22.3%	26.4%
Illinois	1.4%	44.5%	27.0%	27.1%	Oregon	5.2%	32.1%	37.1%	25.6%
Indiana	3.5%	32.6%	41.8%	22.1%	Pennsylvania	6.0%	28.4%	54.2%	11.5%
Iowa	0.9%	66.0%	11.6%	21.5%	Rhode Island	15.3%	35.7%	32.4%	16.5%
Kansas	3.8%	58.0%	19.5%	18.7%	South Carolina	11.9%	41.8%	19.5%	26.8%
Kentucky	0.1%	42.7%	44.9%	12.3%	South Dakota	2.9%	45.2%	11.5%	40.4%
Louisiana	1.7%	14.4%	28.9%	55.1%	Tennessee	0.1%	53.6%	30.4%	15.9%
Maine	7.7%	12.9%	43.9%	35.5%	Texas	5.1%	27.2%	24.5%	43.2%
Maryland	10.0%	38.6%	26.4%	25.0%	Utah	5.3%	36.2%	16.2%	42.3%
Massachusetts	23.9%	16.6%	34.4%	25.2%	Vermont	4.9%	18.0%	54.3%	22.8%
Michigan	29.0%	28.7%	12.9%	29.4%	Virginia	1.7%	53.7%	32.3%	12.3%
Minnesota	8.3%	37.4%	15.4%	38.9%	Washington	6.6%	53.4%	24.2%	15.8%
Mississippi	2.3%	32.3%	38.6%	26.9%	West Virginia	7.3%	21.5%	54.2%	17.0%
Missouri	1.0%	40.1%	39.8%	19.0%	Wisconsin	14.4%	46.8%	18.1%	20.7%
Montana	2.9%	39.5%	27.2%	30.4%	Wyoming	4.5%	40.5%	19.5%	35.5%

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4. INDUSTRY PROFILE

4.1. INTRODUCTION

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.

Because the U.S. Environmental Protection Agency (EPA) is developing regulations to address water quality issues, this document focuses on the construction subsectors most closely associated with land-disturbing activities. General contractors and heavy construction establishments are, by definition, the most likely to conduct activities that could affect water resources. Note, however, that for individual projects, responsibility for land-disturbing activities and potential effects on water quality might not be obvious because general contractors often subcontract all or some of the actual construction work. Hence, the following subsections describe the subsector categories most likely to be responsible for land-disturbing activities at the national level.

The construction and development (C&D) industry is classified in the *2007 North American Industry Classification System* (NAICS) under Sector 23, Construction (U.S. Census Bureau 2008a). NAICS is the system used for classifying industry establishments by type of economic activity, which replaced the U.S. Standard Industrial Classification (SIC) system.

The construction sector comprises establishments primarily engaged in constructing buildings or engineering projects (e.g., highways and utility systems). Establishments primarily engaged in preparing sites for new construction and establishments primarily engaged in subdividing land for sale as building sites also are included in this sector (U.S. Census Bureau 2008a).

Construction work done can include new work, additions, alterations, or maintenance and repairs. Activities of these establishments generally are managed at a fixed place of business, but they usually perform construction activities at multiple project sites. Establishments identified as construction-management firms are also included in the sector. The construction sector is divided into three types of activities or subsectors as described below (from U.S. Census Bureau 2008a):

- **Subsector 236—Construction of Buildings**
  This subsector comprises establishments of the general contractor type and operative builders involved in constructing buildings. The work performed can include new work, additions, alterations, or maintenance and repairs. The on-site assembly of precut, panelized, and prefabricated buildings and construction of temporary buildings are included in this subsector. Part of or all the production work for which the establishments in this subsector have responsibility can be subcontracted to other construction establishments—usually specialty trade contractors. Establishments in this subsector are classified on the basis of the types of buildings they construct. This classification reflects variations in the requirements of the underlying production processes.

- **Subsector 237—Heavy and Civil Engineering Construction**
  This subsector comprises establishments whose primary activity is constructing entire engineering projects (e.g., highways and dams), and specialty trade contractors, whose primary activity is producing a specific component for such projects. Specialty trade contractors in Heavy and Civil Engineering Construction generally are performing activities that are specific to heavy and civil engineering construction projects and are not normally performed on buildings. The work performed can include new work, additions, alterations, or maintenance and repairs.

  Specialty trade activities are classified in this subsector if the skills and equipment present are specific to heavy or civil engineering construction projects. For example, specialized equipment is needed to paint lines on highways. That equipment is not normally used in building applications, so the activity is classified in this subsector. Traffic signal installation, while specific to highways, uses much of the same skills and equipment that are needed for electrical work in building projects and is therefore classified in Subsector 238, Specialty Trade Contractors. Establishments in this subsector are classified on the basis of the types of structures that they construct. This classification reflects variations in the requirements of the underlying production processes.

- **Subsector 238—Special Trade Contractors**
  This subsector comprises establishments whose primary activity is performing specific activities (e.g., pouring concrete, site preparation, plumbing, painting, and electrical work) involved in building construction or other activities that are similar for all types of construction, but that are not responsible for the entire project. The work performed can include new work, additions, alterations, maintenance, and repairs. The production work performed by establishments in this subsector is usually subcontracted from establishments of the general contractor type or operative builders, but especially in remodeling and repair construction. Work also can be done directly for the owner of the property. Specialty trade contractors usually perform most of their work at the construction site, although they might have shops where they perform prefabrication and other work. Establishments primarily engaged in preparing sites for new construction are also included in this subsector. There are substantial differences in types of equipment, work force skills, and other inputs required by specialty trade contractors. Establishments in this subsector are classified on the basis of the underlying production function for the specialty trade in which they specialize.

Table 4-1 provides a list of the 3-digit subsectors, 4-digit industry groups and 5-digit NAICS industries in the construction sector.

Table 4-1. 2007 NAICS subsectors, industry groups, and industries performing construction activities that might disturb land

2007 NAICS Sector 23 - Construction	
236	Construction of Buildings
2361	Residential Building Construction
23611	Residential Building Construction
236115	New Single-Family Housing Construction
236116	New Multifamily Housing Construction
236117	New Housing Operative Builders
236118	Residential Remodelers
2362	Nonresidential Building Construction
23621	Industrial Building Construction
236210	Industrial Building Construction
23622	Commercial and Institutional Building Construction
236220	Commercial and Institutional Building Construction
237	Heavy and Civil Engineering Construction
2371	Utility System Construction
23711	Water and Sewer Line and Related Structures Construction
237110	Water and Sewer Line and Related Structures Construction
23712	Oil and Gas Pipeline and Related Structures Construction
237120	Oil and Gas Pipeline and Related Structures Construction
23713	Power and Communication Line and Related Structures Construction
237130	Power and Communication Line and Related Structures Construction
2372	Land Subdivision
23721	Land Subdivision
237210	Land Subdivision
2373	Highway, Street, and Bridge Construction
23731	Highway, Street, and Bridge Construction
237310	Highway, Street, and Bridge Construction
2379	Other Heavy and Civil Engineering Construction
23799	Other Heavy and Civil Engineering Construction
237990	Other Heavy and Civil Engineering Construction
238	Specialty Trade Contractors
2381	Foundation, Structure, and Building Exterior Contractors
23811	Poured Concrete Foundation and Structure Contractors
238110	Poured Concrete Foundation and Structure Contractors
23812	Structural Steel and Precast Concrete Contractors
238120	Structural Steel and Precast Concrete Contractors
23813	Framing Contractors
238130	Framing Contractors
23814	Masonry Contractors
238140	Masonry Contractors
23815	Glass and Glazing Contractors
238150	Glass and Glazing Contractors
23816	Roofing Contractors
238160	Roofing Contractors
23817	Siding Contractors
238170	Siding Contractors
23819	Other Foundation, Structure, and Building Exterior Contractors
238190	Other Foundation, Structure, and Building Exterior Contractors

2007 NAICS Sector 23 - Construction	
2382	Building Equipment Contractors
23821	Electrical Contractors and Other Wiring Installation Contractors
238210	Electrical Contractors and Other Wiring Installation Contractors
23822	Plumbing, Heating, and Air-Conditioning Contractors
238220	Plumbing, Heating, and Air-Conditioning Contractors
23829	Other Building Equipment Contractors
238290	Other Building Equipment Contractors
2383	Building Finishing Contractors
23831	Drywall and Insulation Contractors
238310	Drywall and Insulation Contractors
23832	Painting and Wall Covering Contractors
238320	Painting and Wall Covering Contractors
23833	Flooring Contractors
238330	Flooring Contractors
23834	Tile and Terrazzo Contractors
238340	Tile and Terrazzo Contractors
23835	Finish Carpentry Contractors
238350	Finish Carpentry Contractors
23839	Other Building Finishing Contractors
238390	Other Building Finishing Contractors
2389	Other Specialty Trade Contractors
23891	Site Preparation Contractors
238910	Site Preparation Contractors
23899	All Other Specialty Trade Contractors
238990	All Other Specialty Trade Contractors

Source: U.S. Census Bureau 2008a

Before NAICS was created, C&D industries were classified using the SIC system. Any data collected before January 1997 might still be classified under that system. SIC classifications are relevant to the effluent guidelines because certain U.S. Census Bureau data for the construction industry were collected until 1994 and, therefore, were classified under the SIC system rather than the NAICS. Under the SIC system, industries that might perform land-disturbing activities were classified under Division C–Construction, and Division H–Finance, Insurance, and Real Estate. Those divisions include the following SIC major groups (from U.S. Census Bureau 2008b):

- **SIC Major Group 15–Building Construction General Contractors and Operative Builders**
  This group includes general contractors and operative builders primarily engaged in constructing residential, farm, commercial, or other buildings. General building contractors who combine a special trade with their contracting are also included.
- **SIC Major Group 16–Heavy Construction other than Building Construction Contractors**
  This group includes general contractors primarily engaged in heavy construction other than building construction, such as highways and streets, bridges, sewers, railroads, irrigation projects, flood control projects, and marine construction, as well as special trade contractors primarily engaged in activities of a type clearly specialized in such heavy construction and not normally performed on buildings or building-related projects.

- **SIC Major Group 17–Construction Special Trade Contractors**
  This group includes special trade contractors who undertake activities of a type that are specialized either in building construction or in both building and non-building projects.
- **SIC Major Group 65–Real Estate**
  This group includes real estate operators and the owners and lessors of real property, as well as buyers, sellers, developers, agents, and brokers.

Major groups 15 and 16 are further defined by the type of construction performed. Table 4-2 provides a list of the more specific industry groups and industries that might perform land-disturbing activities.

The focus of the regulation is on construction activities carried out by firms covered by NAICS codes 233 and 234 or SIC codes 15 and 16. (As discussed in the preamble of the final rule, Special Trade Contractors, NAICS 238 or SIC 17, are typically subcontractors and not identified as National Pollutant Discharge Elimination System permittees.) Furthermore, the residential, nonresidential, and heavy construction subsectors receive the greatest emphasis because they account for the vast majority of construction projects and are responsible for most of the land disturbance in the United States.

Table 4-2. 1987 SIC industry groups performing construction activities that might disturb land

SIC Major Group 15	
Industry Group 152: General Building Contractors - Residential	
1521	General Contractors - Single-family Houses
1522	General Contractors - Residential Buildings, Other Than Single-family
Industry Group 153: Operative Builders	
1531	Operative Builders
Industry Group 154: General Building Contractors - Nonresidential	
1541	General Contractors - Industrial Buildings and Warehouses
1542	General Contractors - Nonresidential Buildings, Other Than Industrial
SIC Major Group 16	
Industry Group 161: Highway and Street Construction, Except Elevated Highways	
1611	Highway and Street Construction, Except Elevated Highways
Industry Group 162: Heavy Construction, Except Highway and Street	
1622	Bridge, Tunnel, and Elevated Highway Construction
1623	Water, Sewer, Pipeline, and Communications and Power Line
1629	Heavy Construction Not Elsewhere Classified
SIC Major Group 17	
Industry Group 179: Miscellaneous Special Trade Contractors	
1771	Concrete Work
1794	Excavation Work
SIC Major Group 65	
Industry Group 655: Land Subdividers and Developers	
6552	Land Subdividers and Developers, Except Cemeteries

Source: U.S. Census Bureau 2008b

4.2. INDUSTRY PRACTICES AND TRENDS

This section first provides a description of the types of C&D activities that result in the disturbance of land and are responsible for the potential discharge of pollutants of concern to surface waters. Then national estimates of the amount of disturbed acreage are provided. Additional information including detailed descriptions of industry size and revenues is in EPA's *Economic Analysis for Final Effluent Guidelines and Standards for the Construction and Development Category* (USEPA 2009a).

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. Such 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.

4.2.1.1. 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 such 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 (ESCs) 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).

4.2.1.2. 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; Reed Business Information 2000; Lynch and Hack 1984; Peurifoy and Oberlender 1989).

Excavation and grading are performed by several different types of machines. Those tasks can also be done by hand, but that 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 stormwater 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; Reed Business Information 2000; Lynch and Hack 1984; 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 excavated soil onto 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 and 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 drive 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 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).

After the 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 that EPA evaluated apply to construction sites of all types (i.e., residential, commercial, and industrial). Because the costs for ESC 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.

4.2.2.1. National Estimates of New Development

EPA used the National Land Cover Dataset (NLCD) to estimate the amount of new developed land occurring annually in the conterminous United States (CONUS) between 1992 and 2001 (see Table 3-1 and Appendix E). EPA's comparison of the 1992 and 2001 NLCD resulted in an estimated annual rate of development of approximately 590,000 acres per year. By overlaying geographic information system (GIS) layers of states and watersheds with the NLCD data, EPA was able to estimate the annual number of acres of new development at both the state and watershed level between 1992 and 2001 (For state-level annual estimates of new development, see Table 4-6). EPA used the Reach File Version 1.0 (RF1) stream reach network and associated watershed boundaries for the watershed-level estimates. EPA estimated annual development rates between 1992 and 2001 for approximately 44,000 RF1 watersheds where a net increase in urban land cover was identified. Approximately 7,800 additional RF1 watersheds showed either no change or a minor decrease in urban land uses between 1992 and 2001. EPA scaled the amount of development in each RF1 to the year 2008 using historical construction spending data. For additional details, see *Economic Analysis for Final Effluent Guidelines and Standards for the Construction and Development Category* (USEPA 2009a). RF1 watersheds and stream reaches are employed by the USGS SPARROW water quality model—the model EPA has selected to assess potential environmental benefits of additional regulation of the industry (USGS 2008). See the *Environmental Impact and Benefits Assessment for Final Effluent Guidelines and Standards for the Construction and Development Category* (EPA 2009b) for additional details and results of the water quality assessment performed by EPA.

Because NLCD data does not exist for Alaska, Hawaii, and the U.S. territories, EPA's analysis does not include pollutant loading reduction or environmental benefits estimates for those areas. However, the amount of development in those areas is expected to be low compared to the rest of the United States; therefore, any errors in EPA's estimates are expected to be minor. EPA did estimate costs for Alaska and Hawaii using economic data as an indicator of the amount of construction activity occurring.

4.2.2.2. Model Project Distribution

EPA broadly characterized the acreage constructed annually into various future land uses and construction project sizes. That characterization provides a basis for developing and then using mathematical models that represent broad sectors of the industry to estimate compliance costs and pollutant loading reductions. EPA divided Notices of Intent (NOIs) into 36 groups based on 12 site size categories and three major land-use types (residential, nonresidential, and transportation). Projects were further subdivided into 12 categories of different durations.

The distribution of model projects into these categories was developed by reviewing NOIs submitted by permittees (see Appendix C, Analysis of Construction Industry Trends using Notice of Intent Records). The NOI records were individually characterized on the basis of land use, and the NOI records used provided site construction acreage and project duration information. Individually, the site project models each represent large fractions of the construction projects developed annually and cover the major project types in the C&D industry. EPA used this model project matrix as a basis for estimating costs and pollutant removals for the industry. Table 4-3 shows the model project matrix developed. Table 9-2 shows the complete model project matrix that includes the breakout by project sizes.

Table 4-3. Model project distribution

		Residential		Nonresidential		Transportation		National	
Size category (acres)	**Median size (acres)**	**Projects**	**Acres**	**Projects**	**Acres**	**Projects**	**Acres**	**Projects**	**Acres**
1–2.99	1.9	4,914	9,337	23,237	44,150	2,417	4,592	30,568	58,079
3–4.99	3.8	3,693	14,033	12,410	47,158	1,298	4,932	17,401	66,124
5–7.49	6.0	1,992	11,952	6,709	40,254	770	4,620	9,471	56,826
7.5–9.99	8.5	1,680	14,280	3,579	30,422	494	4,199	5,753	48,901
10–14.99	12.0	2,421	29,052	4,084	49,008	548	6,576	7,053	84,636
15–19.99	17.0	1,556	26,452	2,102	35,734	272	4,624	3,930	66,810
20–29.99	23.0	1,810	41,630	2,078	47,794	363	8,349	4,251	97,773
30–39.99	34.0	984	33,456	865	29,410	128	4,352	1,977	67,218
40–59.99	46.0	921	42,366	847	38,962	180	8,280	1,948	89,608
60–79.99	69.0	373	25,737	366	25,254	52	3,588	791	54,579
80–99.99	85.1	242	20,594	213	18,126	56	4,766	511	43,486
100 <	145.0	344	49,880	356	51,620	118	17,110	818	118,610
Total		**20,930**	**318,769**	**56,846**	**457,892**	**6,696**	**75,988**	**84,472**	**852,650**

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5. SELECTION OF POLLUTANTS FOR REGULATION

5.1. INTRODUCTION

Construction and development (C&D) 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, those activities can result in both short- and long-term adverse effects on surface water quality in streams, rivers, and lakes in the affected watershed by increasing the loads of various pollutants in receiving waterbodies, including sediments, metals, organic compounds, pathogens, and nutrients. Ground water also can be adversely affected through diminished recharge capacity. Other potential effects include the physical alteration of existing streams and rivers due to the excessive flow and velocity of stormwater runoff.

Construction activities typically involve excavating and clearing existing vegetation. During the construction period, the affected land is usually stripped and the soil compacted, leading to the potential for increased stormwater runoff and high rates of erosion. If the denuded and exposed areas contain hazardous contaminants or pollutants (either naturally occurring or from previous land uses), they can be carried at increased rates to surrounding waterbodies by stormwater 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.

Pollutants associated with C&D stormwater 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. The *Environmental Impact and Benefits Assessment for Final Effluent Guidelines and Standards for the Construction and Development Category* (EPA 2009b) discusses the potential affects of C&D stormwater runoff on the environment. The discussion in the remainder of this section focuses on those pollutants generated at a site during active construction.

5.2. POLLUTANTS ASSOCIATED WITH CONSTRUCTION AND LAND DEVELOPMENT STORMWATER RUNOFF

A number of pollutants are associated with C&D stormwater runoff. The descriptions of pollutants in this subsection do not represent the complete suite of contaminants that can be found in the runoff but focus instead on those that are known to be the most prevalent and of greatest concern to the environment. Those pollutants include sediment, metals, polycyclic aromatic hydrocarbons (PAHs), oil and grease, and pathogens. A more thorough discussion of pollutants and pollutant sources are in the Environmental Assessment document.

5.2.1. SEDIMENT

Sediment is an important and ubiquitous constituent in urban stormwater runoff. Surface runoff and raindrops detach soil from the land surface, resulting in sediment transport into streams and rivers. Sediment and turbidity can affect habitat, water quality, temperature, pollutant transport, and can cause sedimentation in downstream receiving waters. The effects 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 eggs and fry in redds. Effects can also be indirect, as in changes to the chemical composition (e.g., pH, hardness) of the water, light penetration or turbidity, and temperature profile, which in turn affect primary productivity with repercussions in terms of fish behavior, and overall community profiles and trophic structure.

Sediment level measurement can be divided into several distinct subgroups:

- Total suspended solids (TSS) are a dry-weight measure of the suspended particulate material in water. Measuring TSS in urban stormwater allows for estimation of sediment transport, which can have significant effects locally and in downstream receiving waters. TSS is typically measured in milligrams per liter (mg/L).
- Turbidity is a measure of the amount of solids and other materials in the water. Turbidity readings are somewhat dependent on particle size, shape, and color. Turbidity is typically measured in nephelometric turbidity units (NTUs). 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.
- Settleable solids, expressed as milliliters per liter (mL/L), are a measure of the solids that will settle to the bottom of a cone-shaped container (called an Imhoff cone) in a 60-minute period. Settleable solids are primarily a measure of particles that can be removed by sedimentation.
- Suspended sediment concentration (SSC) is a measure similar to TSS; however, there are differences in the two analytical methods. SSC is determined by measuring the dry weight of all sediment from a known volume of sample. TSS is measured by filtering a subsample and measuring the weight of the dried solids. SSC and TSS values from the same sample can vary greatly, especially as the fraction of sand-sized particles in a sample increases. This is primarily because of the subsampling procedure involved in TSS calculations where typically a pipette is used to withdraw a subsample from the sample container. That procedure might not capture a representative fraction of larger particles in the subsample. The U.S. Geological Survey has analyzed differences attributable to the two methods and determined that SSC is a more appropriate measure of the mass of solids in natural-water samples (Gray et al. 2000). That might also apply to stormwater discharges, especially if a significant fraction of sand-sized particles are present.

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 the studies are summarized in Table 5-1. One study, 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 et al. 1986). On a unit area basis, construction sites can export sediment at 20 to 1,000 times the rate of other land uses (Schueler 1997).

Table 5-1. Studies of uncontrolled soil erosion as TSS from construction sites

Site	Mean inflow TSS concentration (mg/L)	Source
Seattle, Washington	17,500	Horner et al. 1990
SR 204	3,502	Horner et al. 1990
Mercer Island	1,087	Horner et al. 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
SB2	476	Schueler and Lugbill 1990
SB4	2,670	Schueler and Lugbill 1990
Pennsylvania Test Basin	9,700	Jarrett 1996
Georgia Model	3,000	Sturm and Kirby 1991
Maryland Model	3,000	Barfield and Clar 1985
Uncontrolled Construction Site Runoff (Maryland)	4,200	York and Herb 1978
Hamilton County, Ohio	2,950	Islam et al. 1998
Mean TSS (mg/L)	3,860	N/A

N/A – Not Applicable

For summaries of studies with monitoring or modeling data and annotated bibliographies for the journal articles and professional conference proceedings that the U.S. Environmental Protection Agency (EPA) reviewed, see Document Control Numbers (DCNs) 44321 and 43114.

5.2.2. METALS

Many toxic metals can be found in urban stormwater, although typically only metals such as zinc, copper, lead, cadmium, and chromium have been identified in the literature as being of primary concern because of their prevalence in urban stormwater runoff and their potential for environmental harm. Those metals are generated by motor vehicle exhaust, weathering of buildings, burning 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 1994). Generally the concentrations found in urban stormwater are not high enough for acute toxicity (Field and Pitt 1990). Rather, it is the cumulative effect of the concentration of the metals over time and the buildup in the sediment and animal tissue that are of greater concern.

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, or if metals are naturally present in site soils. Imported fill can also be a source of contamination. Construction activities alone do not usually result in significant metals contamination, although there is little data available on this subject.

5.2.3. PAHS, AND OIL AND GREASE

Petroleum-based substances such as oil and grease and PAHs are found frequently in urban stormwater runoff. Many constituents of PAHs and oil and grease, such as pyrene and benzo[b]fluoranthene, are carcinogens and toxic to downstream biota (Menzie-Cura & Associates 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.

Construction activities during site development are not believed to be major contributors of these contaminants to stormwater 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 and construction materials), could lead to leakage or spillage of products that contain hydrocarbons.

5.2.4. PATHOGENS

Microbes are commonly found in urban stormwater. 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* (i.e., *E. coli*) indicates a potential health risk. High levels of these bacteria can result in beach closings, restrictions on shellfish harvest, and increased treatment for drinking water to decrease the risk of human health problems.

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. Those systems, however, are typically self-contained; although leaks or spills could result in releases.

5.3. SELECTION OF POLLUTANTS FOR REGULATION

When determining which pollutants to consider for regulation, EPA applied the following priorities for discharges from the C&D industry:

- Focus on pollutants directly attributable to the industry, using indicator pollutants where necessary
- Focus on pollutants most commonly encountered under most settings, (i.e., not to preconstruction site contamination issues or accidental discharges)
- Focus on pollutants that are most manageable given the current suite of available technologies

In support of the 2002 and 2004 regulatory efforts, EPA conducted an extensive evaluation of the literature to identify pollutants present in stormwater discharges from C&D sites. While the literature contains extensive information on pollutants present in stormwater discharges from urban areas, there were little data available on pollutants present in stormwater discharges from construction sites during the active phase of construction other than for sediment, TSS, and turbidity. That is not surprising, because construction site stormwater management is primarily concerned with controlling solids from exposed soil areas. There is the potential for other pollutants to be discharged from construction sites depending on factors such as prior land uses. For example, if the prior land use was agriculture, the potential exists for discharge of pollutants such as nutrients and pesticides. Likewise, areas of redevelopment that occur on sites where previous land uses included industry could discharge pollutants such as organics and metals. In addition, pollutants such as metals and nutrients can be present in native site soils and could be discharged from construction sites. Also, high pH can result from stormwater being exposed to freshly placed concrete. However, EPA was not able to identify sufficient data in the literature to warrant developing controls specific to pollutants other than sediment, TSS, and turbidity in stormwater discharges from active construction sites. Although EPA identified other pollutants of concern for the industry, EPA did not develop regulatory options specifically targeted at controlling each of these individual pollutants. The Environmental Assessment contains a more thorough discussion of pollutants found in stormwater discharges from construction sites.

Instead, EPA chose to develop regulatory options using an indicator pollutant, turbidity. While turbidity might not correlate well with TSS, designing management systems for controlling turbidity will likely result in control of other pollutants such as TSS, nutrients, and metals that are present in the solid-phase (attached to sediments). In addition, turbidity, unlike TSS, can be measured with relative ease in the field using hand-held turbidity meters or automated, in-line turbidity meters. An in-line turbidity meter, coupled with a data logger, can offer real-time data on turbidity levels in stormwater discharges.

Particles that contribute to turbidity can be of such a fine grain that they will not be removed by the mechanisms whereby most best management practices operate, mainly settling and filtration. Hence, the options developed for the final rule focus on passive and active treatment of stormwater runoff using polymers to remove turbidity, as well as TSS and other pollutants. Section 7 discusses technologies designed to reduce and remove such fine colloidal particles.

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6. LIMITATIONS AND STANDARDS: DATA SELECTION AND CALCULATION

6.1. INTRODUCTION

This section describes the data selection and statistical methodology used by the U.S. Environmental Protection Agency (EPA) in calculating the limitations and standards for the Construction and Development (C&D) point source category. As is the case for most effluent limitation guidelines and standards, the effluent limitations and standards are based on long-term average effluent values and variability factors that account for variation in treatment performance within a particular treatment technology over time. For simplicity, the following discussion refers only to effluent limitations guidelines; however, the discussion also applies to new source standards.

EPA is promulgating a daily maximum limitation for turbidity, and Section 6.2 briefly describes the pollutant parameter. Section 6.3 provides an overview of EPA's criteria typically used to select data sets used as the basis for limitations. Section 6.4 describes the available discharge data sets that met the criteria. Section 6.5 describes the data sets that were excluded as a result of applying the criteria. Section 6.6 verifies that the individual values within the retained data sets also are appropriate as the basis of the limitation. Sections 6.7 and 6.8 provide summaries of the data before and after averaging to obtain daily values. Section 6.9 provides an overview of the limitations, percentile basis, and calculations. Section 6.10 describes the engineering review of the limitations. Sections 6.11 and 6.12 discuss issues related to monitoring and compliance with the limitation. Section 6.13 summarizes the steps used to calculate the limitations. Section 6.14 provides references.

In the proposed rule, EPA also was considering a limitation on pH to protect against extreme acidity or alkalinity. EPA has not promulgated a pH limitation for the final rule.

6.2. TURBIDITY

As described in Section 5 and in more detail in the Environmental Assessment, there are a number of pollutants associated with discharges from C&D sites. EPA is promulgating effluent limitations for turbidity, as an indicator of the presence of those pollutants being discharged from the C&D site. Turbidity is a simple measurement that requires only the use of a turbidimeter and can be conducted in the field. Readings are made in nephelometric turbidity units or NTUs. Turbidity measurement does not require any sample preparation, other than shaking the sample bottle well before analysis. The sample is simply poured into a glass tube and placed inside the calibrated instrument. The result is read directly from the instrument. There are also a variety of digital turbidity probes, which can be coupled with a microprocessor controlled data logger and combination meter/data loggers available that can be used to automatically read and log turbidity values in-situ.

6.3. OVERVIEW OF DATA REVIEW AND CRITERIA

To develop a limitation, EPA generally seeks to obtain as much monitoring data as possible on the effectiveness of the different treatment options it evaluates, through solicitation of information from the public and industry. Here, EPA received data from a number of treatment technology vendors, but no data from the regulated industry. As described in Sections 6.4, 6.5, and 6.6, EPA qualitatively reviewed all the data before selecting a large subset to calculate the limitations. In selecting the data, EPA applied the following criteria in determining if the data were appropriate to use as the basis for the final rule. In its rulemakings for other industries, EPA has used the same or similar criteria to develop the limitations and standards.

One criterion requires that the influents and effluents from the treatment components represent typical wastewater (or in the case of the C&D industry, stormwater) from the industry, with no significant incompatible wastewater from other sources (e.g., sanitary wastes). Application of this criterion results in EPA selecting only those sites where the commingled wastewaters did not result in substantial dilution, more concentrated wastewaters, or wastewaters with different types of pollutants than those generated by C&D wastewater.

A second criterion ensures that the pollutants were present in the influent at sufficient concentrations to evaluate treatment effectiveness. By verifying that influent includes measureable solid content, EPA ensures that its limitations resulted from treatment and not simply the absence of turbidity in the wastestream.

A third criterion generally requires that the system demonstrate good operation of the model treatment technology. EPA determines whether a system meets this criterion on the basis of documentation about the system installed at the site, discussions with site management, evaluation of site diagrams, and comparison to the performance of treatment systems at other sites. In addition, because control of turbidity at construction sites is a function of up-slope erosion and sediment controls, as well as proper application and sizing of passive treatment controls, EPA also evaluated whether the overall site controls (if information was available) were representative of BAT, and whether controls were adequately sized, operated and maintained and whether a particular site would represent typical site conditions. In general, EPA reviewed this information to determine if the system was adequately sized; properly operated and maintained; and whether the resulting data represent typical site conditions. As a result of these communications and reviews, EPA determined that some data were representative of normal operating conditions for the facility and that the level of treatment was adequate, and excluded data that reflected a technology application that did not coincide with the selected BAT and/or where the overall site controls were deemed to be inadequate.

A fourth criterion typically requires that the data cannot represent periods of treatment upsets or shut-down periods. This criterion sometimes results in the exclusion of periods when the site first starts operating the equipment (*start-up*). Although this criterion is more applicable to wastewater treatment than stormwater management practices at construction sites, there are some similarities in this case (for example, non-optimized dosage rates). As result of this criterion, EPA could exclude certain time periods and other outliers in the data from an otherwise well-operated site.

EPA has not included the size of the site as a criterion, because the site size and associated runoff volumes determine the design and size of the management practices, rather than its performance.

6.4. DATA SELECTED AS BASIS FOR LIMITATIONS

As a consequence of applying the four criteria, EPA selected only data that were representative of the model technology, which in this case is polymer-aided settling. All of the sites used by EPA as the basis for the limitation employed either polymer-aided settling in ponds (using either chitosan acetate, chitosan lactate or PAM) or polymer-aided settling/filtration using check dams. EPA is confident that the resulting database fully characterizes the performance of the model technology for all C&D sites subject to the limitation for several reasons:

1. Theoretically, there is no reason that the technology cannot be applied everywhere. It is a simple technology that only requires appropriate sizing of the ponds and conveyances, applying the correct polymer, using the appropriate dosing schedule, and conducting needed maintenance activities.
2. Different soil types and rainfall amounts are managed by sizing the ponds and conveyances properly, providing adequate detention time for settling, applying the correct polymer, and using the appropriate dosing schedule. For example, if the soil (e.g., clay) does not readily infiltrate rainfall, then the storage volume would need to be larger than one at a site with more porous soil. In another example, if the site has a steeper slope, then the site might contain more check dams per channel than a more level site.
3. Size of the site is managed by placing the appropriate number of systems on the site and/or sizing the ponds and conveyances properly.
4. The model technology, polymer aided settling, has widespread use across a wide range of industries (e.g., POTWs, drinking water treatment, industrial wastewater treatment) for solids control. In the industries which have used this technology for decades, it has been successful. It is less prevalent in the C&D industry because managing turbidity in stormwater discharges has not been required until recently.

EPA’s database of performance data includes more than 29,000 turbidity measurements that were used as the basis for the limitation. The data were from 25 treatment systems at 9 sites in three states and covers both the Eastern and Western Unites States and a range of construction types. The data were provided by two commercial firms (Cascade EcoSolutions and Clear Water Compliance Services) and researchers at North Carolina State University. Table 6-1 identifies the data sources, the site name or location, and the abbreviations used to identify the systems at those sites. These abbreviations are used throughout Chapter 6 and the data listings in Appendix F.

Table 6-1. Data sources and site identification for systems using EPA's model technology basis

Source	Site name or location	Abbreviation	Construction type
Cascade EcoSolutions	Beacon Hill Reservoir Burying Project, Seattle, WA	BHRBP	Other
	Brightwater Waste Water Treatment Plant in King County, WA	BWWTP	Commercial
	Sea-Tac Airport in King County, WA	SEAAIR	Transportation
	Sound Transit Central Link Light Rail Tacoma/Seattle, WA	STCLLR	Linear
Clear Water Compliance Services, Inc.	Beacon Hill Reservoir Burying Project, Seattle, WA	BHRBP2 *	Linear
	Sea-Tac Airport in King County, WA	KC-variations	Transportation
	Springville, NY highway widening	NY	Transportation
	Redmond, WA residential project	Red.East, Red.West	Residential
NCSU Research (McLaughlin, et al)	North Carolina mountain roadway project in 2006-7	NCR.1 NCR.2	Transportation
	North Carolina mountain roadway project in 2008	NC.Road	Transportation

* Because BHRBP2 is a more complete data set, it was used to calculate the long-term average and variability factor for this site.

6.4.1. CASCADE ECOSOLUTIONS

Cascade EcoSolutions is a vendor that provides the chitosan-based flocculants used by service providers to treat turbid stormwater. For the proposed rule, Cascade EcoSolutions provided influent and effluent data for the advanced treatment system (ATS) at six sites in Washington State. After the proposal, EPA contacted the vendor for more details about the influent data. The vendor confirmed that the influent to ATS for four of the sites was effluent from passive treatment systems, that is, the model technology for the final rule. As a result, EPA concluded that the data from the four sites were appropriate to use in developing the final limitation that is based on passive treatment systems. The four sites are all in the Seattle area in Washington:

- Beacon Hill Reservoir Burying Project (BHRBP)
- Brightwater Wastewater Treatment Plant (BWWTP)
- Sea-Tac Airport (SEAAIR)
- Sound Transit Central Link Light Rail (STCLLR)

For three sites, BHRBP, BWWTP, and STCLLR., the vendor provided turbidity measurements via a ChitoVan Performance Review Data Set (Cascade EcoSolutions 2008). For SEAAIR, the vendor provided detailed information about the treatment and sites in an engineering report (Minton 2006) and a separate Engineering Report Data file (Cascade EcoSolutions 2008). The report identifies the SEAAIR project as supporting the construction of Sea-Tac's third runway.

6.4.2. CLEAR WATER COMPLIANCE SERVICES, INC.

Clear Water Compliance Services Inc. provides comprehensive water treatment services including the design, installation, and monitoring of treatment systems for stormwater and construction runoff. The company provided data for the following 20 systems using the model technology:

- 16 systems at the third runway at Sea-Tac airport. These data sets are identified as KC for King County followed by the Site number (or pond), and then system number. For example, KC1.1 is the first system at site 1.
- One system at a highway widening site in Springville, New York. This data set is identified as "NY."
- Two systems at an 18-acre residential development project in Redmond, Washington. They installed a 250 gallons per minute (gpm) treatment system at the West Basin and a 500 gpm treatment system at the East Basin, both of which operated over a 2 year period. The data sets are identified as Red.West and Red.East.
- One system at a large infrastructure project that is part of the City of Seattle's Reservoir Burying Program. The project involved demolition of an existing reservoir and re-building of a large vault-reservoir that was then buried below the surface and had a park built over the top. The site area for this site was approximately 22 acres. The data set is identified as BHRBP2 to distinguish it from the Cascade EcoSolutions data for this site.

6.4.3. RESEARCH BY NORTH CAROLINA STATE UNIVERSITY

Dr. Richard A. McLaughlin and others at North Carolina State University studied stormwater runoff from three systems for erosion and sediment control on two roadway projects in the North Carolina mountains. EPA determined that three of the systems were consistent with its model technology:

- NC.Road is described in a paper *Target Turbidity Limits for Passive Treatment Systems* (McLaughlin No Date) that provides data for from September 2008 to January 2009.
- NCR.1 and NCR.2 are described in the Journal of Soil and Water Conservation (McLaughlin 2009). The systems were installed as part of a university research project. The measurements were collected from June 2006 to October 2006 at road widening and paving projects in the North Carolina mountains.

6.5. SYSTEMS EXCLUDED AS BASIS FOR LIMITATION

EPA excluded data from all systems that did not meet the criteria described in Section 6.3. Table 6-2 summarizes the system exclusions and EPA's rationale for each. In all cases, the data represented a different technology, such ATS, than the model technology basis for the regulation.

Table 6-2. Systems Excluded as Basis for Limitation

Source	Site name or location	Abbreviation	Reason for exclusion
Clear Creek Systems, Inc. (proposal data)	California, Oregon, and Washington	2 3 4 6 8 11 BZR08 SC05 SC08	The effluent data are from ATS. Influent data is influent into the pretreatment pond. The vendor did not collect data after the pretreatment pond but before ATS filtration, and thus, the influent does not represent EPA's model technology.
Cascade EcoSolutions (proposal data)	WSDOT SR-522 Road Improvement Project (Elliot Road)	ELLRD	The effluent data represent ATS which is not EPA's model technology.
	Lakeside	LSIDE	The effluent data represent ATS. The influent data were not pretreated with EPA's model technology.
Oregon Department of Environmental Quality (proposal data, Jurries no date)	West Linn Corporate Park	WLCPO	The effluent data represent ATS. The influent data were not pretreated with EPA's model technology.
	Hoodview Estates	HEO	
Resource Planning Associates (41107) and Minton (41108)	Six systems at a commercial site in Redmond, CA	RED.1-RED.6	These sites used batch treatment in cells, which is more extensive than EPA's model technology.
Clear Water Compliance Services	Morrisville, NC, was a commercial site with a runoff area of 82 acres and two treatment systems.	not incorporated into EPA's databases	Data were provided only as minimum and maximum values which could not be used to calculate daily averages.

6.6. APPLICATION OF CRITERIA TO LIMITATION DATA SETS

After excluding data sets from systems that were not representative of the model technology for C&D wastewaters, EPA performed a final review of the individual data points from the systems that it had selected as the basis of the limitations. For this review, EPA returned to the criteria identified in Section 6.3 and applied each one to the data sets identified in Table 6-1.

The *first criterion* ensures that the wastewater contains primarily stormwater associated with C&D operations. EPA considered two aspects, post-paving conditions and recirculation, in evaluating the data for this criterion:

- Post-paving conditions: The journal article describing NCR.1 and NCR.2 included data after the pavement was complete. EPA determined that post-paving conditions were not representative of C&D discharges, and excluded them as the basis of the limitation.

- Recirculation: EPA has not excluded any data from systems that recycled effluent. Although some of the sites recycled water after ATS filtration to the pretreatment ponds, EPA determined that this practice would have little overall effect on turbidity within the basin because the recycle flow rate is small in comparison to the storage volumes contained in the ponds. In addition, other inputs into the pond from surface runoff would be expected. Before determining that the data of such systems should be included as the basis of the limitation, EPA considered the effect of recirculation on treatment performance. If recirculation had an impact, it would be expected to dilute the resulting effluent to lower concentration levels.

To evaluate whether this was the case, EPA evaluated the SEAAIR data set, which was one data set that indicated when recirculation occurred. EPA evaluated the individual measurements and the daily averages derived from them.

- Individual measurements: Of the 31 recirculation events (some had multiple events per day), 16 had increased turbidity in the subsequent reading, and 14 had less (one reading was the final of the day and therefore had no subsequent reading). EPA then considered effluent concentration reported for the reading during recirculation and the following measurement. The effect is more pronounced with increased turbidity for 30 measurements and less turbidity for 18. Both evaluations indicate that the effluent concentrations tended to increase after circulation at this location.
- Daily averages: On the five days when recirculation occurred, the observed daily averages were greater on four days and lower on one when including the recirculation events. In each case, the change was less than 6 percent.

Because the effect of recirculation was the opposite from what would be expected if dilution were the only influence (i.e., the effluent turbidity values were generally more concentrated (i.e., higher) not dilute), EPA concluded that recirculation did not appear to have a significant effect on effluent concentrations. Instead, the higher turbidity values might be from sediment resuspension in the pretreatment pond due to the turbulence caused by the recycled water. In addition, additional inputs to the pond from surface runoff, groundwater flows, and activities such as dewatering operations on the site could have contributed additional volume to the ponds, which would also affect the effluent turbidity. Because the recirculation did not appear to significantly influence effluent turbidity, EPA determined that it was appropriate to retain all of the data, including data from time periods where recirculation was occurring, in its limitation data set.

The *second criterion* ensures that the effluent levels are the result of treatment rather than dilute influent. Although most of the effluent data were not paired with the corresponding influent, based upon its review of the existing data and other sources that describe C&D stormwater (see Section 5), EPA is confident that turbidity would have been present at any site, and thus, has not used this criterion to exclude any data set. Influent into the passive treatment system is affected by many parameters. EPA examined the data in several ways.

- EPA considered whether the influents were likely to be more concentrated than the effluents. McLaughlin (2009) provides turbidity concentrations from a section of the roadway construction project with standard best management practices (BMP) for the NCR.1 site. Both sections of the project would be expected to have similar soil types, rainfall, and other characteristics. By comparing data from the two sections, EPA was able to obtain a lower bound of the difference between untreated stormwater and PAM-treated stormwater. That is, EPA would expect even more of a difference than the results using BMP data. Considering only the days when measurements were made at both sections, the BMP site removed turbidity to a level of 3669 NTU, while the model technology (fiber check dams with PAM) removed turbidity to a level of 26.8 NTU for a removal of 99 percent. EPA performed a similar comparison for the NCR.2 data and found a removal of 97 percent. This finding demonstrates that influent would be substantially greater than effluent from the model technology.
- EPA examined the literature to determine turbidity in stormwater generated at construction sites. EPA evaluated a variety of literature sources, and summarized numerous studies evaluating the effectiveness of sediment basins, which are among the most common management practices used at construction sites. The literature indicates that stormwater discharges into sediment basins had turbidity values ranging from tens of NTUs to tens of thousands of NTUs (see DCN 44321). Therefore, turbidity and sediment are clearly present in construction site stormwater.

The *third criterion* requires that the system demonstrate good operation of the model treatment technology. EPA had limited information about whether the treatment technology was well operated. However, because this technology is relatively simple, EPA chose to assume that most effluent data from the model technology represented good performance. In evaluating this criterion, EPA identified several areas that needed additional engineering investigation:

- Red.East and Red.West are two systems at the same residential site. The two systems generally demonstrate larger turbidity values than the other systems. Because these basins were pretreatment basins before ATS filtration, the general goal at this site (as well as other ATS sites used in the calculation of the limitation) was to reduce the turbidity to a level that is acceptable for filtration, which is usually less than 500 NTUs. Therefore, the dosage rate at this site was likely not optimized to reduce turbidity to low levels (because that was not the goal of the pretreatment basin), but the basin did remove significant turbidity. Because the range of data values were generally within the range observed by the other systems in the data set (although more often in the high end), EPA retained the data for both systems as the basis for the limitation.
- NCR.1: The discharge of 335 NTU on 7/25/06 was much greater than the other values observed at this site. In the engineering review, EPA contacted the author and EPA learned that a utility company had buried a line in the center of the treatment ditch after moving the wattles out of the way. Although the wattles were returned to the ditch, they were not stapled in which is essential to proper operation. Consequently, the system performed poorly even during relatively little rain (9 mm). Because the system was not installed properly on that day, EPA excluded the value as a basis for the limitation.

- NCR.2: The discharge of 533 NTU on 9/24/08 was much greater than the other values observed at this site. EPA contacted the author to obtain additional information on the data. Although the author was not able to provide any specific information on site activities that may have contributed to the much higher value on that day, EPA determined that because this data point was not consistent with other data from this site and from NCR.2 that this data point was likely not representative of normal operation. Therefore, this data point was excluded from calculation of the limitation.

The *fourth criterion* ensures that the data represent normal operations. EPA's application of the criterion excluded all turbidity measurements with zero values and/or associated with no flow.

6.7. SUMMARY OF LIMITATION DATA AND DATA CONVENTIONS

In developing the limitation, EPA focused its review on the performance and operating conditions of sites that used systems that were consistent with EPA's model technology. Table 6-3 provides a summary of the reported turbidity measurements from the 25 systems with the model technology (Section 6.4). EPA received more than 29,000 measurements of turbidity from systems that met the requirements for EPA's model technology. These data are provided in Listing 1 of Appendix F. (DCN 42107 provides the data in an electronic spreadsheet file.) This section describes EPA's review of the data, identifies data issues, and explains the rationale for excluding certain data points from the limitations calculations.

EPA excluded the data for BHRBP (from Cascade EcoSolutions), because the data for BHRBP2 (from Clean Water) contained many of the same measurements taken at the same monitoring point at the same time. Although there were a few differences, overall, measurements were the same for sample dates summarized in both files. Because BHRBP2 provided data for a longer period of time, EPA retained this data set and excluded the BHRBP from its calculations and data listings.

Table 6-3. Summary of reported turbidity measurements (NTU) in effluent (individual measurements before daily average calculations)

System	Number of values	Average (NTU)	Standard deviation	Minimum	Median	Maximum
BHRBP2	3,260	73.964	92.456	3.1	47.2	989.7
BWWTP	104	113.579	57.366	2.7	135.25	284
KC1.1	1,374	59.256	36.703	6	51.3	365.2
KC1.2	1,723	61.272	40.033	6.7	50.7	388.2
KC1.3	610	56.131	20.084	6.6	51.9	213.9
KC1.4	127	42.649	11.79	17.3	45.3	114.3
KC1.5	822	42.677	18.16	5.2	39.6	193
KC2.1	1,616	90.528	49.272	8	81.6	637.5
KC2.2	1,476	91.243	47.118	2.5	82.35	644.8
KC2.3	1,928	70.314	41.326	4.4	63.1	574
KC2.4	1,034	74.662	48.28	10.4	69	695.2
KC2.5	1,178	71.082	45.01	1.8	62.45	695.7

System	Number of values	Average (NTU)	Standard deviation	Minimum	Median	Maximum
KC3.1	594	55.245	23.042	12.1	58.1	320
KC3.2	620	55.265	34.903	8.7	56.75	486.6
KC3.3	721	48.263	24.176	10.1	41.4	195.9
KC3.4	622	52.792	21.799	0.4	54.6	224.6
KC3.Pond	110	48.136	18.453	10.4	45.45	130.9
NC.Road[*]						339
NCR.1[**]	105	46.12				
NCR.2[**]	9	61.22				
NY	7,089	101.466	82.395	1.6	90.4	1,000.9
Red.East	3,467	256.524	201.905	1.6	202.7	1,000.9
Red.West	762	132.949	104.745	1.4	117.45	614.1
SEAAIR	366	108.406	33.327	24.51	108.545	209.22
STCLLR	196	66.009	46.555	4.7	57.3	293.9
OVERALL[a,b]	> 29,913			0.4		1,000.9

a. The data for NC.Road included the mean, standard deviation and maximum value for each of 7 days. Because the number of values used to calculate these statistics is not known, the only value that can be reported on this table for NC.Road is the maximum.

b. The data from NCR.1 and NCR.2 included the mean and the number of observations for each day. Samples collected at this site were composites for the entire storm event. Therefore, the only values that can be reported on this table for NCR.1 and NCR.2 are the number of values and the mean.

6.8. DATA AVERAGING PRIOR TO LIMITATION CALCULATIONS

The limitations for turbidity, as presented in today's notice, are provided as the maximum daily discharge limitation. Definitions provided in 40 CFR 122.2 state that the *maximum daily discharge limitation* is the *highest allowable daily discharge*. The definitions also state that "*[d]aily discharge* means the *discharge of a pollutant* measured during a calendar day or any 24-hour period that reasonably represents the calendar day for purposes of sampling."

In calculating the limitations, EPA analyzed the data from each treatment system separately, even if the systems were located at the same site. (This is consistent with EPA's practice for other industrial categories.) To be consistent with the daily discharge definition, EPA arithmetically averaged all measurements recorded for each day from each treatment system before calculating the limitations. EPA refers to this averaged value as the daily value.

Listing 2 of Appendix F identifies the 914 daily values obtained from arithmetically averaging the values summarized in Table 6-3. Table 6-4 provides a summary of the daily values. From the 25 treatment systems, EPA observed a minimum daily value of 2.5 (NY) to a maximum of 672 NTU (Red.East).

Table 6-4. Summary of daily values of turbidity (NTU) in effluent

System	Number of daily values	Arithmetic average	Standard deviation	Minimum	Median	Maximum
BHRBP2	116	69.02	57.57	12.00	53.05	527.75
BWWTP	8	68.43	60.00	12.70	34.88	151.30
KC1.1	28	54.66	18.72	21.85	51.01	103.39
KC1.2	32	54.61	20.95	13.90	50.39	117.17
KC1.3	10	54.63	12.52	41.76	51.26	85.66
KC1.4	3	44.86	7.06	38.63	43.42	52.53
KC1.5	16	41.61	10.37	32.13	38.77	75.88
KC2.1	33	79.53	33.05	23.32	73.98	154.77
KC2.2	30	82.00	37.70	21.12	76.14	192.14
KC2.3	40	61.56	26.77	21.65	58.82	130.94
KC2.4	23	60.00	33.55	23.52	51.49	152.17
KC2.5	19	65.86	23.60	34.08	64.23	117.74
KC3.1	13	48.27	18.58	18.30	44.34	79.02
KC3.2	13	48.17	20.81	18.02	47.14	79.96
KC3.3	15	40.53	21.57	14.78	35.19	79.01
KC3.4	15	42.98	20.26	15.58	44.73	73.54
KC3.Pond	7	43.93	13.78	25.13	42.09	63.99
NC.Road	7	55.14	50.81	11.00	40.00	167.00
NCR.1	12	37.75	28.98	9.00	31.00	109.00
NCR.2	3	49.67	37.82	15.00	44.00	90.00
NY	220	96.50	52.89	2.50	95.64	549.39
Red.East	169	209.73	143.99	5.35	195.03	672.65
Red.West	56	107.96	81.53	11.92	91.86	341.21
SEAAIR	9	103.39	35.61	34.84	105.75	155.92
STCLLR	17	61.05	34.97	11.22	56.68	161.76
Total	914	100.49	93.08	2.50	71.43	672.65

6.9. LIMITATION CALCULATIONS

The limitations for turbidity, as presented in today’s notice, are provided as the maximum daily discharge limitation. This section describes the statistical percentile basis of the limitation (Section 6.9.1), the concepts and calculations for the long-term average, the variability factor, and the limitation (Sections 6.9.2, 6.9.3, and 6.9.4). Section 6.9.5 describes autocorrelation and its effect on the value of the limitation.

6.9.1. STATISTICAL PERCENTILE BASIS FOR LIMITATIONS

The daily maximum limitation is an estimate of the 99th percentile of the distribution of the daily measurements. EPA calculates the daily maximum limitation on the basis of a percentile chosen with the intention, on one hand, to accommodate reasonably anticipated variability within the control of the site and, on the other hand, to reflect a level of performance consistent with the

Clean Water Act requirement that the BAT effluent limitation and NSPS be based on well-operated and maintained facilities. The percentile for the daily maximum limitation is estimated using the product of the long-term average and the variability factor derived from data that represent the performance of the model technology under all conditions when properly operated and controlled. For the rule, EPA estimated the long-term average and variability factor using a statistical model based on the lognormal distribution as described in Appendix G.

6.9.2. LONG-TERM AVERAGE

In the first of two steps in estimating the different types of limitations, EPA determines an average performance level (the *long-term average*) that systems representing well-designed and operated model technologies (which reflect the appropriate level of control) are capable of achieving. This long-term average is calculated from the data from the sites using the model technology. The long-term average of 64.13 NTU is the median value of 25 long-term averages collected from the 25 treatment systems. The long-term averages ranged from a minimum of 37 NTU (NCR.1) to a maximum of 251 NTU (Red.East). The median is the midpoint of the 25 values, and is the 13th largest value, which is associated with KC2.4. As a consequence of using the median, 12 of the system-specific averages are above the long-term average and 12 are below, as shown in Table 6-5. EPA expects that all sites subject to the limitations will design and operate their treatment systems to achieve the long-term average performance level on a consistent basis because sites with well-designed and operated model technologies have demonstrated that this can be done.

Table 6-5. System-specific long-term averages used in limitation calculations

System	Number of daily values	Long-term average (NTU)	Rank (smallest=1)
BHRBP2	116	68.96	15
BWWTP	8	132.41	23
KC1.1	28	55.81	10
KC1.2	32	56.08	11
KC1.3	10	55.77	9
KC1.4	3	46.66	3
KC1.5	16	42.09	1
KC2.1	33	82.67	17
KC2.2	30	85.96	18
KC2.3	40	63.52	12
KC2.4	23	64.13	13 (median)
KC2.5	19	68.46	14
KC3.1	13	52.53	7
KC3.2	13	53.09	8
KC3.3	15	44.88	2
KC3.4	15	47.84	6
KC3.Pond	7	47.59	5
NC.Road	7	88.19	19
NCR.1	12	47.11	4
NCR.2	3	194.31	24

System	Number of daily values	Long-term average (NTU)	Rank (smallest=1)
NY	220	105.20	20
Red.East	169	251.48	25
Red.West	56	122.70	22
SEAAIR	9	117.79	21
STCLLR	17	70.40	16
Median LTA		64.13	

6.9.3. VARIABILITY FACTOR

EPA acknowledges that variability around the long-term average results from normal operations. This variability means that occasionally sites can discharge at a level that is greater than the long-term average. This variability also means that sites can occasionally discharge at a level that is considerably lower than the long-term average. Consequently, in the second step of developing a limitation, EPA determines an allowance for the variation in pollutant concentrations when processed through well-designed and operated treatment systems. This allowance for variance incorporates all components of variability including process and wastewater generation, sample collection, shipping, storage, and analytical variability. This allowance is incorporated into the limitations through the use of the *variability factors*, which are calculated from the data from the sites using the model technology. The variability factor of 4.322 is the arithmetic average (or mean) of 25 variability factors collected from the 25 systems also used as the basis of the long-term average. Table 6-6 provides the 25 system-specific variability factors. The variability factors ranged from a minimum of 1.775 (KC1.5) to a maximum of 10.203 (BWWTP), and were calculated as shown in Appendix G.

Table 6-6. System-specific variability factors used in limitation calculations

System	Number of daily values	Daily variability factor (VF1)
BHRBP2	116	3.642
BWWTP	8	10.203
KC1.1	28	2.283
KC1.2	32	2.508
KC1.3	10	1.867
KC1.4	3	1.953
KC1.5	16	1.775
KC2.1	33	2.890
KC2.2	30	3.104
KC2.3	40	2.845
KC2.4	23	3.646
KC2.5	19	2.576
KC3.1	13	3.219
KC3.2	13	3.503
KC3.3	15	3.878
KC3.4	15	3.819

System	Number of daily values	Daily variability factor (VF1)
KC3.Pond	7	2.809
NC.Road	7	8.135
NCR.1	12	5.859
NCR.2	3	12.968
NY	220	4.140
Red.East	169	6.391
Red.West	56	5.934
SEAAIR	9	3.586
STCLLR	17	4.513
Mean VF1		4.322

In its evaluation of the daily variability factor, because it has not regulated turbidity for other industries, EPA compared the daily variability factor developed from the C&D data with variability factors developed for TSS effluent limitations guidelines and standards promulgated during the past 12 years for various industrial categories. Because turbidity and TSS are treated similarly by treatment systems, EPA would expect TSS levels and turbidity to exhibit similar daily variability factors. While turbidity represents the appropriate parameter to regulate for pollutant control in C&D discharges rather than TSS,[1] EPA looked at TSS variability factors as a check on its calculated turbidity daily variability factor. As shown in Table 6-7, the values for the variability factors are relatively close in value, ranging from 2.9 to 5.4, with an arithmetic average of 4.1 which is close to the variability factor of 4.322 calculated for the C&D turbidity limitation. EPA concluded that the value of 4.322 ensures a level of control that EPA considers achievable for discharges from C&D sites.

Table 6-7. TSS variability factors in recent regulations

Category	Subcategory	Option	Value
Centralized Waste Treatment (USEPA 2000)	Organics	4	4.8
	Oils	9	2.9
	Metals	3	3.2
		4	3.6
Waste Combustors (USEPA 1999b)	Commercial Hazardous Waste Combustors		4.2
Iron and Steel (USEPA 2002)	Coke By-Products	BAT1	4.6
	Other	DRI_BPT	3.5
		FORGING	4.4

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[1] As previously explained, turbidity is the BAT regulated pollutant parameter EPA selected as a pollutant itself and as an indicator of toxic and non conventional pollutants discharged from C&D sites. While the discharge of pollutants may be identified by a number of measures including measurement of, among others, turbidity, suspended solids and total suspended solids, EPA has selected turbidity as the better measure for sediment discharge rather than TSS for several reasons. These include the fact that discharges from sites with appreciable clay soils may exhibit low TSS concentration but still have high turbidity level indicative of higher pollutant content.

Category	Subcategory	Option	Value
Landfills (USEPA 1999a)	1) Hazardous and 2) Non-Hazardous*		4.4
Pulp, Paper, and Paperboard, Cluster Rule (USEPA 1997)	bleached papergrade kraft and soda		3.11
Transportation Equipment Cleaning (Science Applications International Corporation 2000)	Barge/Chemical & Petroleum	1	4.7
	Food Direct	2	5.4

* The variability factors for both subcategories were based on the same data.

6.9.4. CALCULATION OF THE LIMITATION

Using its standard approach for effluent guidelines, EPA calculated the value of the daily maximum limitation (280 NTU) using the product of the long-term average (64.13 NTU) and daily variability factor (4.322):

$$\begin{aligned} \textit{Daily Maximum Limitation} &= \textit{Long-Term Average} \times \textit{Variability Factor} \\ &= (64.13\ \textit{NTU}) \times (4.322) \\ &= 277.17\ \textit{NTU} \end{aligned}$$

EPA rounded the value of the limitation to two significant digits (i.e., 280 NTU).

As a consequence of using the long-term average and variability factor as the basis of the limitation, sites that are designed and operated to achieve long-term average levels should be capable of compliance with the limitations, which incorporate variability, at all times.

6.9.5. LIMITATION INCLUDES AUTOCORRELATION ADJUSTMENT

The limitation calculations include an adjustment for possible bias due to statistical autocorrelation. When data are said to be positively autocorrelated, it means that measurements taken at specific time intervals (such as 1 day or 2 days apart) are related. For example, positive autocorrelation would be present in the data if the effluent concentration was relatively high one day and was likely to remain at similar high values the next and possibly succeeding days. Because the values tend to be similar from day to day, the variance estimate may be dampened even within a relatively large time period. By accounting for autocorrelation, the adjusted variance then better reflects the underlying variability that would be present if the data were collected over an even longer period. To evaluate autocorrelation, generally, the statistical analysis requires at least a 50-day period with measurements from every day during the period.[2] C&D discharge data generally do not have measurements for every day. Instead, they are generally associated with days with precipitation, and no discharge (or zero) for the other days. After determining that the data were not suitable for the statistical analysis, EPA then considered, from an engineering aspect, whether it was likely that treatment from one day to the next would

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[2] Box and Jenkins (1976), a classic textbook on time series analyses, states, "It is normally supposed that successive values of the time series under consideration … are available for analysis. If possible, at least 50 and preferably 100 observations should be used." (page 18)

be similar. On one hand, conditions can vary considerably from day to day which would lead EPA to conclude that treatment would be relatively unaffected by the previous day's treatment. On the other hand, if stormwater is detained in a pond for a sufficient amount of time, the settling process might indicate that discharges one day apart might be similar. Because EPA's engineering review was inconclusive, EPA determined that, as a conservative measure to ensure that the limitation was achievable, it was appropriate to incorporate a statistical adjustment for autocorrelation.

As explained in Section 6.9.3, turbidity has not been regulated in other industries, and thus, EPA again investigated whether it could transfer autocorrelation adjustments developed for TSS limitations in other industries. Of the choices listed in Table 6-7 and for which the statistical documentation is readily available, EPA only adjusted for autocorrelation in the TSS NSPS for the pulp, paper, and paperboard industry. EPA determined that it was appropriate to transfer the autocorrelation adjustment because: 1) EPA expects turbidity and TSS to be treated similarly by the model technology; and 2) the model technologies for the two industries similarly detain the wastestreams prior to discharge. EPA also notes that the adjustment for the 1998 regulation was relatively large, and thus, it is unlikely that the C&D discharges would require an even larger adjustment. Appendix G describes the application of the 1998 adjustment to the variance of the C&D data. The consequence of applying this adjustment to the C&D discharges was an increase in the value of the limitation from 189 to 280 NTU. Table 6-8 provides the values of the system-specific long-term averages and variability factors with and without the autocorrelation adjustment.

Table 6-8. Effect of autocorrelation adjustments on limitation

System	Number of daily values	WITHOUT autocorrelation adjustment		WITH autocorrelation adjustment (used as basis of limitation)	
		Long-term average (NTU)	Daily variability factor (VF1)	Long-term average (NTU)	Daily variability factor (VF1)
BHRBP2	116.00	68.01	3.510	68.96	3.642
BWWTP	8.00	74.32	6.007	132.41	10.203
KC1.1	28.00	54.80	2.067	55.81	2.283
KC1.2	32.00	54.93	2.277	56.08	2.508
KC1.3	10.00	54.66	1.573	55.77	1.867
KC1.4	3.00	45.04	1.417	46.66	1.953
KC1.5	16.00	41.56	1.585	42.09	1.775
KC2.1	33.00	80.40	2.599	82.67	2.890
KC2.2	30.00	83.00	2.746	85.96	3.104
KC2.3	40.00	62.09	2.606	63.52	2.845
KC2.4	23.00	60.43	3.068	64.13	3.646
KC2.5	19.00	66.22	2.204	68.46	2.576
KC3.1	13.00	48.99	2.502	52.53	3.219
KC3.2	13.00	48.91	2.682	53.09	3.503
KC3.3	15.00	41.00	3.005	44.88	3.878
KC3.4	15.00	43.82	2.966	47.84	3.819
KC3.Pond	7.00	44.30	2.008	47.59	2.809
NC.Road	7.00	57.15	4.609	88.19	8.135
NCR.1	12.00	38.43	4.071	47.11	5.859

System	Number of daily values	WITHOUT autocorrelation adjustment		WITH autocorrelation adjustment (used as basis of limitation)	
		Long-term average (NTU)	Daily variability factor (VF1)	Long-term average (NTU)	Daily variability factor (VF1)
NCR.2	3.00	58.60	5.426	194.31	12.968
NY	220.00	104.22	4.054	105.20	4.140
Red.East	169.00	245.48	6.194	251.48	6.391
Red.West	56.00	115.34	5.411	122.70	5.934
SEAAIR	9.00	106.05	2.531	117.79	3.586
STCLLR	17.00	63.20	3.515	70.40	4.513
Median LTA		58.60		64.13	
Mean VF1		3.225		4.322	
99th Percentile		189.00		277.17	

6.10. STATISTICAL AND ENGINEERING REVIEW OF LIMITATION

In conjunction with the statistical methods, EPA performs an engineering review to verify that the limitations are reasonable based on the design and expected operation of the model technologies and the site conditions. Data from some sites demonstrate the best available technology. Data from other sites could demonstrate the same technology but not the best demonstrated design and operating conditions for that technology. EPA recognizes that, as a result of the limitation, some dischargers might need to improve treatment systems, erosion and sediment controls, and/or treatment system operations to consistently meet the effluent limitation. EPA determined that this consequence is consistent with the Clean Water Act statutory framework, which requires that discharge limitations reflect the best available technology (BAT) or best available demonstrated technology (BADT).

The following sections describe several aspects of the engineering review. Section 6.10.1 compares the value of the limitation to the performance data used as the basis of the limitation. Section 6.10.2 compares the performance data for other technologies to the value of the limitation. Section 6.10.3 evaluates the performance data for the C&D model technology collected during the rulemaking for gold placer mining discharges to confirm that the data are consistent with the limitation. Section 6.10.4 compares the limitation to benchmarks established by several states. Section 6.10.5 considers other factors and performance.

6.10.1. PERFORMANCE DATA FOR MODEL TECHNOLOGY COMPARED TO LIMITATION

To evaluate the value of the limitation, EPA compared the value of the limitation to the daily values used to calculate the limitation. Because of the statistical models used to derive the limitation from their data, EPA would expect about one percent of the values to be greater than the limitation. From an engineering perspective, in most instances where the daily values were greater than the turbidity limitation, the system was not optimized appropriately and/or there was some other factor responsible for the higher values. Table 6-9 summarizes the results of this joint statistical and engineering review of the data and the performance at each system.

- 21 of the 25 systems had all the daily values less than the limitation. Because the database contained fewer than 100 daily values for each system, EPA would expect only one, if any, daily values at each system would be greater than the limitation. For these 19 systems, EPA concluded that the finding that none of the values were greater than the limitation is consistent with what is expected from the 99th percentile basis of the statistical methodology. The finding was also consistent from an engineering perspective because properly operated and controlled systems are expected to operate below the level of the limitation.
- BHRBP2 had 1 of 116 (or one percent) daily values greater than the limitation, which is consistent with what is expected from the 99th percentile basis of the statistical methodology. The engineering investigation revealed that the daily value of 528 NTU was observed on December 3, 2007 during an extreme storm event in Seattle, WA (http://www.climate.washington.edu/events/dec2007floods/). The Office of the Washington State Climatologist estimated that 6-hour and 24-hour precipitation amounts were near 100-year rain frequency levels. This event does not represent normal conditions and the rule exempts such events from complying with the limitation. EPA notes that data from 13 other systems in the Seattle area is also available during this storm event and the average turbidities for the day were all below the value of the limitation. Thus, even during the extreme storm event, it was possible to achieve turbidity control.
- New York had two of 220 (one percent) daily values greater than the limitation, which also is consistent with what is statistically expected from the 99th percentile basis of the statistical methodology. The two values, 550 and 284 NTU, were observed on two consecutive days, October 2 and 3 in 2006, which were the first two days reported by the vendor. The engineering review concluded that they were likely the result of insufficient flocculant dosing during start-up operations. EPA has determined that they do not represent normal operations because optimization, even during startup operations, is relatively simple and easy to achieve as demonstrated by the other systems in the limitation data set. In addition, as described earlier, this pond was pretreatment to an ATS system, and therefore the targeted turbidity in the effluent was likely 500 NTUs or less.
- Red.East had 50 of its 169 values greater than the limitation with a maximum value of 673 NTU. Based upon its engineering review of the data, EPA concluded that it was likely not optimizing its system because it only needed to meet a target level of 500 NTU (although several values were above this level). Proper dosing is necessary for adequate turbidity removal, and it is likely that the dosage rate of flocculant was not optimized for obtaining lower turbidity because the other systems evaluated and described here produced consistently lower turbidity values.
- Red.West had 2 of its 56 values greater than the limitation which is slightly more than what is statistically expected. These values were observed on November 6 (334 NTU) and December 14, 2006 (341 NTU). The engineering review concluded that this system was likely not optimized, because it was targeting the model technology to a relatively high level of 500 NTU.

Table 6-9. Daily values greater than daily maximum limitation

System	Number of Daily Values	Daily values greater than daily maximum limitation of 280 NTU	
		Number of values	Percent of total number
BHRBP2	116	1	0.9%
BWWTP	8	0	0.0%
KC1.1	28	0	0.0%
KC1.2	32	0	0.0%
KC1.3	10	0	0.0%
KC1.4	3	0	0.0%
KC1.5	16	0	0.0%
KC2.1	33	0	0.0%
KC2.2	30	0	0.0%
KC2.3	40	0	0.0%
KC2.4	23	0	0.0%
KC2.5	19	0	0.0%
KC3.1	13	0	0.0%
KC3.2	13	0	0.0%
KC3.3	15	0	0.0%
KC3.4	15	0	0.0%
KC3.Pond	7	0	0.0%
NC.Road	7	0	0.0%
NCR.1	12	0	0.0%
NCR.2	3	0	0.0%
NY	220	2	0.9%
Red.East	169	50	29.6%
Red.West	56	2	3.6%
SEAAIR	9	0	0.0%
STCLLR	17	0	0.0%

6.10.2. PERFORMANCE OF OTHER TREATMENT SYSTEMS RELATIVE TO MODEL TECHNOLOGY

EPA compared the limitation to data from other treatment systems to determine if the performance data behaved as expected. For systems, such as ATS, that are more complex than the model technology, EPA expects the performance data to have lower levels of turbidity than the limitation data. For less sophisticated systems, such as best management practices, EPA expects the performance data to have higher levels of turbidity. As described below, these comparisons to the limitation generally confirmed EPA’s expectations.

EPA considered treatment data from systems that were expected to perform better than the model technology. Of the approximately 24,000 effluent measurements from 38 systems using ATS, the largest measured value was 71.6 NTU. As EPA expected, in all cases, the advanced systems demonstrated lower levels of turbidity than required by the limitation. In addition, EPA considered the influent data for the system for the WSDOT SR-522 road improvement project at Elliot Road (ELLRD). Although EPA did not use this data in calculating the limitation, its average value was 42.10 NTU, which was lower than the 64 NTU long-term average basis of the limitation. In addition, the maximum value obtained for ELLRD was 182 NTU which is well below the limitation of 280 NTU. Thus, the ELLRD system performance is better than EPA's model technology.

EPA also considered data from other studies that did not use the model technology (polymer-aided settling) but that used other conventional BMPs. See Chapter 5 and DCN 44321 for a summary of studies evaluating the performance of sediment basins. Two key studies of conventional BMPs are Warner and Collins-Camargo (2001) and Horner, Guedry and Kortenhof (1990). EPA also evaluated other studies that evaluated passive treatment, but were not used as a basis for calculating the limitation. See DCN 43114 for a summary of various other passive treatment approaches. Two key studies evaluating polymer-aided settling were prepared for the Auckland Regional Council (2004 and 2008). These studies evaluated TSS, not turbidity, and hence were not used for calculation of the limitation, but provide useful information on polymer-aided settling in sediment basins.

EPA also considered influent data that it had collected for the proposed rule to determine if the levels appeared to be greater than the turbidity limitation. In this comparison, EPA was verifying that it was establishing a limitation that would require treatment. The 1008 influent measurements that reflect either uncontrolled wastewater and/or runoff managed by upslope BMPs (i.e., relatively minor treatment) prior to the pond. As shown in Table 6-10, the average turbidity levels ranged from 105 to 2581 NTU, and thus, all are greater than the long-term average basis (64 NTU) for the limitation. In addition, the maximum values generally are larger than any value observed from effluent from the model technology. Thus, EPA concluded that treatment is likely to be necessary for sites to comply with the limitation.

Table 6-10. Daily value summary from systems with less than model technology

Site	Number of daily values	Arithmetic average (NTU)	Standard deviation	Minimum (NTU)	Maximum (NTU)
11	32	148.63	187.25	1.08	1,020.00
2	23	2,581.29	1,255.08	853.00	4,816.00
3	16	105.39	96.40	27.40	380.20
4	18	398.86	283.98	10.20	985.00
6	8	552.59	201.28	209.00	951.00
8	14	610.56	329.19	204.00	1,000.00
BZR08	9	323.63	83.90	149.00	420.00
HEO	4	604.00	99.37	466.00	696.00
LSIDE	76	242.45	120.62	52.25	662.89
SC05	7	255.50	47.34	210.00	331.00
SC08	14	848.08	143.65	625.73	1,080.00
WLCPO	10	194.50	123.68	78.10	472.00

6.10.3. PERFORMANCE OF MODEL TECHNOLOGY FOR GOLD PLACER MINING WASTES

As an additional step in the engineering review, EPA reviewed its records for its 1988 rulemaking for the gold placer mining subcategory of the ore mining and dressing point source category. The placer mining regulation established a limitation for settleable solids based on simple settling, which is not equivalent to the model technology for C&D. However, during development of the placer mining regulation EPA conducted treatability studies at placer mining sites to evaluate the performance of simple settling and chemically aided settling in reducing settleable solids, TSS and turbidity. Although the mining wastes evaluated had solids content generally higher than expected for C&D, and that these were jar tests as opposed to basin influent/effluent samples, EPA found comparable performance in the treatability tests. The *1986 Alaskan Placer Mining Study Field Testing Program Report* (USEPA 1987) performed chemically assisted tests that determined the effect of polyelectrolytes and polyethylene oxide (PEO) on turbidity levels. Results, presented in Table 6-11, indicate the PEO, with and without polyelectrolyte, can reduce turbidity to low levels. Moreover, although the initial turbidity levels are generally substantially greater than the levels in C&D wastewater, the model technology was able to drop below 280 NTU within one hour. The only exception (mine 4998) dropped to 220 NTU during the second hour. After 6 hours (EPA expects longer settling periods for C&D wastewater in ponds, which are generally designed to provide 24 to 72 hours of detention time), EPA would expect to see about half of the values to be greater than (and half less than) the long-term average basis of the limitation. The result, with only four values greater than the long-term average, is consistent, and perhaps even better, performance than EPA expects from the model technology. Thus, EPA concludes that the gold placer mining study demonstrates that EPA's model technology can achieve the low levels required by the limitation, even in the presence of extremely high levels of turbidity in the influent.

Table 6-11. Turbidity during 1986 Alaskan placer mining study

Chemically aided settling (PEO tests) turbidity (NTU)									
Mine No.	Test No.	Initial	30 min	1 hr	2 hr	3 hr	4 hr	5 hr	6 hr
4922	21	39,500	35,000	31	21	20	12	11	10
4998	4	39,500	350	275	220	210	175	140	140
4999	8	11,000	188	148	144	140	136	128	122
5000	12	6,500	45	44	42				
5001	15	2,450	54	41	40	38	35		
5002	17	22,500	90	83	82	82	80	80	75
5003	24	1,235	144	95	77	68	60	53	51
5004	29	23,250	134	93	83	71	69	59	52
Average: All Mines (PEO)		18,242	4,501	101	89	90	81	79	75

Chemically aided settling (polyelectrolyte) turbidity (NTU)									
Mine No.	Test No.	Initial	30 min	1 hr	2 hr	3 hr	4 hr	5 hr	6 hr
4922	19	40,000	24,250	52	26				
	20	42,500	21,250	63	50	36	33	27	27
4998	2	18,600	58	37	30	28	28	28	27
	3	8,500	570	54	54				
4999	6	16,250	134	97	90	90	89	89	78
	7	22,000	84	70	67				
5000	10	1,680	37	34	23	22	18	15	15
	11	2,050	40	30	25				
5001	14	2,000	32	29	27	26	25		
5003	23	9,000	14	13	12	12	11	11	10
	25	11,320	41	36	37				
5004	27	23,150	41	20	10				
	28	23,500	45	23	18	11	9	6	5
Average: All Mines (Polyelectrolyte)		16,965	3,584	43	36	32	30	29	27

6.10.4. LIMITATION IS CONSISTENT WITH STATE ACTION LEVELS

EPA also compared its long-term average basis of the limitation with action levels established by four states. EPA is not aware of any statistical studies that were the basis of the action levels in these four states; however, EPA assumes that there was a technology basis or BPJ basis that established that the levels were reasonable. While an action level is not an enforceable limit, it does indicate that the state determined that discharges greater than the action level may require additional optimization or treatment technology. To comply with the limitation, EPA recommends that operators target the system performance to the long-term average basis of the limitation and control discharges above that level. Because the state action levels and the long-term average both indicate a potential need for operator action, EPA compared the state action levels to 64 NTU, the long-term average basis of the limitation, EPA found that its long-term average basis is consistent with or more stringent than the state action levels: 50 NTU in Vermont (DCN 42108); 120 NTU in Oregon (DCN 42109) and Washington (DCN 42110); and 250 NTU in California (DCN 42104). In addition, California has established an enforceable NTU limit of 500 in its current general permit for certain sites. The data from Washington demonstrate that the action levels have generally been effective in controlling the discharges with 75 percent of the daily values less than the action level of 120 NTU.

6.11. MONITORING CONSIDERATIONS

Effluent guidelines act as a primary mechanism to control the discharge of pollutants to waters of the United States. The C&D regulations will be applied to C&D sites through incorporation in individual National Pollutant Discharge Elimination System (NPDES) permits or a general permit issued by EPA or authorized states or tribes under section 402 of the Clean Water Act. In complying with the final rule, the number of measurements required each day would be determined by the permit authority. While the actual monitoring requirements will be determined by the permitting authority, in developing the limitation, the Agency has assumed that sites will report one value for every day that the discharge occurs to be consistent with permit definitions provided in 40 CFR 122.2 that define the *maximum daily discharge limitation* as the “highest allowable *daily discharge*.”

EPA recognizes that some sites regularly monitor multiple times throughout the day to ensure that the treatment system is operating properly. In addition, because turbidity can be measured real-time, it is possible to use an automated turbidity meter in conjunction with a data logger to obtain data during the entire period of discharge. While EPA agrees that such monitoring is appropriate, EPA would, however, discourage the practice of allowing the number of monitoring samples to vary arbitrarily merely to allow a site to achieve a desired average concentration, i.e., a value below the limitation that day. EPA expects that enforcement authorities would prefer, or even require, monitoring samples at some regular, predetermined frequency. As explained below, if a site has difficulty complying with the limitation on an ongoing basis, the site should improve its equipment, operations, and/or maintenance.

6.12. COMPLIANCE

EPA promulgates limitations that sites are capable of complying with at all times by properly operating and maintaining their processes and treatment technologies. However, the issue of exceedances or excursions (values that exceed the limitations) is often raised. Comments often suggest that EPA include a provision that a facility is in compliance with permit limitations if its discharge does not exceed the specified limitations, with the exception that the discharge may exceed the monthly average limitations 1 month out of 20 and the daily average limitations 1 day out of 100. This issue was, in fact, raised in other rules, including EPA’s final Organic Chemicals, Plastics, and Synthetic Fibers (OCPSF) rulemaking. EPA’s general approach in that case for developing limitations based on percentiles was the same as this rule and was upheld in Chemical Manufacturers Association v. U.S. Environmental Protection Agency, 870 F.2d 177, 230 (5th Cir. 1989). The Court determined the following:

> EPA reasonably concluded that the data points exceeding the 99th and 95th percentiles represent either quality-control problems or upsets because there can be no other explanation for these isolated and extremely high discharges. If these data points result from quality-control problems, the exceedances they represent are within the control of the plant. If, however, the data points represent exceedances beyond the control of the industry, the upset defense is available.

Additionally, this issue was raised in EPA’s Phase I rule for the pulp and paper industry. In that rulemaking, EPA used the same general approach for developing limitations based on percentiles that it had used for the OCPSF rulemaking and for the proposed CAAP rule. This approach for the monthly average limitation was upheld in National Wildlife Federation et al. v. Environmental Protection Agency, 286 F.3d 554, 573 (D.C. Cir. 2002). The Court determined that:

> EPA's approach to developing monthly limitations was reasonable. It established limitations based on percentiles achieved by facilities using well-operated and controlled processes and treatment systems. It is therefore reasonable for EPA to conclude that measurements above the limitations are due to either upset conditions or deficiencies in process and treatment system maintenance and operation. EPA has included an affirmative defense that is available to mills that exceed limitations due to an unforeseen event. EPA reasonably concluded that other exceedances would be the result of design or operational deficiencies. EPA rejected Industry Petitioners' claim that facilities are expected to operate processes and treatment systems so as to violate the limitations at some pre-set rate. EPA explained that the statistical methodology was used as a framework to establish the limitations based on percentiles. These limitations were never intended to have the rigid probabilistic interpretation that Industry Petitioners have adopted. Therefore, we reject Industry Petitioners' challenge to the effluent limitations.

As that Court recognized, EPA's allowance for reasonably anticipated variability in its effluent limitations, coupled with the availability of the upset defense, reasonably accommodates acceptable excursions. Any further excursion allowances would go beyond the reasonable accommodation of variability and would jeopardize the effective control of pollutant discharges on a consistent basis and/or bog down administrative and enforcement proceedings in detailed fact-finding exercises, contrary to congressional intent. See, for example, Rep. No. 92-414, 92d Congress, 2d Sess. 64, reprinted in *A Legislative History of the Water Pollution Control Act Amendments of 1972* (at 1482); *Legislative History of the Clean Water Act of 1977* (at 464-65).

More recently, for EPA's rule for the iron and steel industry, EPA's selection of percentiles was upheld in American Coke and Coal Chemicals Institute v. Environmental Protection Agency, 452 F.3d 930, 945 (D.C. Cir. 2006). The Court determined that

> The court will not second-guess EPA's expertise with regard to what the maximum effluent limits represent. See Nat'l Wildlife, 286 F.3d at 571-73. As EPA explains in the Final Development Document, the daily and monthly average effluent limitations are not promulgated with the expectation that a plant will operate with an eye toward barely achieving the limitations. Final Development Document at § 14.6.2. Should a plant do so, it could be expected to exceed these limits frequently because of the foreseeable variation in treatment effectiveness. Rather, the effluent limitations are promulgated with the expectation that plants will be operated with an eye towards achieving the equivalent of the LTA for the BAT-1 model technology. *Id.* However, even operated with the goal of achieving the BAT-1 LTA, a plant's actual results will vary. EPA's maximum daily limitations are designed to be forgiving enough to cover the operations of a well-operated model facility 99% of the time, while its maximum monthly average limitations are designed to be forgiving enough to accommodate the operations of a well-operated model facility 95% of the time. See id. EPA's choice of percentile distribution represented by its maximum effluent limitation under the CWA represents an expert policy judgment that is not arbitrary or capricious.

EPA expects that sites will comply with promulgated limitations *at all times*. If the exceedance is caused by an upset condition, the site would have an affirmative defense to an enforcement action if the requirements of 40 CFR 122.41(n) are met. If the exceedance is caused by a design or operational deficiency, EPA has determined that the site's performance does not represent the appropriate level of control (best available technology for existing sources; best available demonstrated control technology for new sources). For other promulgated limitations and standards, EPA has determined that such exceedances can be controlled by diligent process and wastewater treatment system operational practices such as frequent inspection and repair of equipment, use of backup systems, and operator training and performance evaluations. For this effluent guideline, EPA has provided reasonable relief from the effects of large storm events by requiring that the limitation only apply to discharges on days with precipitation less than the local 2-year, 24-hour storm event.

6.13. SUMMARY OF STEPS USED TO DERIVE THE LIMITATIONS

This section summarizes the steps used to derive the limitations for turbidity:

Step 1 EPA calculated daily averages from the individual measurements for each treatment system.

Step 2 EPA calculated the *system-specific long-term averages* and *daily variability factors* for each of the 25 systems that had the model technology.

Step 3 EPA calculated the *long-term average* of 64.13 NTU as the median of the site long-term averages. (See Table 6-5.) EPA expects that all sites subject to the limitations will design and operate their treatment systems to achieve the long-term average performance level on a consistent basis.

Step 4 EPA calculated the *variability factor* of 4.322 as the mean of the system-specific variability factors. (See Table 6-6.) If a site operates its treatment system to meet the relevant long-term average, EPA expects the site to be able to meet the limitations. The variability factor assures that normal fluctuations in a site's treatment are accounted for in the limitation. By accounting for these reasonable excursions above the long-term average, EPA's use of variability factors results in limitations that are generally well above the actual long-term averages.

Step 5 EPA calculated the *daily maximum limitation* of 280 NTU using the product of the long-term average (64.13 NTU) and the daily variability factor (4.322).

Step 6 EPA *compared* the daily maximum limitations to the site daily values used to develop the limitations. (See Table 6-9.) EPA usually performs this comparison to determine whether it used appropriate distributional assumptions for the data used to develop the limitations. This comparison considers whether the curves EPA used provide a reasonable *fit* to the actual effluent data or if there was an engineering or process reason for an unusual discharge. Although the fact that the Agency performs such an analysis before promulgating limitations might give the impression that EPA expects occasional exceedances of the limitations, this conclusion is incorrect. EPA promulgates limitations that facilities are capable of complying with at all times by properly operating and maintaining their treatment technologies. After performing an engineering evaluation of the larger values, EPA concluded that the limitation was reasonable.

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7. TECHNOLOGY ASSESSMENT

This technology assessment is intended to determine the amount and quality of data available to describe the performance of site runoff control practices, the ability of each practice to effectively control the effects of runoff, and the design criteria or standards used to size each practice to ensure effective control of runoff.

7.1. REVIEW OF HISTORICAL APPROACHES TO EROSION AND SEDIMENT CONTROL (ESC)

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 stormwater, using aboveground cover management, residue management, strip cropping, and terracing to limit the length of overland flow. Effects on 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; total suspended solids (TSS) standards of 35 milligrams per liter (mg/L) average and 70 mg/L peak were also promulgated but were not typically enforced. The U.S. Environmental Protection Agency (EPA) later evaluated the TSS standard and moved to a settleable solids standard of 0.5 mL/L because a modeling effort 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 best management practices (BMPs) and standards for their construction (USEPA 1971). In general, those 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 stormwater discharges from urban areas. The Phase I National Pollutant Discharge Elimination System (NPDES) stormwater regulations were published in 1990, requiring all municipalities with municipal separate storm sewer systems 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 stormwater pollution prevention plan (SWPPP) that typically included a stormwater and sediment control plan. In 1999 the Phase II NPDES stormwater 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 past 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 effects of increased construction on stormwater and chemical production. Much of the government concern originated from the Phase I and Phase II NPDES stormwater 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 effects of surface area on the trapping efficiency in sediment ponds. On the basis of 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 stormwater and sediment control, following the example of South Carolina.

There are no examples in which an integrated approach to stormwater and sediment control has 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. Note 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. That 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). Those 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 et al. 1999), 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 effect of reservoirs (Ward et al. 1977; Wilson and Barfield 1984), check dams (Hirschi 1981), and vegetative filter strips (Hayes et al. 1984). The MUSLE, SEDCAD, and SEDIMOT II models were based on single storms, while the CREAMS model was based on continuous simulation modeling. Details on those models are 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 before 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 affected by changes in flow.

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

7.2. CONTROL TECHNIQUES

The following section presents a discussion of the commonly used ESC practices. Information on applicability, design and installation criteria, maintenance considerations and effectiveness are presented, when available. This section does not discuss proprietary and vendor-supplied BMPs, many of which are variations of conventional BMPs such as sediment barriers, filters, and erosion control and prevention practices.

7.2.1. EROSION CONTROL AND PREVENTION

7.2.1.1. Planning, Staging, Scheduling

General Description

A construction sequence schedule is a specified work schedule that coordinates the timing of land-disturbing activities and installing ESC 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 ESC 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 begin 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 ESC 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 ESC 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 7-1 summarizes other important scheduling considerations in addition to those listed above.

Table 7-1. Scheduling considerations for construction activities

Construction activity	Schedule consideration
Construction survey stakeout	Before 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.
Preconstruction meeting with owner, contractor, and regulatory agency	The 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 installing controls	In conjunction with the construction access, the clearing and grading required for installing ESCs 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 installing principal sediment traps and before land grading. Additional runoff control measures can 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 can 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 installing 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 ESC 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 ESC 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 shows a 42 percent reduction in sediment export in the phased project (Claytor 1997).

Limitations

Weather and other unpredictable variables can affect construction sequence schedules. The proposed schedule and a protocol for making changes resulting from unforeseen problems should be plainly stated in an applicable ESC plan.

Maintenance

The construction sequence should be followed throughout the project, and the written ESC 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 ESC 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 coordinating construction activities and management practices. Additional time might be needed to update the sequencing plan if the current plan is not providing sufficient ESC.

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

7.2.1.2. 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 stormwater 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 could 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 effects 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 might increase runoff infiltration, they cannot remove soil moisture beyond the surface level, leaving slopes potentially saturated and prone to slippage. Shallow, interlocking root systems could 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 can 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 can 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 might influence vegetation projects in a wetland environment (USAF 1998).

Vegetation used for shoreline stabilization work should be native material selected because 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.

Most tree revetment projects use 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. Using vegetative material for streambank stabilization could be the first step in reestablishing 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 of protecting 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 et al. 1988). Table 7-2 includes general guidelines for maximum allowable velocities in streams to be protected by vegetation.

Table 7-2. 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 et al. 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 might not be effective in arid or semi-arid regions where seasonal lack of moisture prevents germination. It might 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 could 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 the following (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 subsections discuss the various types or means of providing vegetative stabilization.

Grass-lined Channels

General Description

Grass-lined channels, or swales, convey stormwater 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. The U.S. Department of Agriculture's (USDA's) Soil Conservation Service's (SCS) *Engineering Field Manual* (1979) recommends the maximum permissible velocities for individual site conditions shown in Table 7-3.

Table 7-3. 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 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 meters (m), and channel depth of at least 30 centimeters (cm). Side slopes usually rise about 1 m for every 10 m horizontal distance but could 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 stormwater 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 stormwater 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 stormwater 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 effects 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 stormwater 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-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, 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.

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 BMP 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; considering soil characteristics; selecting 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 site. The soil on a disturbed site could 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. 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 might be necessary if the mulch is not otherwise anchored. Mulch as an erosion control practice is covered in a subsequent subsection.

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 regularly. Plants must be able to persist with minimal maintenance over long periods. 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 TSS from stormwater 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 ESC measures should be in place to prevent off-site transport of pollutants from disturbed areas. Use of mulches or geotextiles or both could 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 might 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, the installation costs increase. R.S. Means suggests the cost of fine grading, soil treatment, and grassing is approximately $2 per square yard.

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 stormwater 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 on local conditions as seeding is, 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 the following:

- 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. Because sod provides instantaneous cover, mulches are not typically recommended, but anchoring might 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 could 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 can 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 before 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 can 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 TSS in runoff (USEPA 1993). It is therefore a highly effective management practice for ESC.

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 1,000 square feet for 1-inch 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 1,000 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).

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 stormwater 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 they 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 might 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 7-4 presents guidelines for installing mulches, but local conditions could warrant additional requirements.

Table 7-4. 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; can 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 nontoxic agent.	Apply with compressed air ejector. Tack with emulsified asphalt at a rate of 25-35 gal/1,000 ft2 .

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 7-5 shows soil loss and water velocity reductions for different mulch treatments.

Table 7-5. 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 could 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 for various types of mulches vary by the type of material and also whether seeding is incorporated. The costs of seed and mulch average $1,500 per acre and range from $800 to

$3,500 per acre (USEPA 1993). Ground hydromulching applied between fiscal year 2000 and 2003 in the southwestern United States had a cost range of $1,675 to $3,000 per acre (Napper 2006). The California Stormwater Quality Association's (CSQA's) *Stormwater BMP Handbook: Construction* reports the average cost of installing wood fiber mulch as $900 per acre (CSQA 2003). R.S. Means (2000) estimates the cost of power mulching to be $22.50 per 1,000 square feet, for large volume applications.

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 stormwater 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 could be 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 stormwater 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, because 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 preventing flow from concentrating to maintain adequate the travel time through the buffer to allow 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 they are relatively ineffective in removing dissolved phosphorus (Gillman 1994). However, because the hydraulics of flow through buffer strips are not well defined and can vary considerably by 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 stormwater 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 on the basis of 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 applying traditional lawn seed. The cost for field seed is lower than lawn seed, reducing the coverage price. Where gently sloping areas need to be grassed only with acceptable species, the cost can be as low as $0.38 per square yard.

7.2.1.3. Non-Vegetative Stabilization

Non-vegetative practices can also 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 stormwater pollutants. Non-vegetative stabilization techniques operate on the same principles as vegetative stabilization; however, these practices use a variety of synthetic on natural materials (such as coconut fiber) to stabilize exposed soils. Non-vegetative practices are particularly useful as temporary stabilization measures until vegetative practices have had a chance to become established. The following discussion refers to non-vegetative stabilization as a construction BMP that stabilizes and protects soil from erosion. A variety of proprietary and vendor-supplied materials are in this category, which are not discussed in detail.

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 such 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 can 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 on 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 before installation. Some geotextiles might promote increased runoff and can 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 can 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).

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. That 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 should be placed in the channel or on the slope parallel to the direction of flow and secured with staples and check slots. It should be 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 should be 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 should be 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. TRMs 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. That gives the established turf a higher strength and resistance to erosion (USDOT 1995).

ECRMs 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 permanent mulch and allow vegetation to grow through the mat (USDOT 1995).

Effectiveness

The effectiveness of erosion control matting depends on 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. That ensures 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 1999), 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 its 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 that reason must be protected before 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 could be reduced if the matting is not properly selected, designed, or installed.

Maintenance

Regular inspections are necessary to determine whether cracks, tears or breaches have formed in the matting. 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 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 (ECTC—a geotextile industry support association) estimates that TRMs cost approximately $7.00 per square yard (installed) for channel protection (Lancaster et al. 2002). 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 (Honnigford 2002).

USDA's *Burned Area Emergency Response (BAER) Treatment Catalog* reports that most rolled erosion control products are priced by the square yard and sold in rolls with prices, without installation, ranging from $0.35 to $0.50 per square yard to more than $1 per square yard (Napper 2006). CSQA's *Stormwater BMP Handbook: Construction* reports material costs of $0.50 to $0.57 per square yard for biodegradable materials, $3.00 to $4.50 per square yard for permanent materials, and $0.04 to $0.05 per staple (CSQA 2003). The installation cost for jute mesh, 100 square yards per roll, 4 inches wide, stapled is $0.49 per square yard (R.S. Means 2009).

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, 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 are 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 7-6 summarizes the cubic yards of topsoil required for application to various depths.

Table 7-6. 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 could be left rough after spreading topsoil. A disk can 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 the 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) reports unit cost values of $3 and $4 per square yard, for 4 and 6 inches of topsoil cover, respectively. That price is for furnishing and placing of topsoil, and includes materials, labor, and equipment, with profit and overhead.

7.2.2. WATER HANDLING PRACTICES

7.2.2.1. 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. The 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 before 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 might 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 could be required to control erosion. Slopes greater than 8 percent could require riprap. Dikes can be removed when the drainage area and outlet are stabilized (NAHB, No Date). Dike design criteria must incorporate site-specific conditions because dimensions depend on expected flows, soil types, and climatic conditions. All such inputs vary tremendously across 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 might 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 erosion occurs 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 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. Earth dikes 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). On the basis of that 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. That suggests that the size of the dike is required before specifying a cost, which requires a site-specific hydrologic evaluation. On the basis of standards for Virginia, most small drainage areas (made up of 5 acres 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, 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. That adds approximately $6 per linear foot of dike. Where gently sloping areas need to be grassed only with acceptable species, the cost can be as low as $0.38 per square yard.

7.2.2.2. 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 stormwater runoff for a specified water quality volume. As stormwater runoff flows through such channels, it is treated by filtering through the vegetation in the channel, filtering through a subsoil matrix, 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 1.97 acres (0.8 hectare) and usually work best on gently sloping terrain. Perimeter dikes might 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.

Stormwater Hot Spots. Stormwater hot spots are areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those commonly found in stormwater. 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. Such practices either infiltrate stormwater or intersect the ground water, making use of the practices for hot spot runoff a threat to ground water quality.

Stormwater Retrofit. A stormwater retrofit is a stormwater 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 stormwater away from roads as quickly as possible. In some cases, it might 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). Because 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. Such 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.

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 because of 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 stormwater treatment through infiltration and filtration.

Slope. Grassed swales should be used on sites with relatively flat slopes (less than 4 percent). Runoff velocities in the channel become too high on steeper slopes. That 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 in 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 stormwater 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 subsection 7.2.1.2, under *Grass-lined Channels*) 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 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 stormwater 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 stormwater 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. On the basis of 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 is in *Design of Storm Water Filtering Systems* (CWP 1996).

Dry Swales. Dry swales are similar in design to bioretention areas. Such 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. The system is a gravel layer that encases a perforated pipe. Stormwater treated in the soil bed flows through the bottom into the underdrain, which conveys the treated stormwater 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. Such a design variation incorporates a shallow, permanent pool and wetland vegetation to provide stormwater treatment. The 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 property owners sometimes view the shallow, standing water in the swale as a nuisance.

Regional Variations

Cold Climates. In cold or snowy climates, swales can serve a dual purpose by acting as both a snow storage/treatment practice and a stormwater 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 stormwater runoff volume passes through the swale and infiltrates into the soil. Table 7-7 summarizes grassed swale pollutant removal efficiencies.

Table 7-7. Grassed swale pollutant-removal efficiency data

Study	Grassed swale removal efficiencies						
	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
Yousef et al. 1985	--	8	13	11	14–29	--	Drainage channel
Yousef et al. 1985	--	-19.5	8	2	41–90	--	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 swale 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 can 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 the practices to function properly.

Maintenance

As with any BMP, swales must be maintained to continue to effectively remove pollutants. Maintenance can 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, 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 7-8 summarizes additional costs of grass swales.

Table 7-8. Average annual operation and maintenance costs for a grass swale

Component	Estimated unit cost ($)	$ for swale size: 0.5m deep 0.3m bottom width 3m top width	$ for swale size: 1m deep 1m bottom width 7m 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.

7.2.2.3. 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. Such a 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 stormwater 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

Because 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 that 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 ESC 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

Installing temporary storm drain diversion can 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. Installing an outlet stabilization structure is typically required and can 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 removing 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 labor costs for installation and removal of the system, all of which could involve excavation, re-grading, and inspections. Because of 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-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 combine to add approximately $200 per pipe installation, based on $25 per cubic yard of stone (R.S. Means 2000).

7.2.2.4. 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, the 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. The 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 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 7-9 (NAHB, No Date).

Table 7-9. 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 stormwater 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 placed 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 on the basis of 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 could empty into a sediment trap (USDOT 1995). Table 7-10 summarizes slope drain characteristics.

Table 7-10. Slope drain characteristics

Capacity	2-year frequency, 24-hour-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-foot depth, 4-foot top width, and 6 inches 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 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. Overtopping of the inlet is a common slope drain problem because of an undersized or blocked pipe or erosion at the outlet point from insufficient protection (UNEP 1994). Other common failures caused by overtopping are from inadequate pipe inlet capacity and reduced diversion channel capacity and ridge height, as well as the following:

- Overtopping because the drainage area might 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.
- Washout—A washout along a pipe from seepage and piping can be caused by inadequate compaction, insufficient fill, or installation that might be too close to the edge of the slope.
- 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).

7.2.2.5. 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 sediment is able to settle out of the water column. Check dams can be constructed of stone, gabions, treated lumber, or logs (NAHB, No Date). Recent work by Dr. Richard McLaughlin involves the use of fiber check dams installed at grade with polyacrylamide (PAM) applied to the check dam (McLaughlin 2009) and PAM blocks on the downhill side of triangular silt dikes (McLaughlin, No Date b)for passive dosing to greatly reduce turbidity.

Check dams are inexpensive and easy to install. They can be used permanently to settle sediment, reduce the velocity of runoff, and provide aeration. Check dams are often used in combination with other practices, such as sediment traps or basins.

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 time and 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. They should not be built in stream channels, either intermittent or perennial (UNEP 1994). Check dams can be effective sediment trapping devices when designed appropriately.

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 because they can 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 can 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. Such a 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 that 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.

Dr. Richard McLaughlin reports dramatic turbidity reductions using fiber check dams with PAM, to levels below 200 nephelometric turbidity units (NTUs) and in some cases to below 50 NTUs. McLaughlin also reports reductions when PAM is added to conventional rock check dams (McLaughlin, No Date a). McLaughlin (2009) states that fiber check dams are much more effective than rock check dams, according to data presented in the study. For summaries of studies with monitoring data, and annotated bibliographies for the journal articles and professional conference proceedings that EPA reviewed, see DCN 43114.

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 standalone substitute for other sediment-trapping devices. Also, leaves have been shown to be a significant problem because 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 from accumulated sediment and debris. When designing check dams, because they reduce the capacity of a channel to transmit stormwater runoff and, thus, need to be sized appropriately should be taken into account (UNEP 1994). The check dam could 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 might 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 stormwater flow. In addition, the center of a check dam should always be lower than its edges. Additional stone might 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, take care 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 according to 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) estimate 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, might be a less expensive alternative, but they could require higher maintenance costs. McLaughlin estimates that fiber check dams are comparable in cost to stone check dams, however installation costs can be much lower because fiber check dams can be positioned and staked in place by hand (stone check dams usually require a backhoe or other equipment to install) (McLaughlin, personal communication). Fiber check dams will likely require periodic replacement for longer-duration projects. Costs for PAM addition to check dams is minimal, with a new application required every few storm events. Application is done by hand, and a predetermined quantity of dry PAM is simply applied to the surface of the check dam. McLaughlin (2009) reports costs for installation and maintenance for standard BMPs (stone check dams with preceding excavations) and fiber check dams with and without PAM at two linear road projects in North Carolina. The installation cost per linear meter was $6.50 (site 1) and $5.74 (site 2) for standard BMPs, $5.59 (site 1) for fiber check dams only, and $4.33 (site 1) and $5.35 (site 2) for fiber check dams with PAM. The cost per maintenance action was $416 at each site for the standard BMPs and $74 to $79 for fiber check dams with PAM.

7.2.2.6. Lined Waterways

General Description

Lined channels convey stormwater 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 stormwater 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 would 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 that reduces runoff velocity and provides water quality benefits through filtration and infiltration. If the velocity in the channel would erode the grass or sod, one can use riprap, concrete, or gabions (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. Such 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 on 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 can 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 could require using straw mulch and installing 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 can 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 stormwater 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 stormwater 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 stormwater 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 effects 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 stormwater conveyance.

Common problems in lined channels include channel erosion 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-foot-deep, 21-foot-wide grassed channel is estimated at $12,909 to $33,404 per trench (SWRPC 1991).

EPA also refers readers 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 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 that TRMs cost approximately $7.00 per square yard (installed) for channel protection (Lancaster et al. 2002). R.S. Means indicates that 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 those riprap sizes (assuming depth of riprap is 1.5 times the maximum size). Such 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).

7.2.3. 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 it 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 effects 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 applying 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 effects 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). Because the aggregates have higher settling velocities than primary particles, the degree of aggregation that is present has a large effect 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).

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

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

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

7.2.3.1. Silt Fence and Compost Filter Berms/Socks

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. Compost filter berms and socks can also be used in lieu of silt fences. A compost filter berm is a dike of compost or a compost product that is placed perpendicular to sheet flow runoff to control erosion in disturbed areas and retain sediment. A compost filter sock is a mesh or geotextile tube filled with composted material. Compost filter berms are commonly used as perimeter controls, and are sometimes used in combination with silt fence to provide redundant control of perimeter ditch.

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 on the basis of design storms and local hydrologic conditions so that the silt fence is not expected to overtop. A typical design calls for no greater than one-quarter acre of drainage area per 100 feet of fence, but that is highly variable, depending on climate. The fence should be stable enough to withstand runoff from a 10-year peak storm. Table 7-11 lists the maximum slope length specified by the U.S. Department of Transportation (USDOT). The slope lengths should be based on sediment load and flow rates. That would mean that the values given below should be adjusted for climatic conditions instead of *one size fits all* to ensure maximum effectiveness.

Table 7-11. 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 (30 m)	250 ft (75 m)
10	50 ft (15 m)	150 ft (45 m)
20	25 ft (8 m)	70 ft (21 m)
25	20 m (6 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 (3 m)	25 ft (8 m)

Source: USDOT 1995.

Typical standards and specifications call for the silt fence to be on fairly level ground and follow the land contour, although it is recognized that a slight slope can 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 could 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
- Selecting appropriate installation criteria such that the silt fence performs 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 with 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 use 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, depending on the opening size and size of the sediment (Britton et al. 2001; Wyant 1980; Barrett et al. 1995; Fisher and Jarrett 1984). Thus, results from model studies to date are suspect and need to be modified to account for the effects 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} of the eroded sediment, divided by the ratio of discharge to ponded surface area.[3] 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 affect 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 gallons per minute (gpm) per sqare foot. On the basis of 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

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[3] 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.

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 according to 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.
- 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 on the basis of 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 presented in Table 7-12.

Table 7-12. 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 gallons/square feet/minute
Water Flow Rate	15 gallons/square feet/minute	220 gallon/square feet/minute
UV Resistance	70%	85%

Source: NCDNR 1988; IDNR 1992.

Note that those numbers, particularly the flow rates, can vary widely depending on the local soil condition because of 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 according to local wet soil strength characteristics. Some standards and specifications for the 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 continuously from a single roll of fabric 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 on the basis of 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, the spacing depends 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 for 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 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 because of inadequate *toe-ins*
- Silt fence damaged and partially covered by the temporary placement of stockpiles of materials

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 TSS 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, 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 such as 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 ESC practices). In addition, the silt fence visibility makes site inspection easier for contractors and government inspectors (CWP 1996).

EPA's *National Menu of Best Management Practices for Stormwater Phase II* reports that compost filter socks and berms are at least as effective as other traditional ESC BMPs in controlling sediment; however, the results of the studies vary depending on the site conditions (USEPA 2008).

Limitations

Silt fences should not be installed along areas where rocks or other hard surfaces prevent uniform anchoring of fence posts and entrenching of the filter fabric. An insufficient anchor greatly reduces their effectiveness and might create runoff channels. In addition, open areas where wind velocity is high could present a maintenance challenge because high winds can 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 stormwater from the pools that 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 that 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 could fail from a sudden storm event.

Cost

There is a wide range of data on installation costs for silt fences. EPA estimates the costs at approximately $6.00 per linear foot (USEPA 1992) while Southeastern Wisconsin Regional Planning Commission (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). Those values are significantly greater than that reported by R.S. Means (2000), which indicates a 3-foot-tall silt fence installation costs between $0.68 and $0.92 per linear foot (for favorable and challenging installations). Note that the R.S. Means value covers only installation, without the expected costs of maintenance (e.g., removal of collected sediment). In addition, the type of silt fence fabric employed also affects the total installation costs.

The Texas Commission on Environmental Quality reports that the cost of a 12-inch diameter compost filter sock ranges from $1.40 to $1.75 per linear foot when used as a perimeter control (McCoy 2005). The costs for an 18-inch diameter sock used as a check dam range from $2.75 to $4.75 per linear foot (McCoy 2005). Those costs do not include the cost of removing the compost filter sock and disposing of the mesh after construction ends; however, filter socks are often left on-site to provide slope stability and post-construction stormwater control. The cost to install a compost filter sock varies, depending on the availability of the required quality and quantity of compost and the availability of an experienced installer (USEPA 2008).

The Texas Commission on Environmental Quality reports that compost filter berms cost $1.90 to $3.00 per linear foot when used as a perimeter control and $3 to $6 per linear foot when used as a check dam (McCoy 2005). The Oregon Department of Environmental Quality reports that compost filter berms cost approximately 30 percent less to install than silt fences (ODEQ 2004). Those costs do not include the cost of removal and disposal of the silt fence or the cost of dispersing the compost berm after construction ends. The cost to install a compost filter berm varies, depending on the availability of the required quality of compost in an area (USEPA 2008).

7.2.3.2. Super Silt Fence

General Description

Super silt fence is a modification of a standard silt fence. The two main differences between the standard silt fence and the super silt fence is that the super silt fence has a 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 installing 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 7-13 lists the distance a super silt fence should be from a slope to ensure maximum effectiveness (MDE 1994).

Table 7-13. 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
- Selecting appropriate installation criteria such that the silt fence performs as designed.

Hydrologic Design

Hydrologic design criteria are the same as those 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 7-14 describes the physical properties of Geotextile Class F fabric (MDE 1994).

Table 7-14. Minimum requirements for super silt fence Geotextile Class F fabric

Physical properties	Requirements
Tension strength	50 pounds/inch
Tensile modulus	20 pounds/inch
Flow rate	0.3 gallon/ft^2/minute
Filtering efficiency	75%

Effectiveness

EPA did not identify any performance data for super silt fences.

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.

7.2.3.3. 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 7-15 lists the distance a straw bale dike should be placed from a slope to ensure maximum effectiveness.

Table 7-15. 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 is 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 dike (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, on the basis of visual observations, that sediment clogs 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 effect of clogging on flow rate.

Installation Criteria

The USDOT’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
- Sized so that impounded water depth does 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 one-quarter acre per 100 feet of dam and the total drainage area draining to a straw bale dike to 2 acres.

Effectiveness

The information on straw bale dikes performance is very limited. In laboratory studies of bales at varying orientations, Kouwen (1990) found that trapping efficiencies range from 60 to 100 percent. While field data on trapping have not been collected, bales deteriorate rapidly and need to be replaced frequently. Because of such problems, using straw bale dikes as a perimeter control is not recommended, except in special circumstances. Only 27 percent of ESC experts rate the straw bale dike as an effective ESC practice, although their use is 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 such conditions, erosion around the end of the bales, overtopping and undercutting of the bales, and bale collapsing and dislodging are likely to occur. Overtopping also occurs if the storage capacity is underestimated and where provisions are not made for safe bypass of storm flow (IDNR 1992). Undercutting occurs if the bales are not entrenched at least 4 inches and backfilled with compacted soil or are 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 is relatively low, making their use attractive. R.S. Means (2000) indicates a staked straw bale unit cost of $2.61 per linear foot (including materials, labor, and equipment, with profit and overhead).

7.2.3.4. 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 or embankments or both constructed at designated locations accessible for cleanout. The outlet for a sediment trap is typically a porous rock fill structure that detains the flow, but a pipe structure can also be used. A temporary sediment trap can placed be in a drainageway, at a storm drain inlet, or at other points of discharge from a disturbed area. They can be constructed independently or in conjunction with diversions and can be used in most drainage situations to prevent excessive siltation of pipe structures (USEPA 1992).

Applicability

Sediment traps can simplify the stormwater 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 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 potential overflows. Traps should be accessible for clean-out and placed 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. That 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 selecting 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. Such 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. (1988) specify 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 that 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 effect 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 affected by clogging. That 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. Those values might 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 on the basis of the contributing drainage area (Table 7-17) (USDOT 1995). The outlet apron should be a minimum of 5 feet long, and placed 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 on the basis of 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, USDOT has specified the weir length for a given drainage area as shown in Table 7-16. However, the values should be adjusted for each climatologic area to account for local hydrologic and return period rainfall.

Table 7-16. 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 1983), Stahre and Urbonas (1990), and Haan, et al. (1994), reports that sediment basins effectively trap sediment and chemicals as shown in Table 7-17.

Table 7-17. 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 those 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 stormwater 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 7-18.

Table 7-18. Common concerns associated with sediment traps

Common concern	Result
Inadequate spillway size	Results in overtopping of the dam and possible failure of the structure
Omitted or improperly installed 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
Inadequate storage capacity	Results in a less than adequate settling time (can also be caused by an insufficient amount of sediment being removed from the basin)
Contact slope between stone spillway and earth embankment too steep	Results in piping failure
Outlet pipe installed in the vertical side of the trench	Results in piping failure of embankment
Corrugated tubing used as an outlet pipe	Results in crushed pipe and inadequate outlet capacity

Source: IDNR 1992.

Maintenance

The primary maintenance consideration for temporary sediment traps is removing 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 that 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 estimates 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) indicates 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).

7.2.3.5. Sediment Basin

General Description

A sediment basin is a stormwater 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 post-development flow to be less than or equal to predevelopment flow during construction could 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 stormwater 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. Such 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 stormwater 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 might be subject to additional regulation, particularly state and federal regulations related to dam safety.

Sediment basins can be used for any size watershed, but USDOT 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 on the basis of sediment yield using relationships such as the RUSLE with an appropriate delivery ratio (Renard et al. 1994) or a computer model such as SEDIMOT III (Barfield et al. 1996) or SEDCAD (Warner et al. 1999). Many design specifications, however, base the sediment storage volume on a volume per acre disturbed. For example, Pennsylvania specifies a sediment storage volume of 1,000 cubic feet per acre drained (see DCN 43050, *Pennsylvania Erosion and Sediment Pollution Control Program Manual*). This volume is highly site-specific, depending on rainfall distributions, soil types, and construction techniques.

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. USDOT, for example, recommends 67 cubic yards per acre (126 m^3/ha) (USDOT 1995). That standard has been adopted by many states as well. 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. Because 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 and 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 stormwater detention ponds (i.e., are used to limit future flooding due to stormwater). EPA's review of state construction site regulations found that 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 or expected runoff from the local 2-year, 24-hour storm event 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 and at a rate determined to trap the required amount of sediment 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 on the basis of 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. Because 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.

For discussion of skimmers in lieu of rock and perforated outlets in sediment traps and basins, see Section 7.2.3.6.

Emergency Spillway. Because 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 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, because 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 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. Because sediment trapping is inversely proportional to flow rate, the trapping efficiency will be affected 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 before 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) show that a surface area-to-peak discharge ratio of 0.01 acre per cubic foot would trap more than 75 percent of the sediment coming from the Coastal Plain and Piedmont regions in Maryland. That 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 effects 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 stormwater detention basins 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 (Jarrett 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.
- 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 (1.5-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 allows for more sediment deposition, decreases the sediment loss from the basin (Jarrett 1999).

Table 7-19 presents a summary of sediment basin monitoring or modeling data. Table 5-1 shows corresponding influent TSS data when available. For summaries of studies with monitoring or modeling data, and annotated bibliographies for the journal articles and professional conference proceedings that EPA reviewed, see DCN 44321.

Table 7-19. Studies of TSS in sediment basin effectiveness and effluent from construction sites

Site	Mean effluent TSS concentration (mg/L)	Mean TSS reduction (percent)	Source
Seattle, Washington	154	98.6%	Horner et al. 1990
SR 204	626	86.7%	Horner et al. 1990
Mercer Island	63	75.1%	Horner et al. 1990
SB1	322	54.7%	Schueler and Lugbill 1990
SB2	91	80.3%	Schueler and Lugbill 1990
SB4	875	66.8%	Schueler and Lugbill 1990
Pennsylvania Test Basin	800	94.2%	Jarrett 1996
Georgia Model	600	65%	Sturm and Kirby 1991
Maryland Model	700	84%	Barfield and Clar 1985
Hamilton County, Ohio	3,507	35%	Islam et al. 1998
Johnston County, North Carolina SkB1	1,042	87%	Markusic and McLaughlin 2008; McLaughlin and Markusic 2007.
Mean TSS (mg/L)	798	75%	N/A

N/A – Not Applicable

Limitations

Neither a sediment basin with an earthen embankment nor a rock dam should be used in areas of continuously running water (live streams). Using 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, such 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 7-20.

Table 7-20. 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	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 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 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 confirms the value of $0.30 per cubic foot (USEPA 2003). Annual maintenance costs are 25 percent of installation costs (Brown and Schueler 1997).

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 (that value includes a 100 percent surcharge for wet excavation). Disposal of material on-site will result in an additional cost that can be computed only 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.

7.2.3.6. Faircloth Skimmer

General Description

A Faircloth Skimmer® is a surface drain that floats on top of the water in a sediment basin. The skimmer inlet controls the rate of outflow and rises and falls as the basin fills and drains. It releases the cleanest water in the basin from near the surface. Although the Faircloth Skimmer is a proprietary device, the same concept applies to any device that withdraws water from the surface of the basin as opposed to dewatering through a perforated riser or stone outlet structure.

Applicability

A Faircloth Skimmer is used instead of the rock and perforated riser outlets in sediment traps and basins.

Design and Implementation Criteria

The Faircloth Skimmer can be attached directly to an outlet pipe that drains through the dam or attached to an outlet pipe through a riser. The key design parameters in sizing a Faircloth Skimmer is volume to drain and the length of time for the basin to drain. As the size of the skimmer increases, the basin drainage time decreases. Faircloth recommends 3 days in the absence of state specifications. North Carolina specifies 1 to 3 days and Pennsylvania 4 to 7 days.

Effectiveness

The skimmer allows water to be released from the top of the basin, which is the cleanest water (Faircloth 1999). EPA summarizes skimmer basin performance data from an active construction site in Johnston County, North Carolina (see DCN 44321).

Limitations

There are many factors in addition to a surface drain for a basin to be efficient. For limitations of sediment basins, see Section 7.2.3.5.

Maintenance

Routine inspection and maintenance of sediment basins with or without skimmers is essential to their continued effectiveness. For maintenance of sediment basins, see Section 7.2.3.5.

Cost

EPA obtained Faircloth Skimmer equipment and shipping costs and added costs for additional required ancillary equipment (e.g., PVC pipe, glue), as well as labor for installation. Assuming a 3-day drainage time, EPA developed the following cost equation:

Total skimmer cost (2009 dollars) = 0.0138 × (basin volume in cubic feet) + 1,049.

DCN 43113 documents the development of that cost equation.

7.2.3.7. Enhanced Sediment Trapping

General Description

Work in recent years has focused on a number of passive, PAM-based systems to enhance pollutant removal in sediment basins. Other chemicals used in such passive systems include chitosan acetate, chitosan lactate, gypsum, and alum. PAM, available in *floc logs*, has also seen increased placement in conveyance channels. Chitosan lactate *gel socks* have also been used in that application. As water flows through the channel, the chemical dissolves, and the turbulence in the channel aids in the flocculation process. Flocs can then settle out in sediment control devices, such as check dams, sediment traps or basins. PAM (and other flocculants) can also be added in liquid form to stormwater and is commonly used to dose sediment basins to help remove sediment. For discussion of fiber check dams installed at grade with PAM applied to the check dam for passive dosing, see Section 7.2.2.5. At least one vendor is also using a tube settler coupled with polymer addition before filtration to help remove sediment.

Applicability

Treatment chemicals can enhance sediment removal when traditional BMPs are not capable of meeting numeric standards (e.g., because of fine-grained, suspended sediment or colloidal particles, or a retention device design is not optimal because of site limitations). Auckland Regional Council (2004) notes that passive treatment using flock blocks requires no power and is less expensive and less complex than active systems.

Design and Implementation Criteria

For information on commonly available coagulant/flocculants and toxicity information, see Section 7.2.5.

Effectiveness

McLaughlin demonstrated the ability to meet a 50-NTU limit at a research site in North Carolina by adding PAM to a basin equipped with baffles and a surface skimmer (see DCN 43082, *The Potential for Substantial Improvements in Sediment and Turbidity Control*). North Carolina now requires skimmers on all sediment basins, and the North Carolina Department of Transportation has developed draft standards for the use of porous baffles in sediment basins (see DCNs 43083 and 43045, NCDOT draft baffles standards and North Carolina Erosion and Sediment Control Planning and Design Manual with requirements for skimmers). Bhardwaj and McLaughlin (2008a) found that both active and passive-dosed PAM systems significantly reduced turbidity, with the active dosing being slightly more effective. Bhardwaj and McLaughlin (2008a, 2008b) and McLaughlin (2006) reports that basin modifications (e.g., baffles, outlet type) have minor effects on turbidity in comparison to PAM addition. For summaries of studies with monitoring data and annotated bibliographies for the journal articles and professional conference proceedings that EPA reviewed, see DCN 43114.

Limitations

McLaughlin (2006) reports that blocks that were allowed to dry were much less effective. McLaughlin (No Date b) notes that blocks in ditches without slope tend to become buried more easily than blocks placed in stepper ditches. Auckland Regional Council (2004) notes that the primary disadvantage of the passive blocks is that the exact dosage is unknown, dependent on flow and condition of the block.

Maintenance

Routine inspection and maintenance of BMPs with or without passive chemical treatment is essential to their continued effectiveness.

Cost

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 at a large airport construction project amounted to $90,000, although the author notes that costs for some of the initial piping might have been unwarranted. Monthly expenses average $18,000 for operations and maintenance and $13,000 for materials and equipment, but the author notes that high monthly costs were driven by record rainfall and extremely wet weather experienced. The author states that “passive dosing systems being tested as a complementary BMP present considerable cost savings and may provide similar effectiveness.” The total costs for this phase totaled about $245,000, less than 1 percent of total construction costs. Auckland Regional Council (2004) reports a total cost of approximately $2,400 per installation for a rainfall-driven, liquid dosing system that does not require flow runoff measurement or a dosing pump.

7.2.4. OTHER CONTROL PRACTICES

7.2.4.1. 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 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 or flow rate to pass the design storm; and selecting appropriate installation criteria such that the stone outlet performs 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 can 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 one-half acre.

7.2.4.2. 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, stormwater 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 could 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 because of 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 can 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 two times the size selected in Table 7-21 (MDE 1994).

- Thickness: Riprap specification values are summarized in Table 7-21.

Table 7-21. Riprap sizes and thicknesses

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

Source: USDOT 1995

- 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 can 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 can 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 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 should 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 can 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 would 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 so as 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

No information is available 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 could 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 could 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 (which 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. Those costs include all costs of materials, labor, and installation.

7.2.4.3. 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. That 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 can relocate sump pits to optimize use, but discharge location changes should be coordinated with inspectors.

A perforated, vertical standpipe should be wrapped with 1/2-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 1/2-inch hardware cloth and geotextiles. The perforations should be 1/2-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

No information is available on the effectiveness of the sump pit.

Limitations

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

Maintenance

To maintain performance, 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 assessing a wide range of dewatering scenarios (i.e., different sump sizes, dewatering durations, and discharge conditions). In general, installing 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.

7.2.4.4. Sediment Tank

Description

A sediment tank is a compartmented container through which sediment-laden water is pumped to trap and retain sediment before 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

No information is available on the effectiveness of sediment tanks.

Limitations

The sediment tank does not provide any natural infiltration; thus, the trapped sediment and stormwater 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

No information is available on the cost of sediment tanks.

7.2.4.5. 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 off-site 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 a 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, stabilizing construction site entrances might not be very effective unless a wash rack is installed and routinely used (Corish 1995), although that 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 can still be deposited from vehicle tires onto paved surfaces. To further reduce the chance that sediments will pollute stormwater 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 such a case, water might 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 off-site 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).

7.2.4.6. 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 should be prepared that establishes which areas of the site will be graded, how drainage patterns will be directed, and how runoff velocities will affect receiving waters. 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 stormwater 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 stormwater 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 stormwater management and ESC 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 stormwater patterns can 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 ESC and stormwater 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 ESC practices should be periodically checked, especially after heavy rainfalls. All sediment should be promptly removed from diversions or other stormwater conveyances. If washouts or breaks occur, they should be repaired immediately. Prompt maintenance of small-scale, eroded areas is essential to prevent them from becoming significant gullies.

Cost

Land grading is practiced at virtually all construction sites—additional site planning to incorporate stormwater and ESCs 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 stormwater, 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.

7.2.4.7. 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 could 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. 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 can 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, excavating 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, rates are probably on the order of 20 to 50 percent of the bridge (permanent) cost but will vary according to the rental duration and mobilization distance.

7.2.4.8. 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 (WDEC 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 (WDEC 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 before 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 site. The owner, operator, and contractors responsible for dust control should determine which practices accommodate their needs on the basis of 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 7-22 shows application rates for some common spray-on adhesives as recommended by Smolen et al. (1988).

Table 7-22. Application rates for spray-on adhesives

Spray on adhesive	Water dilution	Type of nozzle	Application (gal/acre)
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: Mulch can reduce wind erosion by up to 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 could require near constant attention. If water is applied in excess, runoff can result from the site and possibly create conditions where vehicles can 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 can contaminate ground water if infiltrated. Chemical applications can 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 regularly to ensure that 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 estimates 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.

7.2.4.9. 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, such measures are temporary controls that are implemented before large-scale disturbance of the surrounding site. The 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 as follows:

- 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 stormwater drop inlet protection can also be achieved using 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 stormwater entry to the inlets and capture sediments from erosion. This final inlet protection measure can be used as an aesthetically pleasing way to slow stormwater 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). The technique shows good results on initial tests, trapping more than 50 percent of the incoming sediment in flows typical of those into urban storm drains. The 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 before disturbing 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 stormwater control techniques.

Design and Installation Considerations

Hydrologic Design

Hydrologic computations are not necessary with present technologies. A specified limitation of one drainage acre per inlet limits flow rates, depending 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 stormwater 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 standalone 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, stormwater 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 periodically.

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 can 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 SWRPC has estimated that the cost of installing inlet protection devices ranges from \$106 to \$154 per inlet (SWRPC 1991).

7.2.4.10. 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.

The effectiveness of PAMs to prevent or reduce erosion is due to its affinity for soil particles, largely via coulombic and Van der Waals attraction. Such 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. The 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 ESC. 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 in 1,000 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 concludes that when a solution of PAM-mix with mulch/seeding is applied to dry soil and compared with the control (no PAM-mix application to dry soil), the PAM-mix has an average reduction of 93 percent in sediment yield. 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 is 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 7-23 summarizes the 225 samples analyzed by Tobiason et al. (2000).

Table 7-23. Turbidity reduction values from PAM

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

Limitations

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 (Sojka and Lentz 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.

Cost

The cost of PAM ranges from $1.25 per pound to $5.00 per pound (Entry and Sojka 1999). The cost of PAM application depends on the system employed. 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. Numerous suppliers 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, reapplication of PAM in granular or liquid form to areas with rill development (poor vegetation cover) would require additional funds. Where reapplication 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.

7.2.5. ADVANCED TREATMENT AND CONTROL TECHNOLOGIES

7.2.5.1. Active Treatment Systems (ATS) Technologies

EPA researched technologies available for treating construction stormwater runoff, with the specific goal of identifying technologies that could reliably meet a low-effluent turbidity limit. EPA primarily identified active treatment systems (ATS) that use coagulation/flocculation and filtration for treating stormwater runoff from active construction sites as the most reliable technology for meeting a low (i.e., less than 10 NTUs) effluent limit. Technologies used at construction sites to control suspended sediment and turbidity in stormwater runoff from discharging typically include erosion control, storage/containment, gravitational settling, chemical treatment (i.e., coagulation/flocculation), and filter media. For an ATS to be effective, many (if not all) of the abovementioned treatment technologies need to be incorporated into an ATS before treated effluent discharge. This section provides an ATS process description and costs and discusses applicability, demonstration status, and limitations. Treatment chemical addition and filtration are separately discussed in detail in subsequent sections.

ATS Process Description and Costs

EPA assumed that the key components of an ATS would include the following:

- On-site storage by using a combination of sediment basins, tanks or other impoundments
- Chemical addition (see Section 7.2.5.2)
- Mix tank/clarification tank and/or basin
- Media filtration (see Section 7.2.5.3)
- Instrumentation (e.g., monitoring of influent and effluent)

The ATS capital costs include purchased (or leased) equipment cost, including ancillary equipment (e.g., piping, valves, and controllers), delivery cost, and installation/construction cost (including labor and site work). The ATS annual (operation and maintenance) costs include treatment chemicals, operating labor and material, maintenance labor and material, energy, waste disposal, monitoring, and rented equipment.

The ATS are typically equipped with automated instrumentation to monitor water quality, flow rate, and dosage control for both influent and effluent flows. Following the coagulation/flocculation process, the densified floc is settled out via gravitational settling, skimming, or media filtration (e.g., sand, gravel, bag filters).

EPA determined that some vendors offer gel socks containing treatment chemical, often for pretreatment of stormwater runoff. For example, the StormKlear Gel-Floc™ is a fabric sock containing a flake form of chitosan that slowly dissolves as the influent stormwater flows over it. The gel sock is typically anchored within the influent pipe of the ATS.

An ATS can be in either a batch or flow-through design, as described in Table 7-24. The ATS design depends on factors including existing structures (e.g., detention basins, storm sewer systems, sump areas), influent turbidity, flow rate, and space limitations. Clear Creek Systems, Inc., in a comment letter to the California State Water Resources Control Board (Gannon 2007) regarding the draft construction general permit, stated that “Batch treatment is a relatively outdated and inefficient method of operations.”

Table 7-24. ATS operating modes

Operation mode	Description
Batch (Pump-Treat-Hold-Test Release)	Stormwater runoff is collected, stored or contained in a basin or tank until treatment is complete before discharging.
Flow-through or continuous treatment	Involves pumping stormwater runoff from a collection, storage or containment basin, treating the water, and directly discharging.

Source: ATS Industry Task Force 2007.

Figure 7-1 presents a general ATS batch operating mode process diagram. The batch treatment process incorporates a period for treatment in a settling, mixing, or holding tank(s) before discharge. This is different from the continuous flow or *flow-through* treatment process in which treatment and discharge occurs continuously. Figure 7-2 shows an ATS using continuous mode.

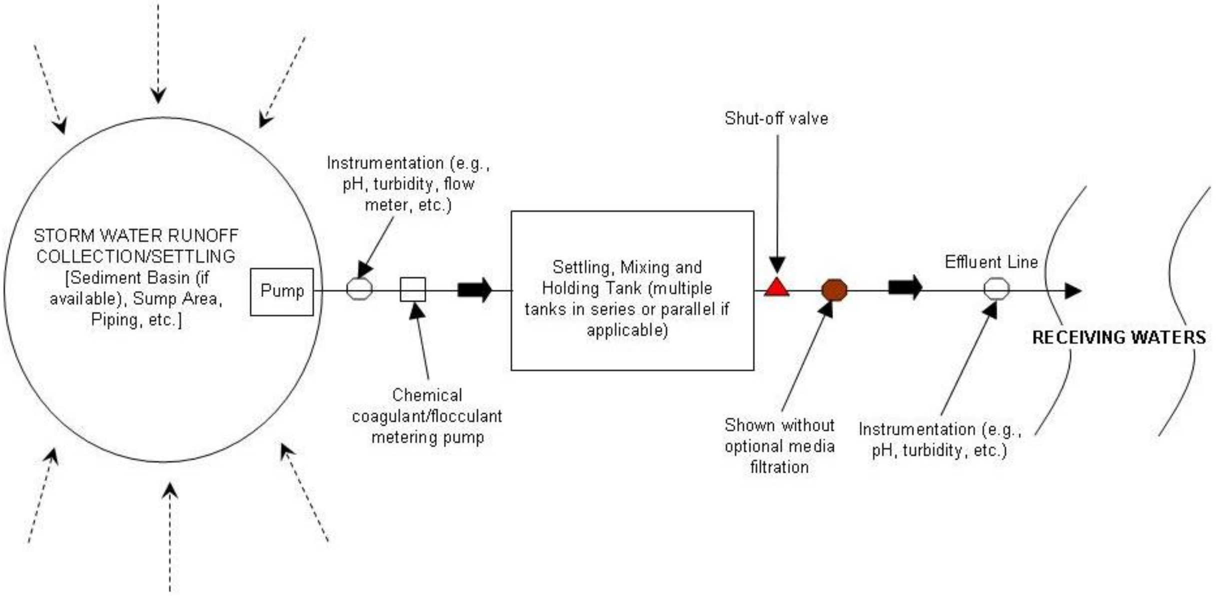

Figure 7-1. General ATS batch-operating mode

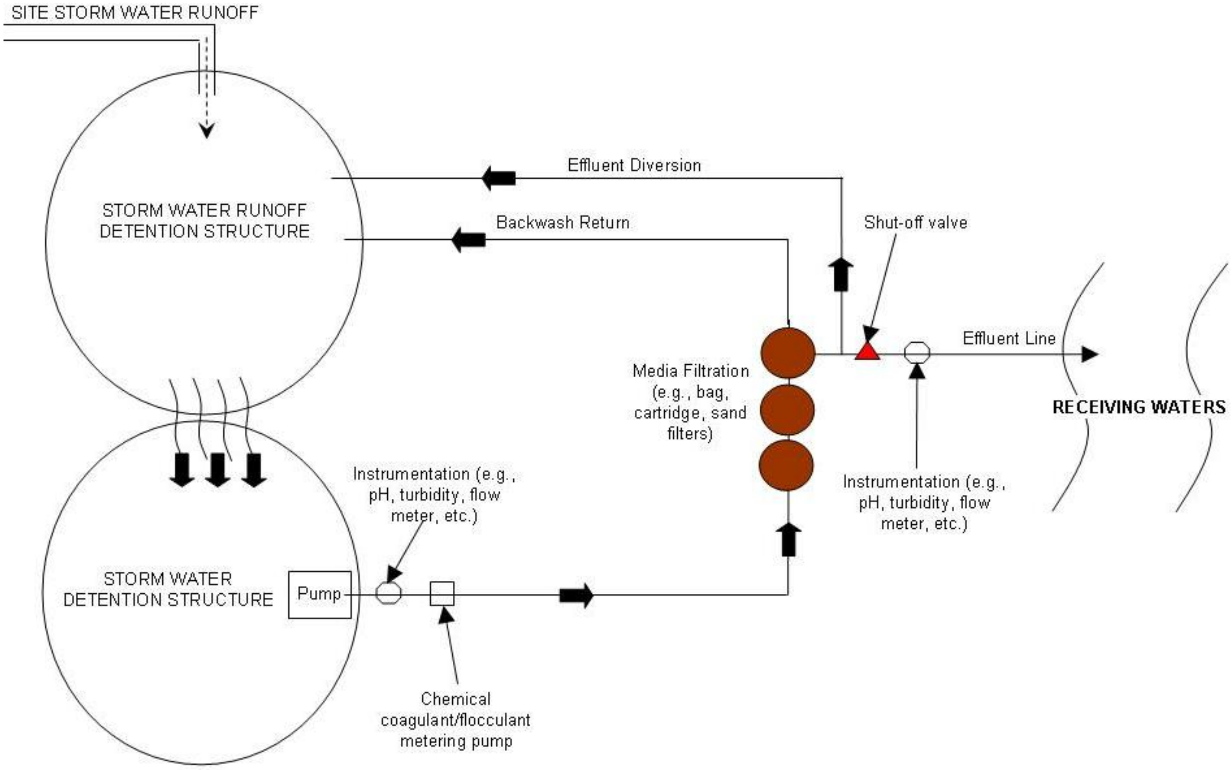

Figure 7-2. Flow-through ATS operating mode

ATS Applicability

The ATS is well suited as a method of runoff control when traditional BMPs are not capable of meeting numeric standards. ATS provides quick and efficient removal of fine-grained, suspended sediment or colloidal particles and can be custom tailored for site-specific requirements. Gravitational settling of fine or colloidal soil particles can have limited effectiveness and might not be completed in a timely manner. Therefore, ATS could be necessary to enhance small particulate solids removal and minimize project timelines and costs. The ATS can minimize potential adverse environmental effects on receiving water through automated water quality measurements. ATS generally produces very low turbidity values (often < 10 NTUs) in the effluent discharge.

The vendors contacted by EPA stated that ATS were typically meeting discharge standards of 10 NTU or less. Therefore, ATS would work well for a low-NTU standard. Vendors reported little cost savings in designing an ATS for higher, less stringent, NTU limits (e.g., 50, 100, 150, 200, 250 NTU).

Demonstration Status

EPA determined from information obtained from vendor calls that ATS using chemical treatment with polymer coagulation/flocculation is prevalent in the industry. The majority of the vendors contacted are using the polymer chitosan in conjunction with gravitational settling and filtration for treating stormwater runoff. EPA did not obtain information on how many of the systems are batch or flow-through treatment systems. The polymer Diallydimethyl-ammonium chloride (DADMAC) is also used frequently by vendors. Following the chemical treatment, media filtration is commonly used. Sand filters in combination with small-micron (e.g., 0.5) particulate filters appeared to be the media of choice by many of the vendors for removing the floc material and polishing. However, bag and cartridge filters are also being used either as a standalone treatment or in combination with the sand filters for treatment purposes. Many of the treatment technologies used are very site-specific according to the water quality (i.e., turbidity, chemical composition) and footprint available.

The vendors contacted have implemented ATS primarily in the west (California, Oregon, and Washington). Washington State's Department of Ecology (WDEC) has a new technology evaluation program in which vendors complete a Chemical Technology Assessment Protocol—Ecology (CTAPE) for new and emerging technologies. Following a performance evaluation, vendors may receive a conditional use designation (CUD) or a general use level designation (GULD) for a particular chemical treatment technology. For construction sites, WDEC has approved conditional use or general use designations for Chitosan-enhanced sand filtration using StormKlear™ Liquifloc™, FlocClear™, and Chitovan™ chemical treatments. Table 7-25 shows known or draft state ATS requirements or recommendations at the time of this writing.

Table 7-25. ATS state requirements/recommendations

State	ATS requirements and/or recommendations
California	The 2009-0009-DWQ Construction General Permit, effective July 1, 2010, provides specific requirements for dischargers who choose to use an ATS, including numeric effluent limits (NELs) and design to capture and treat a volume equivalent to the runoff from a 10-year, 24-hour storm event in a 72-hour period with a runoff coefficient of 1.0. The NELs for discharges from an ATS include the following: o Turbidity less than 10 NTU (for daily flow-weighted average) and 20 NTU (for any single sample) o Residual chemical must be less than 10% of the maximum allowable threshold concentration for the most sensitive species of the chemical used Complete ATS requirements are presented in Attachment F to the permit (see DCN 43115).
Oregon	Mr. Dennis Jurries with the Oregon Department of Environmental Quality (DEQ) stated that ATS is not required; however, for sites with difficulty reaching water quality standards, it is recommended that a chitosan-enhanced sand filtration treatment be implemented. Water Quality Requirements If discharging to a 303(d) listed waterbody or a waterbody with a TMDL for sediment and turbidity, sampling for turbidity is required to meet a 160-NTU benchmark. If unable to meet benchmark, an Action Plan using a BMP such as water treatment using electro-coagulation, chemical flocculation or filtration must be implemented.

State	ATS requirements and/or recommendations
Washington	BMP C250 Construction Storm Water Chemical Treatment states that formal, written approval from the Department of Ecology is required for using chemical treatment regardless of site size. Through the use of the Washington CTAPE, new technology evaluation program, the following have been accepted with use designations: o Construction Site Treatment Technologies o Chitosan-Enhanced Sand Filtration Using StormKlear™ LiquiFloc™ (GULD) o Chitosan-Enhanced Sand Filtration Using FlocClear™(GULD and CUD) o Chitosan Enhanced Sand Filtration Using ChitoVan™ (CULD and GULD) o Water Tectonics Electrocoagulation Subtractive Technology (CUD) o GULD—General Use Level Designation o CUD—Conditional Use Designation Water Quality Requirements Turbidity shall be no more than 5 NTU over background (if background is 50 NTU or less), or no more than 10% over background (if background is 50 NTU or greater). Sites that disturb more than 1 acre are required to sample for turbidity. Turbidity exceeding the benchmark of 25 NTU but less than 250 NTU requires BMP and SWPPP review, and additional treatment if three consecutive days exceed the benchmark. Turbidity exceeding 250 NTU requires notifying the Department of Ecology and additional treatment.

ATS Limitations

Treatment chemicals must have the proper dose and contact time to avoid potential toxicity in effluent discharges. Many of the polymers used in ATS precipitate only in a designated pH range (e.g., 6.5 to 8.5).

ATS Costs

EPA obtained ATS costs (i.e., chitosan-enhanced sand filtration) from three vendors. The ATS costs associated with treating active construction site stormwater runoff, as provided by vendors, is included in Table 7-26. For estimating compliance costs for the regulatory options that incorporate ATS, EPA determined system flowrate for the various model projects and estimated equipment rental costs, operating costs and other ancillary costs using the data supplied by Rain for Rent. EPA also added costs for providing storage for impounding runoff from the 2-year/24-hour storm event as an approximation of the additional costs for storage that might be required on-site. Additional details of this analysis are in the ATS Cost Spreadsheet Model (DCN 43119). The costs associated with ATS vary by site-specific factors such as turbidity, available footprint area for basins or equipment, effluent discharge requirements, and the like. In addition to the data provided by vendors, EPA obtained cost data on specific projects incorporating ATS from several reports. Table 7-27 summarizes ATS costs for a number of case studies reflecting varying site sizes and different system configurations.

For additional details on ATS and on ATS costing, see DCNs 43000 through 43011, DCNs 41130 and 41131, and Section 9.

Table 7-26. Summary of vendor costs

Cost type		Cost (2008 dollars)	Source
Total Cost	Large Site	$0.005/gal	StormKlear
	Small Site	$0.01/gal	
Total Cost	Large/Small	$0.01–0.03/gal	Clear Water
Labor	Large Site	$1,250/Mgal	Clear Creek
	Small Site	$5,000/Mgal	
Chemical	All Sites	$1,000–$8,000/Mgal	
Equipment Rental (18 month rental)	10-acre Site	$130,000	
	50-acre Site	$250,000	
	100-acre Site	$500,000	
Media Filter	500-gpm system. 16 acres @ 24 inches of rainfall during 6-month project period (10,248,192 gallons).	$4,000/month	Rain for Rent
System		$4,000/month	
2 Pumps		$3,300/month	
2 Tanks		$2,520/month	
4 Hoses		$392/month	
2 Elbows		$72/month	
Generator		$1,050/month	
Sand and Gravel		$1,222	
Mobilization/Demobilization		$2,970	
System Calibration		$1,300	
Pipes, valves, and electrical		$6,000	
Install pipes, valves, and electrical		$7,500	
Misc. lab equipment and supplies		$4,250	
Fuel		10 gallons/hour	

Table 7-27. Summary of ATS case studies

Project	Type of ATS*	Approximate treated volume	Project duration (months)	Project size (acres)	Cost per gallon
City of Redmond	CESF	1 million gallons	2.5	32	$10.22 per thousand gallons
City of Redmond (2 sites)	Electrocoagulation	6.2 million gallons	Unknown	8 and 23 acres	$5.83 and $8.00 per thousand gallons
Confidential Builder Project #1	CESF	~ 100 million gallons	Unknown	> 500	$16.00 per thousand gallons
Confidential Builder Project #2	DADMAC	~ 15 million gallons		~ 300 acres	$36.00 per thousand gallons

*CESF = Chitosan-Enhanced Sand Filtration, DADMAC = Diallyldimethyl Ammonium Chloride

McLaughlin (2008) noted that less complex systems (e.g., introducing a polymer such as PAM into a pump intake followed by a sediment basin) can reduce chemical cost and might not require media filtration (compared to active chitosan systems). McLaughlin (2008) also noted that small quantities of water could be treated with polymer introduced into the pump intake and pumped through geotextile sediment bags.

7.2.5.2. ATS Coagulation/Flocculation

The effective design of an ATS relies heavily on an analysis of site conditions (e.g., land use, soils, toxins, water chemistry, flowrate, receiving water chemistry). Coagulants and flocculants function as the primary treatment process used in ATS. Treatment chemical addition to influent stormwater runoff is to destabilize the suspended particles by various mechanisms, aggregating into larger particles that are easier to remove through settling or filtering. Coagulation is the reduction of the net electrical repulsive forces at particle surfaces by adding coagulating chemicals, whereas flocculation is the agglomeration of the destabilized particles by chemical joining and bridging.

The coagulants/flocculants are typically added to the influent via an injection pump in a metered dose just upstream of the clarifier tank or basin. The treatment chemicals are allowed to mix to maximize the formation of a dense floc. Proper dosing of the treatment chemicals is critical to minimize toxicity, maximize system efficiency, and ensure proper effluent water quality. The optimum dose is very site-specific (e.g., varying with changing types of soils, flow rate) and should be based on a series of jar tests.

Water treatment chemicals are predominately water soluble and classified as cationic (positively charged), anionic (negatively charged), nonionic (neutral), or amphoteric (changeable depending on the pH of water). Table 7-28 lists common coagulants, regulatory status, and available residual tests. Several of these common coagulants and toxicity information are discussed below.

Table 7-28. Examples of some commonly available coagulants

Coagulant	Chitosan	PAC	DADMAC	PAM	PASS	Alum
Description	Chitosan acetate based cationic biopolymer	Poly-aluminum chloride	Diallyl-dimethyl-ammonium chloride	Poly-acrylamide	Poly-aluminum chloride Silica/sulfate modified	Aluminum sulfate
Regulatory status	Approved in Washington	N/A	N/A	Approved in Florida, New Hampshire	N/A	Approved in Florida
Approved dosage (or dosage where no toxic effects are observed)	N/A	N/A	N/A	Florida has no limit New Hampshire has limit of one-half of NOEC[b] or IC25[c]	N/A	No limit
Residual test available[a]	Presence/ absence	Presence/absence and quantitative				
Method detection limit of residual	0.1 mg/L presence/ absence	< 0.5 mg/L presence/absence 0.5 mg/L quantitative				

Source: ATS Industry Task Force 2007.

a. Residual tests can be presence/absence tests or quantitative tests. A presence/absence test verifies that a chemical is or is not present at or above a method detection limit; it does not quantify (with a numerical value) how much is present above the method detection limit. A quantitative test yields the concentration of the chemical at or above the method detection limit; it t typically yields a concentration in mg/L.

b. NOEC: No Observed Effect Concentration. Highest concentration of effluent where the effect (e.g., reproduction) is not significantly different from the control.

c. IC25: 25 Percent Inhibition Concentration. Concentration causing a 25 percent reduction in the effect.

N/A – Not Available

Chitosan acetate

This polymer is widely used at active construction sites in ATS for stormwater runoff. Specifically, Washington, Oregon, and California have had numerous projects using this polymer. It is an approved, general-use-level designated polymer for treating construction site runoff in Washington State. Chitosan is derived from chitin, the major component of crustacean shells and is a cationic polyelecrolyte. It is a very plentiful natural polymer with supply stemming from shellfish wastes. Chitosan is able to coagulate/flocculate non-polar hydrocarbons (e.g., oil), suspended sediment, and to chelate heavy metals (Nichols 1997).

Table 7-29 presents information from several studies regarding toxicity of chitosan acetate to aquatic organisms, chemical hazard information, and filter pass-through results.

Table 7-29. Chitosan acetate study results

Vendor/source	Results
MacPherson 2006a (references Nautilus Environmental, Redmond, Washington 2004)	Toxicity. Chitosan acetate (1% solution) was reported to have an LC50 for Daphnia pulex of 1,370 mg/L, 642 mg/L for fathead minnow, and 168 mg/L for rainbow trout in clean water and 452 mg/L in 500-NTU water.
Bullock et al. 2000	Toxicity. The toxicity of chitosan has generally been considered to be nontoxic; however, Chitosan when dissolved in acetic acid and added to a culture system at 1.0 part per million (ppm) to remove organic solids was found to have acute toxicity to rainbow trout, related to gill lesions, and the severity was dose dependent.
ProTech GCS 2004	Toxicity. ProTech GCS in conjunction with GE Betz conducted research on the polymer chitosan (1% solution). The test was conducted using > 1,000 NTU water from a Sacramento, CA, project site. Survival rates for *daphnia magna*, rainbow trout, and fathead minnow were 100% at a dose of 1,100 ppm and 2,200 ppm.
MacPherson 2006b	Toxicity/Filter pass-through. Chitosan is trapped in the sand filter and not released into the receiving water.
Blandford 2006	Filter pass-through. A study evaluating the retention of chitosan acetate in a mixed media filter (anthracite, sand, and garnet) was conducted by GE Betz. The results upon a side-by-side comparison for Klaraid™ PC 1192 (DADMAC) with chitosan acetate demonstrated that both products pass through a standard mixed media filter without any retention in the layers of the filter.
Ray 2001	Hazard. This polymer is listed as Resource Conservation and Recovery Act (RCRA) hazardous because of the acidity (at a pH of about 4).
	Hazard. Chitosan acetate (1% solution) has a pH of 3.9 to 4.0 and is reported to be mildly irritating to the eyes.

Diallydimethyl-ammonium chloride (DADMAC)

This polymer is also used in ATS for treating construction site stormwater runoff. DADMAC is considered to be water soluble over a wide pH range. It has a high affinity for suspended sediment but can have the ability to pass through treatment media to the receiving water (MacPherson 2006a).

Table 7-30 presents information from several studies regarding toxicity of DADMAC to aquatic organics, and filter pass-through results.

Table 7-30. DADMAC acetate study results

Vendor/source	Results
Macpherson 2006a	Toxicity. Tramfloc, Inc., reports *daphnia magna*, 48-hour LC50 of 0.23 mg/L for the Tramfloc Polydadmac 552, 553 and 557 products; however, aquatic toxicity is reduced by factors of 10 to 100 times in the presence of 5 to 10 mg/L organics found in most surface waters.
Macpherson 2006a	Filter pass-through. High affinity for suspended sediment but might have the ability to pass through treatment media to the receiving water
ProTech GCS, Inc., in conjunction with GE Betz	Toxicity. Demonstrated that, on a dose/response basis, DADMAC reduced > 1,000 NTU-water to 2 NTU at a dose of 25 ppm. In addition, aquatic toxicity testing revealed a 95%, 100%, and 100% survival rate for *daphnia magna,* rainbow trout, and fathead minnow, respectively. The ProTech and GE study reports that the polymer DADMAC was the most economical for its removal of suspended sediment and disposal costs.

Polyacrylamide (PAM)

PAM are a broad class of compounds that include cationic (positively charged) and anionic (negatively charged) polyacylamides. PAMs are water soluble over a wide pH range and exhibit a high affinity for suspended sediment.

Table 7-31 presents information from several studies regarding toxicity of PAMs to aquatic organics and hazard information.

Table 7-31. PAM study results

Vendor/source	Results
(see Section 7.2.4.10)	Toxicity. At very high doses, irritation in humans and toxicity to certain aquatic organisms can be observed; however, in general PAMs are considered to be nontoxic to aquatic organisms.
	Hazard. PAM in the solid state has highly hygroscopic dust and, if inhaled, could impair breathing.
MacPherson 2006a	Toxicity. Anionic PAMs are not expected to be toxic to aquatic life at normal dose rates (LC50 for most aquatic species is greater than 100 mg/L).

PAMs have been approved for use in Florida and New Hampshire (ATS Industry Task Force 2007). In California, Washington, Michigan, and Oregon, cationic PAM cannot be used for construction site soil stabilization practices (MacPherson 2006a). McLaughlin has conducted extensive research on the use of PAM on construction sites in North Carolina, as well as PAM toxicity.

Aluminum-Based Coagulants

The aluminum-based coagulants do not appear to be as widely used in ATS at construction sites for stormwater runoff. Table 7-32 presents aluminum toxicity on aquatic organisms. Note that aluminum floc will be in various aluminum complexes, which can become aqueous aluminum depending on time and site-specific physical and environmental conditions (e.g., pH, temperature, hardness and alkalinity, release of trapped sediment).

Table 7-32. Aluminum-based coagulant study results

Vendor/source	Results
MacPherson 2006a	Toxicity. Specifically, studies with juvenile striped bass indicate that this species is extremely sensitive to several forms of aqueous aluminum (referenced Driscoll et al. 1980; Palawski et al. 1985; Skogheim and Rosseland 1986; Rosselan et al. 1992).
	Toxicity. An in situ study (Hall et al. 1985) with larval striped bass found 90% to 99% mortality in river water with 0.48 to 4.1 mg/L aluminum and pH levels between 6.0 and 6.8.
	Toxicity. Klauda et al. (1989) support the theory that monomeric aluminum (mAl), the inorganic fraction, is potentially the most toxic to early life stages of migratory fish.
Sutherland 1999 (references Oughton 1992)	Toxicity. Polymers created from aluminum and water collect on gills and limit respiration.
ProTech GCS, Inc., in conjunction with GE Betz	Toxicity. ProTech GCS and GE Betz conducted a study using the coagulant/flocculant Aluminum Chlorhydroxide and found that at optimum dose (75 ppm) survival rates for *daphnia magna*, rainbow trout, and fathead minnow were 95%, 100%, and 95%, respectively. At two times, the optimum dose (150 ppm) results were similar, showing no increased toxicity.
MacPherson 2006a	Hazard. These aluminum-based water treatment agents also pose a risk to human eyes and skin if not properly handled.

7.2.5.3. ATS Filtration

Filtration is a final treatment step in ATS designed to remove residual, low concentrations of target pollutants before discharge. Multimedia filtration (mixed-media filtration) is one of the oldest and most widely applied types of filtration for removing suspended solids from aqueous liquid streams. This form of filtration uses a bed of granular particles as the filter medium. Granular media filters are used to remove suspended solids from construction stormwater after chemical addition creates a floc to filter. The bed can consist of one type of medium (e.g., sand) of the same particle size, or multiple particle sizes. Different types of media (e.g., sand and gravel, sand and anthracite) with differing densities and different particle sizes compose the bed of a multimedia filter. Multimedia filters can be more efficient but more expensive and complex than single-media filters. For that reason, sand filters are most commonly used in construction ATS. The filter bed is inside a basin or tank and is supported by an underdrain system, which allows the filtered liquid to be drawn off while retaining the filter medium in place. As suspended particle-laden water passes through the bed of the filter medium, particles are trapped on top of and within the bed. Once the pressure drop across the filter is large enough to impede flow, the filter is backwashed, and the backwash water is typically recirculated to the influent flow.

Vendors are also marketing bag and cartridge filters that can be used as a final filtration step. Bag filters are available in a range of pore sizes, and cartridge filters are available with various media types. The filters can be used as a final polishing step before discharge.

7.2.5.4. Other Emerging Treatment Technologies

While EPA's analysis was based primarily on chitosan-enhanced filtration, several other advanced technologies are available to treat construction site stormwater runoff. Electrocoagulation has been successfully used on a number of construction sites to meet turbidity limits. At least one vendor is using a tube settler coupled with polymer addition before filtration to help remove sediment. In addition, several commenters provided information to EPA about other advanced turbidity control technologies that are in use or in development (see DCNs 43122 and 43123, and Docket Numbers EPA-HQ-OW-2008-0465.0525 and EPA-HQ-OW-2008-0465.0527/0527.1).

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8. BCT COST-REASONABLENESS ASSESSMENT

This section presents a summary of the Best Conventional Pollutant Control Technology (BCT) methodology and the results of the two-part cost-reasonableness test. In considering whether to promulgate BCT limits more stringent than the requirements being promulgated for Best Practicable Control Technology (BPT), the U.S. Environmental Protection Agency (EPA) considered whether technologies are available that would achieve greater removals of conventional pollutants than the BPT effluent limitations guidelines. EPA also considered whether those technologies are cost-reasonable according to the BCT cost test, which compares the incremental removals and costs associated with BCT limitations to benchmarks associated with BPT and publicly owned treatment works (POTWs).

8.1. BACKGROUND ON THE BCT COST TEST

In 1977 Congress amended the Clean Water Act to include section 304(b)(4)(B). This provision specifies that, among other factors, the assessment of BCT effluent limitations must include consideration of

> ...the reasonableness of the relationship between the costs of attaining a reduction in effluents and the effluent reduction benefits derived, and the comparison of the cost and level of reduction of such pollutants from the discharge of publicly owned treatment works to the cost and level of reduction of such pollutants from a class or category of industrial sources...

Accordingly, EPA developed the *BCT methodology* to determine whether it is *cost-reasonable* for an industry category or subcategory to control conventional pollutants at a level more stringent than would be achieved by BPT effluent limitations.

The BCT methodology was originally published on August 29, 1979, along with the promulgation of BCT effluent limitations guidelines for a number of industry sectors (44 *Federal Register* [FR] 50732). The crux of the methodology was a comparison of the costs of removing conventional pollutants for an average-sized POTW. The Fourth Circuit of the U.S. Court of Appeals remanded the BCT regulation and directed EPA to develop an industry cost test in addition to the POTW test. EPA subsequently proposed a revised BCT methodology in 1982 that addressed the industry cost test (47 FR 49176; October 29, 1982). In 1984 EPA again addressed the BCT methodology and proposed to base the POTW benchmark on model plant costs (49 FR 37046; September 20, 1984). The final BCT methodology was published in 1986, maintaining the basic approach of the 1982 proposed BCT methodology and adopting the use of the new model POTW data (51 FR 24974; July 9, 1986). These guidelines state that the BCT cost analysis "...answers the question of whether it is 'cost reasonable' for industry to control conventional pollutants at a level more stringent than BPT effluent limitations already require." See 51 FR at 24974. Conventional pollutants are biochemical oxygen demand (BOD), total suspended solids (TSS), oil and grease, fecal coliform, and pH.

The final BCT methodology incorporates two cost tests to establish cost reasonableness: the POTW test and the industry cost-effectiveness test. Each of these tests is compared with established benchmarks, the derivation of which is described in detail in the 1986 FR notice. The BCT cost methodology is described in more detail in the following section.

8.2. OPTIONS EVALUATED FOR BCT

8.2.1. OPTION 1

Option 1 contains requirements for implementing a variety or erosion and sediment controls on all construction sites that are required to obtain a permit.

8.2.2. OPTION 2

Option 2 contains the same requirements as Option 1. In addition, construction sites of 30 or more acres of disturbed land would be required to meet a numeric turbidity limit in stormwater discharges from the site based on the application of ATS.

8.2.3. OPTION 3

Option 3 contains the same requirements as Option 1. Option 3 also requires all sites with 10 or more acres of disturbed land to meet a numeric turbidity standard based on the application of ATS.

8.2.4. OPTION 4

Option 4 contains the same requirements as Option 1. Option 4 also requires all sites with 10 or more acres of disturbed land to meet a numeric turbidity standard based on the application of passive treatment systems.

8.3. CALCULATION OF THE BCT COST TEST

POTW Test

The first part of the BCT cost test is the POTW test. The POTW test compares the cost per pound of conventional pollutants removed by industrial dischargers in upgrading from BPT to BCT candidate technologies, to the cost per pound of removing conventional pollutants in upgrading POTWs from secondary treatment to advanced secondary treatment.

To *pass* the POTW test, the cost per pound of conventional pollutant discharges removed in upgrading from BPT to the candidate BCT must be less than the POTW benchmark. The POTW benchmark presented in the 1986 *Federal Register* notice is $0.25 per pound (in 1976 dollars) for industries in which the cost per pound of pollutant reduction is based on long-term performance data. EPA used cost index data from R.S. Means Historical Cost Indices to update this POTW benchmark to 2008 dollars according to the following equation:

$$\frac{\text{Index for 2008}}{\text{Index for 1976}} \times \textit{Cost in 1976\$} = \textit{Cost in 2008\$}$$

$$\frac{173.0}{46.9} \times \$0.25 = \$0.92$$

Using estimated reductions for TSS, EPA then calculated the incremental costs per pound of conventional pollutant removed ($/lb) for each candidate BCT technology option. If any candidate technology option passes the first part of the BCT cost test (i.e., is less than the inflation-adjusted value of $0.92 in 2008 dollars), the technology is further evaluated in the second part of the test. EPA used only TSS pollutant reductions for the cost test calculations, because of the limited data available. However, EPA expects that discharges of oil and grease and fecal coliform would be minimal from construction sites. EPA also expects that BOD, where present, would be removed along with TSS. The results of the POTW test are presented in Table 8-1.

Table 8-1. POTW cost test results

BCT option	Total annual costs and conventional pollutant removals		Incremental costs and conventional pollutant removals, relative to BPT[a]			POTW cost test result (< $0.92/lb)
	Cost (million $) (2008$)	Pollutant removals (million lbs)	Cost (million $) (2008$)	Pollutant removals (million lbs)	Cost per pound ($/lb)	
1	176	1,743				
2	4,863	3,616	4,687	1,873	2.50	Fail
3	9,081	4,507	8,905	2,764	3.22	Fail
4	959	3,971	783	2,228	0.35	Pass

[a] Option 1 is equal to the BPT effluent limitations. Therefore, all incremental values are calculated relative to Option 1.

Industry Cost-Effectiveness Test

The second part of the BCT cost test is the industry cost-effectiveness test, which computes the ratio of two incremental costs. The first of these incremental costs is the cost per pound of conventional pollutants removed in upgrading from BPT to the BCT candidate technology. This value serves as the numerator of the ratio. The second incremental cost, which serves as the denominator of the ratio, is the cost per pound of conventional pollutants removed by BPT relative to no treatment (i.e., this value compares raw wasteload to pollutant load after application of BPT). This ratio is compared to an industry cost benchmark, which is based on POTW cost and pollutant removal data. The industry cost benchmark is also a ratio of two incremental costs: the cost per pound to upgrade a POTW from secondary treatment to advanced secondary treatment, divided by the cost per pound to initially achieve secondary treatment. If the industry cost-effectiveness test is lower than the industry cost benchmark of 1.29 (i.e., the normalized cost increase must be less than 29 percent), the candidate BCT technology passes this part of the cost test. The calculation and results of the industry cost-effectiveness test are presented in Tables 8-2 and 8-3. Because Options 2, 3, and 4 fail the second part of the BCT cost test, BCT is set equal to BPT, which is Option 1.

Table 8-2. Cost and pollutant removals for BPT

	Total annual costs (million $) (2008$)	Conventional pollutant removals (million lbs)	BPT cost per pound ($/lb)
Baseline	2,804	44,620	
Option 1 Incremental	176	1,743	
Total BPT	2,980	46,363	0.064

Table 8-3. Industry cost-effectiveness test results

BCT option	Incremental cost per pound to upgrade from BPT to BCT ($/lb)	Calculated ratio	Industry cost-effectiveness test result (< 1.29)
1	0	0	Pass
2	2.50	38.92	Fail
3	3.22	50.12	Fail
4	0.35	5.47	Fail

8.4. REFERENCES

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9. ESTIMATING INCREMENTAL COSTS FOR THE FINAL REGULATION

9.1. OVERVIEW

This section presents the approach used for estimating the incremental costs associated with the regulatory options considered. This section also includes discussion on selecting and developing cost model inputs; the components of cost; and the methodology for estimating costs, including an overview of the C&D Cost Spreadsheet Models. The economic analyses conducted for the industry are described in the document *Economic Analysis for Final Action for Effluent Guidelines and Standards for the Construction and Development Category* (USEPA 2009).

The U.S. Environmental Protection Agency's (EPA's) first step in estimating national costs for each option was developing an array of model construction sites. EPA then estimated unit compliance costs for the regulatory options. The most significant input parameter in estimating the size and cost of treatment equipment for model construction sites is the volume of rainfall requiring treatment. EPA estimated the amount of stormwater runoff requiring treatment using the drainage area of the model site, state-specific rainfall estimates, and runoff coefficients to estimate the volume of rainfall converted to runoff and requiring subsequent treatment. The model project costs were then scaled to the state and national level on the basis of the national project distribution described in Table 4-3.

Costs for the U.S. territories were not estimated because EPA lacked data on the annual amount of new construction acreage in these areas. However, assuming a small amount of construction occurs in those areas, EPA expects that the values would be low in comparison to the national costs.

The total costs of the options considered are presented in Table 9-1.

Table 9-1. Estimated total annual social costs of regulatory options for the C&D industry

Regulatory option	Annual cost (millions 2008 dollars)
Option 1	$176
Option 2	$4,863
Option 3	$9,081
Option 4	$959

9.2. DEVELOPMENT OF MODEL CONSTRUCTION SITES AND ESTIMATING TREATMENT VOLUMES

9.2.1. MODEL CONSTRUCTION SITES

As discussed in Section 4.2.2 and in Appendix C, EPA developed a series of model projects from an analysis of NOI data. This matrix consisted of 12 model project sizes and 12 model project duration, yielding a total of 144 individual model projects. By analyzing the NOI data, EPA was able to develop a distribution of model projects for each model project size and duration category for three project types (residential construction, nonresidential construction, and transportation). For each state and the District of Columbia, EPA was able to estimate the number of model projects in those site size categories. Table 9-2 shows the model project matrix. Table 9-3 shows the estimated number of acres developed per year for the model projects. (Tables 9-2 and 9-3 appear later in this section grouped with other tables of similar size.)

EPA based its costing on the size of the model site, the volume of runoff being treated, and the duration of land disturbance. EPA assumes, for costing purposes, that the duration of construction activities (and hence the duration of time needed to meet the turbidity limits) under Options 2, 3, and 4 for some projects are shorter than the NOI project durations. That is because projects are likely to transition from major land disturbing activities into the vertical construction phase. For the final months of a project, the majority of soil disturbance would likely be complete as structures are constructed. Final stabilization of remaining disturbed areas around the building footprint would be complete once the majority of the exterior construction work is complete. Final vegetation is usually one of the last steps in the construction sequence, and the Notice of Termination (NOT) is usually filed after final stabilization. Because the turbidity limits under Options 2, 3, and 4 are tied to the disturbed area of the site, EPA expects that disturbed land on the majority of construction sites subject to the turbidity limit would fall below the associated thresholds several months before the end of the project. Table 9-4 presents the original project durations based on NOIs and the duration used for costing purposes. For projects shorter than 7 months, the duration of the project for costing purposes was not changed. For projects longer than 7 months, the duration of the project was reduced by 1 month (for a 7-month project) up to 6 months (for a 36-month project).

Table 9-4. Model project durations

NOI Project Duration (months)	1	2	4	7	10	13
Duration for Costing (months)	1	2	4	6	8	10
NOI Project Duration (months)	16	19	22	27	32	36
Duration for Costing (months)	13	15	16	21	26	30

(Tables 9-2 and 9-3 appear later in this section grouped with other tables of similar size.)

For costing ATS, EPA assumed that 100 percent of each construction site would be producing stormwater runoff that would require treatment. That is a conservative assumption, because some portion of sites will likely discharge through perimeter controls because diffuse runoff and would not require sampling and compliance with the numeric limit. EPA notes that these assumptions for project duration and amount of the site requiring treatment, while useful for modeling, likely vary considerably among actual construction projects. However, because EPA lacks data on the typical duration of disturbed soils at construction projects and the duration that treatment would need to be in place, this modeling approach provides a reasonable, if somewhat conservative, means of estimating runoff volumes requiring treatment and incremental compliance costs of the options.

9.2.2. ESTIMATION OF RAINFALL DEPTHS AND STORAGE VOLUMES

To calculate basin sizing for storage for ATS under Options 2 and 3 and to determine runoff volumes for costing treatment systems, EPA evaluated several references to determine rainfall depths for a series of design storm return periods for one indicator city in each state (for a discussion of that analysis, see Section 3.5.3 and Appendix D). The storm depths for each indicator city were used as point estimates for rainfall depths in each respective state. Using the storm depths, EPA estimated runoff coefficients for each state using the process described in TR-55 (USDA 1986). EPA estimated a runoff curve number using the Soil Conservation Service runoff curve number equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

where

Q = runoff (in)
P = rainfall (in)
S = potential maximum retention after runoff begins (in)
I_a = initial abstraction (in) = 0.2S

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

$$S = \frac{1000}{CN} - 10$$

Using the values contained in TR-55 for Curve Numbers for Developing Urban Areas (from TR-55, Table 2-2a), along with the 2-year, 24-hour storm depths in Table 3-3, EPA calculated runoff coefficients for the four hydrologic soil groups in each state for the 2-year, 24-hour storm event (see Table 9-5). Using data on the prevalence of soils by hydrologic soil groups obtained from STATSGO for each state (see Table 3-4), EPA then calculated a weighted runoff coefficient for each state for the 2-year, 24-hour storm event. These results are summarized in Table 9-5 and were used to determine the required basin sizes for capturing runoff from the 2-year, 24-hour storm event in each state, which is a requirement for Options 2 and 3 (see Table 9-6). Table 9-6 also contains baseline sediment basin sizes for states based on a review of current state permit requirements. The rainfall analysis data is DCN 43095, and the STATSGO soils data evaluation is DCN 43096 in the Administrative Record.

9.2.3. ESTIMATION OF ATS TREATMENT VOLUMES

For estimating average runoff volumes for each model site in each state, EPA multiplied the average annual precipitation in each state by the site size and a runoff coefficient of 0.4. This value of 0.4 was chosen as a reasonable estimate of the percent of average rainfall that would be converted to runoff. EPA acknowledges that this approach likely overestimates runoff volumes (and hence, volumes requiring treatment and associated treatment costs) because many smaller storm events would not produce any, or very little, runoff. This approach also does not account for precipitation that falls as snow. It also assumes that the entire site is in a *newly graded areas* state, as defined by TR-55, for the entire duration of the project. In reality, site areas during various states of the construction project would be in various states, ranging from bare soil, to temporarily stabilized with mulch, to vegetated. As a result, curve numbers could be much lower and associated runoff volumes could be much lower. However, this approach does allow for a reasonable, albeit conservative, estimate of treatment volumes for determining compliance costs. EPA multiplied the average annual runoff volumes for each model project by the project duration (in years) account for length of time stormwater would be produced. This analysis does not account for seasonal variations in rainfall—EPA assumed that precipitation would be evenly distributed over the year. So, for a project that is less than one year in duration, the treatment volume was based on the associated fraction of the year, irrespective of when construction would actually occur.

Table 9-7 summarizes the monthly treatment volumes for each state for each of the 14 model project size categories. Treatment volumes for each model project were determined by multiplying the monthly treatment volumes by the project durations (in months). For each state and each model project size category, EPA determined the treatment system flowrate needed to treat runoff from the 2-year, 24-hour storm event within 72 hours. Table 9-8 shows the system flowrate required. For selecting a design flowrate for costing, if the treatment flowrate was 100 gallons per minute (gpm) or less, a design flowrate of 100 gpm was selected. If the treatment flowrate was greater than 100 gpm, the design flowarate was selected by rounding up in 500-gpm increments. Although ATS filtration systems are available in various flowrates depending on the vendor, 500 gpm is a typical sand filter flowrate. Table 9-9 shows the design flowrates selected for costing purposes. EPA notes that rounding up to 500-gpm increments is a conservative assumption, because a 500-gpm system could operate at a higher flowrate. So, for example, EPA estimated that a 46-acre site in Illinois would require 525 gpm of treatment. A 500-gpm sand filter would likely be able to operate at 525 gpm, but EPA selected a 1,000-gpm system for this model project. The 500-gpm system would have a lower rental cost than the 1,000-gpm system, but treatment times (and hence operator labor requirements) would be longer.

Table 9-2. Model project matrix

RESIDENTIAL													
Project size (acres)	Duration (days)												Total by site size
	0–46	47–91	92–182	183–274	275–365	366–456	457–547	549–639	640–730	731–912	913–1,095	> 1,096	
1.9	124	147	632	571	1,111	926	283	293	222	450	98	57	4,914
3.8	68	100	351	341	703	657	312	213	249	397	125	177	3,693
6	44	28	242	168	444	301	81	110	169	220	76	109	1,992
8.5	22	26	187	172	318	309	52	70	109	180	68	167	1,680
12	23	14	195	218	506	388	139	78	72	430	75	283	2,421
17	18	2	84	174	209	219	95	107	74	360	77	137	1,556
23	1	28	107	133	239	303	73	90	103	325	101	307	1,810
34	1	--	48	59	182	143	23	42	18	214	69	185	984
46	11	--	33	84	126	114	11	24	70	155	101	192	921
69	--	--	1	38	38	54	17	19	18	60	11	117	373
85	--	--	--	2	17	36	--	7	7	43	27	103	242
145	--	--	8	11	45	50	15	12	37	50	39	77	344
Total Residential	312	345	1,888	1,971	3,938	3,500	1,101	1,065	1,148	2,884	867	1,911	20,930

NONRESIDENTIAL													
Project size (acres)	Duration (days)												Total by site size
	0–46	47–91	92–182	183–274	275–365	366–456	457–547	549–639	640–730	731–912	913–1,095	> 1,096	
1.9	558	1,359	4,910	5,334	4,806	3,276	940	685	442	592	180	155	23,237
3.8	219	547	1,990	2,973	2,643	1,715	910	461	199	465	140	148	12,410
6	150	206	996	1,368	1,516	1,059	513	285	240	188	89	99	6,709
8.5	55	97	578	736	616	617	165	152	144	274	49	96	3,579
12	77	73	493	660	950	741	347	178	162	291	41	71	4,084
17	13	82	246	261	505	419	203	60	114	131	29	39	2,102
23	38	59	166	264	542	250	215	208	135	142	25	34	2,078
34	3	27	78	164	176	126	48	72	29	101	5	36	865
46	--	17	49	65	129	150	57	152	12	131	51	34	847
69	2	2	29	50	33	30	30	87	16	71	2	14	366
85	--	--	10	1	86	22	11	21	--	51	--	11	213
145	--	8	25	46	124	25	10	11	5	58	29	15	356
Total Nonresidential	1,115	2,477	9,570	11,922	12,126	8,430	3,449	2,372	1,498	2,495	640	752	56,846

TRANSPORTATION													
Project size (acres)	Duration (days)												Total by site size
	0–46	47–91	92–182	183–274	275–365	366–456	457–547	549–639	640–730	731–912	913–1,095	> 1,096	
1.9	82	210	629	418	308	323	136	55	132	117	7	--	2,417
3.8	25	87	277	255	246	146	81	60	34	58	22	7	1,298
6	16	23	184	138	170	53	45	26	--	78	15	22	770
8.5	7	15	70	73	78	78	33	89	17	7	21	6	494
12	8	21	70	109	39	95	52	43	17	36	13	45	548
17	--	3	63	49	13	15	21	2	8	64	6	28	272
23	5	2	31	36	6	76	40	27	14	95	16	15	363
34	--	--	1	26	17	6	16	4	9	5	42	2	128
46	--	1	2	19	9	25	21	15	9	24	4	51	180
69	--	--	--	--	3	9	10	4	--	5	21	--	52
85	--	--	7	--	--	3	--	--	2	4	12	28	56
145	--	--	--	1	3	4	1	9	11	24	35	30	118
Total Transportation	143	362	1,334	1,124	892	833	456	334	253	517	214	234	6,696
NATIONAL TOTAL	1,570	3,184	12,792	15,017	16,956	12,763	5,006	3,771	2,899	5,896	1,721	2,897	84,472

Table 9-3. Acreage developed matrix

RESIDENTIAL													
Project size (acres)	Duration (days)												Total by site size
	0–46	47–91	92–182	183–274	275–365	366–456	457–547	549–639	640–730	731–912	913–1,095	> 1,096	
1.9	236	279	1,201	1,085	2,111	1,759	538	557	422	855	186	108	9,337
3.8	258	380	1,334	1,296	2,671	2,497	1,186	809	946	1,509	475	673	14,033
6	264	168	1,452	1,008	2,664	1,806	486	660	1,014	1,320	456	654	11,952
8.5	187	221	1,590	1,462	2,703	2,627	442	595	927	1,530	578	1,420	14,280
12	276	168	2,340	2,616	6,072	4,656	1,668	936	864	5,160	900	3,396	29,052
17	306	34	1,428	2,958	3,553	3,723	1,615	1,819	1,258	6,120	1,309	2,329	26,452
23	23	644	2,461	3,059	5,497	6,969	1,679	2,070	2,369	7,475	2,323	7,061	41,630
34	34	--	1,632	2,006	6,188	4,862	782	1,428	612	7,276	2,346	6,290	33,456
46	506	--	1,518	3,864	5,796	5,244	506	1,104	3,220	7,130	4,646	8,832	42,366
69	--	--	69	2,622	2,622	3,726	1,173	1,311	1,242	4,140	759	8,073	25,737
85	--	--	--	170	1,447	3,064	--	596	596	3,659	2,298	8,765	20,594
145	--	--	1,160	1,595	6,525	7,250	2,175	1,740	5,365	7,250	5,655	11,165	49,880
Total Residential	2,090	1,894	16,184	23,741	47,849	48,182	12,249	13,625	18,834	53,424	21,931	58,766	318,769
NONRESIDENTIAL													
Project size (acres)	Duration (days)												Total by site size
	0–46	47–91	92–182	183–274	275–365	366–456	457–547	549–639	640–730	731–912	913–1,095	> 1,096	
1.9	1,060	2,582	9,329	10,135	9,131	6,224	1,786	1,302	840	1,125	342	295	44,150
3.8	832	2,079	7,562	11,297	10,043	6,517	3,458	1,752	756	1,767	532	562	47,158
6	900	1,236	5,976	8,208	9,096	6,354	3,078	1,710	1,440	1,128	534	594	40,254
8.5	468	825	4,913	6,256	5,236	5,245	1,403	1,292	1,224	2,329	417	816	30,422
12	924	876	5,916	7,920	11,400	8,892	4,164	2,136	1,944	3,492	492	852	49,008
17	221	1,394	4,182	4,437	8,585	7,123	3,451	1,020	1,938	2,227	493	663	35,734
23	874	1,357	3,818	6,072	12,466	5,750	4,945	4,784	3,105	3,266	575	782	47,794
34	102	918	2,652	5,576	5,984	4,284	1,632	2,448	986	3,434	170	1,224	29,410
46	--	782	2,254	2,990	5,934	6,900	2,622	6,992	552	6,026	2,346	1,564	38,962
69	138	138	2,001	3,450	2,277	2,070	2,070	6,003	1,104	4,899	138	966	25,254
85	--	--	851	85	7,319	1,872	936	1,787	--	4,340	--	936	18,126
145	--	1,160	3,625	6,670	17,980	3,625	1,450	1,595	725	8,410	4,205	2,175	51,620
Total Nonresidential	5,519	13,346	53,079	73,096	105,451	64,856	30,995	32,820	14,614	42,443	10,244	11,429	457,892

TRANSPORTATION													
Project size (acres)	Duration (days)												Total by site size
	0–46	47–91	92–182	183–274	275–365	366–456	457–547	549–639	640–730	731–912	913–1,095	> 1,096	
1.9	156	399	1,195	794	585	614	258	105	251	222	13	--	4,592
3.8	95	331	1,053	969	935	555	308	228	129	220	84	27	4,932
6	96	138	1,104	828	1,020	318	270	156	--	468	90	132	4,620
8.5	60	128	595	621	663	663	281	757	145	60	179	51	4,199
12	96	252	840	1,308	468	1,140	624	516	204	432	156	540	6,576
17	--	51	1,071	833	221	255	357	34	136	1,088	102	476	4,624
23	115	46	713	828	138	1,748	920	621	322	2,185	368	345	8,349
34	--	--	34	884	578	204	544	136	306	170	1,428	68	4,352
46	--	46	92	874	414	1,150	966	690	414	1,104	184	2,346	8,280
69	--	--	--	--	207	621	690	276	--	345	1,449	--	3,588
85	--	--	596	--	--	255	--	--	170	340	1,021	2,383	4,766
145	--	--	--	145	435	580	145	1,305	1,595	3,480	5,075	4,350	17,110
Total Transportation	617	1,390	7,292	8,084	5,664	8,103	5,363	4,823	3,672	10,115	10,149	10,717	75,988
NATIONAL TOTAL	8,226	16,631	76,556	104,921	158,964	121,141	48,607	51,268	37,120	105,981	42,323	80,912	852,650

Table 9-5. State runoff coefficients for 2-year, 24-hour storm events

	2-year, 24-hour storm depth (inches)	Runoff coefficient for A soils	Runoff coefficient for B soils	Runoff coefficient for C soils	Runoff coefficient for D soils	% A soils	% B soils	% C soils	% D soils	Weighted runoff coefficient 2-year, 24-hour storm
Alabama	4.50	0.49	0.67	0.78	0.85	8.7%	41.2%	28.8%	21.3%	0.72
Arizona	1.40	0.12	0.31	0.47	0.61	4.7%	38.6%	17.2%	39.5%	0.44
Arkansas	4.10	0.46	0.64	0.76	0.83	0.6%	28.3%	35.9%	35.1%	0.75
California	2.00	0.22	0.42	0.58	0.70	10.9%	32.2%	18.4%	38.5%	0.54
Colorado	2.00	0.22	0.42	0.58	0.70	7.2%	46.7%	24.6%	21.4%	0.51
Connecticut	3.10	0.37	0.56	0.70	0.79	9.1%	41.1%	35.9%	13.9%	0.63
Delaware	3.26	0.38	0.58	0.71	0.80	20.8%	30.9%	13.4%	34.9%	0.63
Florida	4.75	0.51	0.68	0.79	0.86	18.1%	6.3%	8.6%	67.0%	0.78
Georgia	3.70	0.43	0.62	0.74	0.82	6.6%	53.1%	16.9%	23.5%	0.67
Idaho	1.20	0.08	0.25	0.42	0.56	4.4%	46.8%	23.1%	25.7%	0.36
Illinois	2.85	0.34	0.54	0.68	0.77	1.4%	44.5%	27.0%	27.1%	0.64
Indiana	2.95	0.35	0.55	0.69	0.78	3.5%	32.6%	41.8%	22.1%	0.65
Iowa	3.25	0.38	0.58	0.71	0.80	0.9%	66.0%	11.6%	21.5%	0.64
Kansas	3.50	0.41	0.60	0.73	0.81	3.8%	58.0%	19.5%	18.7%	0.66
Kentucky	3.00	0.36	0.55	0.69	0.78	0.1%	42.7%	44.9%	12.3%	0.64
Louisiana	5.25	0.54	0.70	0.80	0.87	1.7%	14.4%	28.9%	55.1%	0.82
Maine	2.80	0.33	0.53	0.67	0.77	7.7%	12.9%	43.9%	35.5%	0.66
Maryland	3.16	0.37	0.57	0.70	0.79	10.0%	38.6%	26.4%	25.0%	0.64
Massachusetts	3.10	0.37	0.56	0.70	0.79	23.9%	16.6%	34.4%	25.2%	0.62
Michigan	2.40	0.28	0.48	0.63	0.74	29.0%	28.7%	12.9%	29.4%	0.52
Minnesota	2.75	0.33	0.53	0.67	0.77	8.3%	37.4%	15.4%	38.9%	0.63
Mississippi	4.45	0.49	0.66	0.78	0.85	2.3%	32.3%	38.6%	26.9%	0.75
Missouri	3.45	0.40	0.60	0.72	0.81	1.0%	40.1%	39.8%	19.0%	0.68
Montana	1.30	0.10	0.28	0.45	0.58	2.9%	39.5%	27.2%	30.4%	0.41
Nebraska	3.00	0.36	0.55	0.69	0.78	31.9%	53.6%	3.0%	11.5%	0.52
Nevada	1.00	0.05	0.20	0.36	0.50	5.6%	26.4%	17.7%	50.3%	0.37
New Hampshire	2.80	0.33	0.53	0.67	0.77	17.1%	24.8%	41.4%	16.6%	0.60
New Jersey	3.31	0.39	0.58	0.71	0.80	12.5%	32.8%	25.1%	29.6%	0.66
New Mexico	1.54	0.15	0.34	0.50	0.63	5.6%	41.9%	16.5%	36.0%	0.46
New York	2.90	0.35	0.54	0.68	0.78	9.6%	18.5%	51.1%	20.7%	0.64

	2-year, 24-hour storm depth (inches)	Runoff coefficient for A soils	Runoff coefficient for B soils	Runoff coefficient for C soils	Runoff coefficient for D soils	% A soils	% B soils	% C soils	% D soils	Weighted runoff coefficient 2-year, 24-hour storm
North Carolina	3.34	0.39	0.59	0.72	0.80	7.9%	48.8%	16.5%	26.8%	0.65
North Dakota	1.90	0.21	0.41	0.57	0.69	4.7%	56.1%	16.6%	22.6%	0.49
Ohio	2.62	0.31	0.51	0.66	0.76	0.6%	16.8%	54.6%	28.0%	0.66
Oklahoma	3.70	0.43	0.62	0.74	0.82	6.8%	44.5%	22.3%	26.4%	0.68
Oregon	2.50	0.30	0.50	0.64	0.75	5.2%	32.1%	37.1%	25.6%	0.61
Pennsylvania	3.23	0.38	0.58	0.71	0.80	6.0%	28.4%	54.2%	11.5%	0.66
Rhode Island	3.20	0.38	0.57	0.71	0.79	15.3%	35.7%	32.4%	16.5%	0.62
South Carolina	3.62	0.42	0.61	0.73	0.82	11.9%	41.8%	19.5%	26.8%	0.67
South Dakota	2.25	0.26	0.46	0.62	0.73	2.9%	45.2%	11.5%	40.4%	0.58
Tennessee	3.37	0.40	0.59	0.72	0.80	0.1%	53.6%	30.4%	15.9%	0.66
Texas	3.90	0.44	0.63	0.75	0.83	5.1%	27.2%	24.5%	43.2%	0.73
Utah	1.40	0.12	0.31	0.47	0.61	5.3%	36.2%	16.2%	42.3%	0.45
Vermont	2.40	0.28	0.48	0.63	0.74	4.9%	18.0%	54.3%	22.8%	0.61
Virginia	3.11	0.37	0.56	0.70	0.79	1.7%	53.7%	32.3%	12.3%	0.63
Washington	2.00	0.22	0.42	0.58	0.70	6.6%	53.4%	24.2%	15.8%	0.49
West Virginia	2.56	0.30	0.50	0.65	0.75	7.3%	21.5%	54.2%	17.0%	0.61
Wisconsin	2.80	0.33	0.53	0.67	0.77	14.4%	46.8%	18.1%	20.7%	0.58
Wyoming	1.60	0.16	0.35	0.51	0.64	4.5%	40.5%	19.5%	35.5%	0.48
District of Columbia	3.16	0.37	0.57	0.70	0.79	10.0%	38.6%	26.4%	25.0%	0.64

Table 9-6. ATS storage requirements for states

	Baseline sediment basin size (cf/acre)	2-year, 24-hour runoff basin size (cf/acre)
Alabama	1,800	11,798
Arizona	2,254	2,254
Arkansas	3,600	11,179
California	3,389	3,898
Colorado	1,800	3,685
Connecticut	3,600	7,043
Delaware	3,600	7,487
Florida	3,600	13,371
Georgia	1,800	9,019
Idaho	3,600	1,585
Illinois	1,585	6,591
Indiana	3,600	6,968
Iowa	1,800	7,536
Kansas	3,600	8,337
Kentucky	3,600	7,004
Louisiana	3,600	15,638
Maine	3,600	6,744
Maryland	3,600	7,353
Massachusetts	3,600	6,977
Michigan	3,600	4,530
Minnesota	3,600	6,247
Mississippi	3,600	12,147
Missouri	3,600	8,574
Montana	3,600	1,948
Nebraska	1,800	5,680
Nevada	1,800	1,350
New Hampshire	1,350	6,064
New Jersey	3,600	7,886
New Mexico	1,800	2,570
New York	2,570	6,776
North Carolina	3,600	7,884
North Dakota	1,800	3,361
Ohio	3,361	6,261
Oklahoma	1,800	9,184
Oregon	3,600	5,495
Pennsylvania	3,600	7,754
Rhode Island	5,000	7,239
South Carolina	1,800	8,756
South Dakota	3,600	4,745
Tennessee	3,600	8,095
Texas	3,600	10,403
Utah	3,600	2,284
Vermont	3,099	5,345
Virginia	1,800	7,141

	Baseline sediment basin size (cf/acre)	**2-year, 24-hour runoff basin size (cf/acre)**
Washington	3,600	3,575
West Virginia	512	5,679
Wisconsin	3,600	5,884
Wyoming	1,800	2,770
District of Columbia	1,800	7,353

Table 9-7. Monthly ATS treatment volumes (gallons)

State	Model site size (acres)											
	1.9	3.8	6	8.5	12	17	23	34	46	69	85	145
Alabama	84,331	168,662	266,308	377,270	532,617	754,540	1,020,849	1,509,081	2,041,697	3,062,546	3,777,140	6,435,785
Arizona	13,309	26,617	42,028	59,539	84,055	119,078	161,106	238,156	322,212	483,317	596,091	1,015,667
Arkansas	81,888	163,775	258,593	366,340	517,185	732,679	991,272	1,465,359	1,982,544	2,973,816	3,667,707	6,249,324
California	31,628	63,256	99,878	141,494	199,756	282,988	382,866	565,976	765,732	1,148,598	1,416,604	2,413,720
Colorado	22,885	45,770	72,269	102,381	144,537	204,761	277,030	409,522	554,060	831,089	1,025,010	1,746,492
Connecticut	76,378	152,755	241,193	341,690	482,385	683,379	924,572	1,366,758	1,849,143	2,773,715	3,420,915	5,828,821
Delaware	73,984	147,968	233,634	330,981	467,267	661,962	895,596	1,323,924	1,791,191	2,686,787	3,313,704	5,646,147
Florida	106,642	213,284	336,764	477,083	673,528	954,165	1,290,930	1,908,331	2,581,859	3,872,789	4,776,440	8,138,469
Georgia	87,456	174,911	276,176	391,249	552,352	782,499	1,058,674	1,564,997	2,117,349	3,176,023	3,917,096	6,674,252
Hawaii	31,452	62,905	99,323	140,708	198,647	281,417	380,740	562,833	761,480	1,142,220	1,408,738	2,400,317
Idaho	19,491	38,983	61,552	87,198	123,104	174,397	235,949	348,794	471,897	707,846	873,010	1,487,503
Illinois	56,824	113,648	179,444	254,213	358,888	508,425	687,869	1,016,850	1,375,739	2,063,608	2,545,117	4,336,568
Indiana	68,246	136,492	215,514	305,312	431,028	610,623	826,137	1,221,247	1,652,275	2,478,412	3,056,709	5,208,258
Iowa	54,449	108,899	171,945	243,589	343,891	487,178	659,124	974,357	1,318,248	1,977,371	2,438,758	4,155,346
Kansas	63,087	126,174	199,222	282,231	398,443	564,462	763,683	1,128,923	1,527,367	2,291,050	2,825,628	4,814,525
Kentucky	77,407	154,815	244,445	346,297	488,889	692,593	937,038	1,385,186	1,874,076	2,811,113	3,467,040	5,907,412
Louisiana	101,070	202,140	319,168	452,155	638,336	904,309	1,223,478	1,808,619	2,446,955	3,670,433	4,526,867	7,713,228
Maine	71,652	143,304	226,269	320,548	452,538	641,095	867,364	1,282,190	1,734,728	2,602,092	3,209,247	5,468,165
Maryland	72,714	145,427	229,622	325,298	459,245	650,597	880,219	1,301,193	1,760,438	2,640,657	3,256,810	5,549,206
Massachusetts	72,921	145,842	230,277	326,226	460,554	652,451	882,728	1,304,902	1,765,456	2,648,184	3,266,093	5,565,024
Michigan	52,076	104,152	164,451	232,972	328,902	465,944	630,395	931,888	1,260,789	1,891,184	2,332,460	3,974,228
Minnesota	49,451	98,902	156,161	221,228	312,322	442,456	598,617	884,912	1,197,234	1,795,850	2,214,882	3,773,888
Mississippi	90,244	180,489	284,982	403,724	569,964	807,449	1,092,431	1,614,898	2,184,862	3,277,293	4,041,994	6,887,064
Missouri	63,161	126,323	199,457	282,564	398,914	565,129	764,586	1,130,257	1,529,172	2,293,758	2,828,968	4,820,216
Montana	20,256	40,513	63,968	90,621	127,935	181,242	245,209	362,484	490,419	735,628	907,275	1,545,886
Nebraska	48,692	97,383	153,763	217,831	307,526	435,661	589,424	871,323	1,178,848	1,768,273	2,180,870	3,715,935
Nevada	6,567	13,134	20,738	29,378	41,475	58,757	79,495	117,514	158,989	238,484	294,130	501,161
New Hampshire	69,179	138,357	218,459	309,483	436,917	618,966	837,425	1,237,932	1,674,849	2,512,274	3,098,471	5,279,416
New Jersey	80,817	161,633	255,210	361,548	510,421	723,096	978,307	1,446,193	1,956,613	2,934,920	3,619,735	6,167,586
New Mexico	26,580	53,160	83,937	118,911	167,875	237,823	321,760	475,645	643,520	965,281	1,190,513	2,028,488
New York	63,472	126,943	200,437	283,953	400,874	567,905	768,342	1,135,810	1,536,684	2,305,027	2,842,866	4,843,896
North Carolina	74,271	148,541	234,539	332,263	469,077	664,526	899,065	1,329,052	1,798,129	2,697,194	3,326,539	5,668,016

State	Model site size (acres)											
	1.9	3.8	6	8.5	12	17	23	34	46	69	85	145
North Dakota	27,663	55,327	87,358	123,757	174,715	247,513	334,871	495,027	669,742	1,004,613	1,239,023	2,111,144
Ohio	64,983	129,967	205,211	290,715	410,421	581,430	786,641	1,162,860	1,573,282	2,359,922	2,910,571	4,959,257
Oklahoma	56,430	112,861	178,201	252,451	356,402	504,903	683,104	1,009,805	1,366,207	2,049,311	2,527,484	4,306,523
Oregon	70,026	140,052	221,135	313,274	442,270	626,549	847,684	1,253,098	1,695,368	2,543,051	3,136,430	5,344,094
Pennsylvania	71,565	143,130	225,994	320,158	451,988	640,316	866,310	1,280,633	1,732,621	2,598,931	3,205,348	5,461,521
Rhode Island	76,941	153,883	242,973	344,211	485,945	688,423	931,395	1,376,845	1,862,790	2,794,185	3,446,162	5,871,839
South Carolina	78,161	156,322	246,824	349,668	493,649	699,336	946,160	1,398,672	1,892,321	2,838,481	3,500,793	5,964,924
South Dakota	27,679	55,358	87,407	123,826	174,813	247,652	335,059	495,305	670,118	1,005,177	1,239,718	2,112,329
Tennessee	79,292	158,584	250,396	354,727	500,791	709,454	959,850	1,418,908	1,919,700	2,879,549	3,551,444	6,051,227
Texas	55,927	111,855	176,613	250,201	353,225	500,403	677,015	1,000,805	1,354,030	2,031,046	2,504,956	4,268,139
Utah	25,034	50,068	79,055	111,994	158,110	223,989	303,043	447,977	606,087	909,130	1,121,261	1,910,491
Vermont	58,475	116,950	184,657	261,598	369,315	523,196	707,854	1,046,392	1,415,707	2,123,561	2,619,058	4,462,555
Virginia	69,392	138,784	219,132	310,438	438,265	620,875	840,007	1,241,750	1,680,015	2,520,022	3,108,027	5,295,699
Washington	60,638	121,275	191,487	271,273	382,974	542,546	734,033	1,085,092	1,468,066	2,202,099	2,715,922	4,627,600
West Virginia	73,641	147,283	232,552	329,449	465,104	658,897	891,449	1,317,794	1,782,898	2,674,347	3,298,361	5,620,004
Wisconsin	54,119	108,239	170,903	242,113	341,807	484,226	655,130	968,453	1,310,260	1,965,390	2,423,981	4,130,167
Wyoming	25,340	50,679	80,020	113,361	160,040	226,723	306,743	453,446	613,485	920,228	1,134,948	1,933,812
Puerto Rico	87,290	174,579	275,651	390,506	551,302	781,012	1,056,663	1,562,023	2,113,326	3,169,988	3,909,652	6,661,570
District of Columbia	71,780	143,560	226,673	321,120	453,346	642,240	868,913	1,284,481	1,737,827	2,606,740	3,214,979	5,477,932

Table 9-8. ATS system flowrate required (gpm)

State	Model site size (acres)											
	1.9	3.8	6	8.5	12	17	23	34	46	69	85	145
Alabama	39	78	123	174	245	347	470	695	940	1,410	1,738	2,962
Arizona	7	15	23	33	47	66	90	133	180	269	332	566
Arkansas	37	74	116	165	232	329	445	658	890	1,336	1,647	2,807
California	13	26	40	57	81	115	155	229	310	466	574	979
Colorado	12	24	38	54	77	108	147	217	294	440	543	925
Connecticut	23	46	73	104	146	207	280	415	561	841	1,038	1,768
Delaware	25	49	78	110	156	220	298	441	596	894	1,103	1,880
Florida	44	88	139	197	278	394	532	787	1,065	1,597	1,970	3,357
Georgia	30	59	94	133	187	265	359	531	718	1,078	1,329	2,264
Hawaii	42	85	134	189	267	379	512	758	1,025	1,537	1,896	3,231
Idaho	5	10	16	23	33	47	63	93	126	189	234	398
Illinois	22	43	68	97	137	194	262	388	525	787	971	1,655
Indiana	23	46	72	103	145	205	277	410	555	832	1,027	1,749
Iowa	25	50	78	111	157	222	300	444	600	900	1,110	1,892
Kansas	27	55	87	123	173	245	332	491	664	996	1,228	2,093
Kentucky	23	46	73	103	146	206	279	412	558	837	1,032	1,758
Louisiana	51	103	162	230	325	460	623	921	1,246	1,868	2,304	3,926
Maine	22	44	70	99	140	199	269	397	537	806	994	1,693
Maryland	24	48	76	108	153	216	293	433	586	878	1,083	1,846
Massachusetts	23	46	72	103	145	205	278	411	556	834	1,028	1,752
Michigan	15	30	47	67	94	133	180	267	361	541	667	1,137
Minnesota	21	41	65	92	130	184	249	368	498	746	920	1,568
Mississippi	40	80	126	179	252	358	484	715	967	1,451	1,790	3,050
Missouri	28	56	89	126	178	252	341	505	683	1,024	1,263	2,153
Montana	6	13	20	29	40	57	78	115	155	233	287	489
Nebraska	19	37	59	84	118	167	226	334	452	679	837	1,426
Nevada	4	9	14	20	28	40	54	79	108	161	199	339
New Hampshire	20	40	63	89	126	178	241	357	483	724	894	1,522
New Jersey	26	52	82	116	164	232	314	464	628	942	1,162	1,980
New Mexico	8	17	27	38	53	76	102	151	205	307	379	645
New York	22	45	70	100	141	199	270	399	540	810	998	1,701
North Carolina	26	52	82	116	164	232	314	464	628	942	1,162	1,979

State	Model site size (acres)											
	1.9	**3.8**	**6**	**8.5**	**12**	**17**	**23**	**34**	**46**	**69**	**85**	**145**
North Dakota	11	22	35	49	70	99	134	198	268	402	495	844
Ohio	21	41	65	92	130	184	249	369	499	748	923	1,572
Oklahoma	30	60	95	135	191	270	366	541	731	1,097	1,353	2,306
Oregon	18	36	57	81	114	162	219	323	438	656	810	1,380
Pennsylvania	26	51	81	114	161	228	309	456	618	926	1,143	1,947
Rhode Island	24	48	75	107	150	213	288	426	577	865	1,067	1,817
South Carolina	29	58	91	129	182	258	349	515	697	1,046	1,290	2,198
South Dakota	16	31	49	70	99	140	189	279	378	567	699	1,191
Tennessee	27	53	84	119	168	238	322	477	645	967	1,193	2,032
Texas	34	68	108	153	216	306	414	612	829	1,243	1,533	2,612
Utah	8	15	24	34	47	67	91	134	182	273	337	573
Vermont	18	35	56	79	111	157	213	315	426	639	788	1,342
Virginia	23	47	74	105	148	210	284	420	569	853	1,052	1,793
Washington	12	24	37	53	74	105	142	210	285	427	527	898
West Virginia	19	37	59	84	118	167	226	334	452	678	837	1,426
Wisconsin	19	39	61	87	122	173	234	346	469	703	867	1,477
Wyoming	9	18	29	41	58	82	110	163	221	331	408	695
Puerto Rico	37	74	116	165	233	329	446	659	891	1,337	1,649	2,809
District of Columbia	24	48	76	108	153	216	293	433	586	878	1,083	1,846

Table 9-9. ATS system flowrate selected for costing (gpm)

State	Model site size (acres)											
	1.9	3.8	6	8.5	12	17	23	34	46	69	85	145
Alabama	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000	3,000
Arizona	100	100	100	100	100	100	100	500	500	500	500	1,000
Arkansas	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000	3,000
California	100	100	100	100	100	500	500	500	500	500	1,000	1,000
Colorado	100	100	100	100	100	500	500	500	500	500	1,000	1,000
Connecticut	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000
Delaware	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000
Florida	100	100	500	500	500	500	1,000	1,000	1,500	2,000	2,000	3,500
Georgia	100	100	100	500	500	500	500	1,000	1,000	1,500	1,500	2,500
Hawaii	100	100	500	500	500	500	1,000	1,000	1,500	2,000	2,000	3,500
Idaho	100	100	100	100	100	100	100	100	500	500	500	500
Illinois	100	100	100	100	500	500	500	500	1,000	1,000	1,000	2,000
Indiana	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000
Iowa	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000
Kansas	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,500
Kentucky	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000
Louisiana	100	500	500	500	500	500	1,000	1,000	1,500	2,000	2,500	4,000
Maine	100	100	100	100	500	500	500	500	1,000	1,000	1,000	2,000
Maryland	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000
Massachusetts	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000
Michigan	100	100	100	100	100	500	500	500	500	1,000	1,000	1,500
Minnesota	100	100	100	100	500	500	500	500	500	1,000	1,000	2,000
Mississippi	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000	3,500
Missouri	100	100	100	500	500	500	500	1,000	1,000	1,500	1,500	2,500
Montana	100	100	100	100	100	100	100	500	500	500	500	500
Nebraska	100	100	100	100	500	500	500	500	500	1,000	1,000	1,500
Nevada	100	100	100	100	100	100	100	100	500	500	500	500
New Hampshire	100	100	100	100	500	500	500	500	500	1,000	1,000	2,000
New Jersey	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000
New Mexico	100	100	100	100	100	100	500	500	500	500	500	1,000
New York	100	100	100	100	500	500	500	500	1,000	1,000	1,000	2,000
North Carolina	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000

State	Model site size (acres)											
	1.9	3.8	6	8.5	12	17	23	34	46	69	85	145
North Dakota	100	100	100	100	100	100	500	500	500	500	500	1,000
Ohio	100	100	100	100	500	500	500	500	500	1,000	1,000	2,000
Oklahoma	100	100	100	500	500	500	500	1,000	1,000	1,500	1,500	2,500
Oregon	100	100	100	100	500	500	500	500	500	1,000	1,000	1,500
Pennsylvania	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000
Rhode Island	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000
South Carolina	100	100	100	500	500	500	500	1,000	1,000	1,500	1,500	2,500
South Dakota	100	100	100	100	100	500	500	500	500	1,000	1,000	1,500
Tennessee	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,500
Texas	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000	3,000
Utah	100	100	100	100	100	100	100	500	500	500	500	1,000
Vermont	100	100	100	100	500	500	500	500	500	1,000	1,000	1,500
Virginia	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000
Washington	100	100	100	100	100	500	500	500	500	500	1,000	1,000
West Virginia	100	100	100	100	500	500	500	500	500	1,000	1,000	1,500
Wisconsin	100	100	100	100	500	500	500	500	500	1,000	1,000	1,500
Wyoming	100	100	100	100	100	100	500	500	500	500	500	1,000
Puerto Rico	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000	3,000
District of Columbia	100	100	100	500	500	500	500	500	1,000	1,000	1,500	2,000

9.3. ESTIMATION OF COSTS

EPA estimated costs for the regulatory options using three categories of costs: erosion and sediment controls (ESCs), ATS storage and treatment costs, and passive treatment costs. The components of the estimated costs are discussed below.

9.3.1. EROSION AND SEDIMENT CONTROL COSTS

EPA estimated costs for ESCs under baseline conditions as well as incremental costs as a result of the regulatory options. Estimating baseline costs was necessary to conduct the BCT cost test. While a variety of controls are likely to be used on individual construction sites, EPA does not have any comprehensive data on current practices because a survey of the industry was not conducted. Therefore, EPA made assumptions about controls employed for each of the model projects as a way of estimating baseline industry costs. EPA assumes that baseline controls would consist of sediment basins (for sites greater than 10 acres), silt fence, and soil cover.

For estimating basin unit costs, EPA determined existing state sediment basin sizing requirements on the basis of a review of state permits. Table 9-6 shows the baseline sediment basins sizing requirements for each state. Table 9-11 shows the corresponding baseline basin size for each the model projecs greater than 10 acres. Descriptions of sediment traps and basins, including design criteria, performance, and costs are described in detail in Section 7.2.3.

EPA (1993) references the Southeastern Wisconsin Regional Planning Commission's 1991 Costs of Urban Nonpoint Source Water Pollution Control Measures (SWRPC 1991) for estimating costs of temporary sediment basins. Costs include site preparation (e.g., grading, excavation, place and compact fill), site development (e.g., riprap, temporary basin inlet and outlet structures), and contingencies. Temporary basins are a generally less expensive option as compared to permanent basins (e.g., SWRPC assumes temporary basin inlet and outlet costs to be one-half of permanent detention basin inlet and outlet costs). Table 9-10 summarizes the cost data EPA used for estimating sediment basin costs. EPA used the average value of $0.30 per cubic foot of storage for calculating incremental costs for sediment basins and for storage volumes required for ATS. EPA adjusted all sediment basin costs from 1989 dollars to 2008 dollars.

Table 9-10. Sediment basin construction cost data

Cost data source	Cost	Basin size range of validity	Basis year
USEPA (1993), original reference is SWRPC (1991). Numerous sources reference this data. Many of these sources adjusted USEPA (1993) to other basis years.	$0.10 to $0.40 per cubic foot of storage, average of $0.30.	12,000 ft^3 to 195,000 ft^3 SWRPC (1991)	1989

EPA (1993) estimates annual operation and maintenance costs for temporary sediment basins (associated with runoff from active construction sites) as 25 percent of construction costs. EPA used this value to estimate costs for sediment basins.

Capital and annual cost data for basins were standardized to 2008 dollars on the basis of the *Engineering News-Record* (ENR) Construction Cost Index (CCI). The sediment basin cost reference used by EPA was based on a study completed in 1989. The ENR CCI in 1989 was 4,615, and the value in February of 2008 was 8,084. EPA adjusted sediment basin costs obtained in 1989 dollars to 2008 dollars by increasing costs by 57 percent (8,084 / 4,615 = 1.57). All other data was obtained in 2008 and 2009, so no standardization was necessary to arrive at year 2008 costs. Table 9-11 shows the baseline sediment basin size, and Table 9-12 shows the baseline sediment basin costs for each state and the District of Columbia for each of the model site sizes greater than 10 acres.

Table 9-11. Baseline sediment basin size (cubic feet)

State	Site size (acres)							
	12	17	23	34	46	69	85	145
Alabama	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
Arizona	27,048	38,318	51,842	76,636	103,684	155,526	191,815	326,830
Alaska	6,144	8,704	11,776	17,408	23,552	35,328	43,571	74,240
Arkansas	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
California	40,662	57,605	77,936	115,209	155,872	233,807	288,362	491,334
Colorado	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
Connecticut	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Delaware	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Florida	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Georgia	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
Hawaii	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Idaho	19,020	26,945	36,455	53,890	72,910	109,365	134,884	229,825
Illinois	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Indiana	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
Iowa	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Kansas	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Kentucky	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Louisiana	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Maine	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Maryland	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Massachusetts	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Michigan	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Minnesota	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Mississippi	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Missouri	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Montana	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
Nebraska	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
Nevada	16,200	22,950	31,050	45,900	62,100	93,150	114,885	195,750
New Hampshire	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
New Jersey	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
New Mexico	30,840	43,690	59,110	87,380	118,220	177,330	218,707	372,650

State	Site size (acres)							
	12	17	23	34	46	69	85	145
New York	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
North Carolina	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
North Dakota	40,332	57,137	77,303	114,274	154,606	231,909	286,021	487,345
Ohio	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
Oklahoma	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Oregon	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Pennsylvania	60,000	85,000	115,000	170,000	230,000	345,000	425,500	725,000
Rhode Island	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
South Carolina	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
South Dakota	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Tennessee	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Texas	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Utah	37,188	52,683	71,277	105,366	142,554	213,831	263,725	449,355
Vermont	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
Virginia	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Washington	6,144	8,704	11,776	17,408	23,552	35,328	43,571	74,240
West Virginia	43,200	61,200	82,800	122,400	165,600	248,400	306,360	522,000
Wisconsin	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
Wyoming	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000
District of Columbia	21,600	30,600	41,400	61,200	82,800	124,200	153,180	261,000

Table 9-12. Baseline sediment basins costs

State	Site size (acres)							
	12	17	23	34	46	69	85	145
Alabama	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
Arizona	$17,790	$25,202	$34,097	$50,405	$68,195	$102,292	$126,160	$214,961
Alaska	$4,041	$5,725	$7,745	$11,450	$15,491	$23,236	$28,657	$48,829
Arkansas	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
California	$26,744	$37,887	$51,260	$75,775	$102,519	$153,779	$189,660	$323,158
Colorado	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
Connecticut	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Delaware	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Florida	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Georgia	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
Hawaii	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Idaho	$12,510	$17,722	$23,977	$35,444	$47,954	$71,931	$88,715	$151,159
Illinois	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Indiana	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
Iowa	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Kansas	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Kentucky	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Louisiana	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Maine	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Maryland	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Massachusetts	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Michigan	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327

State	Site size (acres)							
	12	17	23	34	46	69	85	145
Minnesota	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Mississippi	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Missouri	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Montana	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
Nebraska	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
Nevada	$10,655	$15,095	$20,422	$30,189	$40,844	$61,266	$75,562	$128,748
New Hampshire	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
New Jersey	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
New Mexico	$20,284	$28,736	$38,878	$57,471	$77,755	$116,633	$143,847	$245,098
New York	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
North Carolina	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
North Dakota	$26,527	$37,580	$50,843	$75,160	$101,687	$152,530	$188,120	$320,534
Ohio	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
Oklahoma	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Oregon	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Pennsylvania	$39,463	$55,906	$75,637	$111,812	$151,274	$226,912	$279,858	$476,843
Rhode Island	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
South Carolina	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
South Dakota	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Tennessee	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Texas	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Utah	$24,459	$34,650	$46,880	$69,301	$93,760	$140,640	$173,456	$295,548
Vermont	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
Virginia	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Washington	$4,041	$5,725	$7,745	$11,450	$15,491	$23,236	$28,657	$48,829
West Virginia	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327
Wisconsin	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
Wyoming	$14,207	$20,126	$27,229	$40,252	$54,459	$81,688	$100,749	$171,664
District of Columbia	$28,413	$40,252	$54,459	$80,504	$108,918	$163,376	$201,498	$343,327

Under baseline conditions, EPA also calculated costs for installing silt fence and costs for installing temporary soil cover. For silt fence, EPA assumes that silt fence would be installed around the entire perimeter of the site. The perimeter was calculated assuming the sites were square. For temporary cover, EPA assumes that a percentage of the project would require cover, ranging from 10 percent for the 1.9-acre model project to 20 percent for the 145-acre model project. Costs for silt fence and temporary cover do not vary geographically because the controls are only a function of site size. R.S. Means (2000) reports that a 3-foot-tall silt fence installation costs between $0.68 and $0.92 per linear foot (for favorable and challenging installations). EPA used a cost of $0.92 per linear foot for estimating baseline silt fence costs. For temporary cover, EPA used an average cost based on a range of several types of temporary cover (see Table 9-13). Table 9-14 shows the baseline costs assumptions for silt fence and temporary cover.

Table 9-13. Temporary cover costs

Type	Installed cost (per acre)
Jute mesh	$6,500
Curled wood fiber	$10,500
Straw	$8,900
Wood fiber	$8,900
Coconut fiber	$13,000
Straw coconut fiber	$10,900
AVERAGE	$9,783

Table 9-14. Baseline silt fence and temporary cover assumptions and costs

Site size (acres)	% Cover	Cost cover	Length silt fence (ft)	Cost silt fence
1.9	10%	$1,859	288	$265
3.8	10.1%	$3,767	407	$374
6.0	10.3%	$6,038	511	$470
8.5	10.5%	$8,699	608	$559
12.0	10.7%	$12,569	723	$665
17.0	11.1%	$18,387	861	$792
23.0	11.5%	$25,820	1,001	$921
34.0	12.2%	$40,727	1,217	$1,120
46.0	13.1%	$58,876	1,416	$1,303
69.0	14.7%	$99,167	1,734	$1,595
85.1	15.8%	$131,675	1,925	$1,771
145.0	20%	$283,717	2,513	$2,312

EPA also estimated costs for installing surface outlets on basins. EPA developed these costs on the basis of an assumed 3-day drain time for sediment basins and assumptions about the number of basins contained on projects of different sizes in Table 9-15. Surface outlet costs are a function of the outlet size, which is a function of the flowrate needed to drain the basin in the specified period. Table 9-16 shows the assumptions used to develop costs for outlets of various size. Table 9-17 shows the per-state costs for surface outlets for the various model project sizes. When calculating costs for linear projects, the per-project costs in Table 9-16 were multiplied by 3 to account for the larger number of basins that might be present on linear projects.

Table 9-15. Basin assumptions

Site size (acres)	# of basins	Site size (acres)	# of basins
145	4	34	2
85.1	3	23	2
69	3	17	1
46	2	12	1

Table 9-16. Surface outlet cost assumptions

Skimmer size (inches)	Price per skimmer	Shipping	Ancillary equipment	Installation labor	Cubic feet drained per day	Cubic feet drained over 3 days	Total cost
1.5	$435	$20	$30	$600	1,728	5,184	$1,085
2	$535	$20	$30	$600	3,283	9,849	$1,185
2.5	$660	$22	$30	$600	6,234	18,702	$1,312
3	$795	$25	$30	$600	9,774	29,322	$1,450
4	$1,135	$32	$30	$600	20,109	60,327	$1,797
5	$1,655	$155	$30	$600	32,832	98,496	$2,440
6	$2,470	$280	$30	$600	51,840	155,520	$3,380
8	$3,900	$500	$30	$600	97,978	293,934	$5,030

Notes:

- Faircloth recommends 3 days to drain. EPA used 3 days for all states for cost estimates.
- Ancillary costs (pipe, glue) estimated as $30 for all sizes.
- Assumed 8 hours assembly time x $75/hour for installation.

Table 9-17. Costs for surface outlets

State	Site size (acres)							
	12	17	23	34	46	69	85.1	145
Alabama	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Alaska	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Arizona	$1,450	$1,797	$2,900	$3,594	$3,594	$5,391	$7,320	$9,760
Arkansas	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
California	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Colorado	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Connecticut	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Delaware	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
District of Columbia	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Florida	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Georgia	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Hawaii	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Idaho	$1,450	$1,450	$2,624	$2,900	$3,594	$5,391	$5,391	$7,188
Illinois	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Indiana	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Iowa	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Kansas	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Kentucky	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Louisiana	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Maine	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Maryland	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Massachusetts	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Michigan	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Minnesota	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Mississippi	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Missouri	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Montana	$1,450	$1,797	$2,900	$3,594	$3,594	$5,391	$5,391	$9,760
Nebraska	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520

State	Site size (acres)							
	12	17	23	34	46	69	85.1	145
Nevada	$1,312	$1,450	$2,624	$2,900	$3,594	$5,391	$5,391	$7,188
New Hampshire	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
New Jersey	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
New Mexico	$1,797	$1,797	$2,900	$3,594	$3,594	$5,391	$7,320	$13,520
New York	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
North Carolina	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
North Dakota	$1,797	$1,797	$3,594	$3,594	$4,880	$7,320	$7,320	$13,520
Ohio	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Oklahoma	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Oregon	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Pennsylvania	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Rhode Island	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
South Carolina	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
South Dakota	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Tennessee	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Texas	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Utah	$1,450	$1,797	$2,900	$3,594	$3,594	$5,391	$7,320	$9,760
Vermont	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Virginia	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Washington	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
West Virginia	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Wisconsin	$1,797	$2,440	$3,594	$4,880	$4,880	$7,320	$7,320	$13,520
Wyoming	$1,797	$1,797	$3,594	$3,594	$4,880	$7,320	$7,320	$13,520

9.3.2. PASSIVE TREATMENT COSTS

EPA estimated costs for passive treatment on the basis of implementing a liquid polymer dosing system for sediment basins and compost filter berms. For a liquid polymer dosing system, a study conducted in Auckland, New Zealand, indicates that the cost for a rainfall-driven system ranges from $2,400 NZ to $12,000 NZ ($1,600 to $8,000 U.S.). EPA used the average of the two values, $4,800, as an estimate of the cost for implementing such a system at each sediment basin. EPA also estimated using best professional judgment (BPJ) that $500 per month, per system, would be required for operation and maintenance. Chemical requirements were based on an estimate of $1,000 per million gallons treated. EPA made various assumptions about the number of laborers and the hours of labor per storm event required for sampling. Those assumptions, as well as the costs for labor (assuming a labor rate of $30 per hour) and the polymer dosing system costs are presented in Table 9-18 for the various model project sizes.

For filter berms, EPA used the same assumptions used for estimating silt fence length under baseline conditions (berms installed around the entire perimeter). EPA used a cost of $1.70 per linear foot installed. The costs assumptions for filter berms are in Table 9-19.

Tables 9-20 through 9-22 show monthly treatment volumes and associated monthly costs for passive treatment. Appendix I shows the per-project costs for all options.

Table 9-18. Passive treatment unit costs: polymer dosing system and labor

Site size (acres)	# Basins	Cost polymer dosing system	Monthly O&M	Sampling laborers	# Events per month monitored	Labor hours per event	Labor cost per event	Monthly labor cost
1.9	0	$-	$-	1	2	4	$120	$240
3.8	1	$4,800	$500	1	2	4	$120	$240
6.0	1	$4,800	$500	1	2	4	$120	$240
8.5	1	$4,800	$500	1	2	4	$120	$240
12.0	1	$4,800	$500	1	2	4	$120	$240
17.0	1	$4,800	$500	1	2	4	$120	$240
23.0	2	$9,600	$1,000	1	2	4	$120	$240
34.0	2	$9,600	$1,000	1	2	4	$120	$240
46.0	2	$9,600	$1,000	2	2	4	$240	$480
69.0	3	$14,400	$1,500	2	2	4	$240	$480
85.1	3	$14,400	$1,500	2	2	4	$240	$480
145.0	4	$19,200	$2,000	3	2	4	$360	$720

Table 9-19. Passive treatment unit costs: filter berms

Site size (acres)	Project length (ft)	Length filter berms (ft)	Cost filter berms
1.9	72	288	$490
3.8	102	407	$692
6.0	128	511	$869
8.5	152	608	$1,034
12.0	181	723	$1,229
17.0	215	861	$1,464
23.0	250	1,001	$1,702
34.0	304	1,217	$2,069
46.0	354	1,416	$2,407
69.0	434	1,734	$2,948
85.1	481	1,925	$3,273
145.0	628	2,513	$4,272

Table 9-20. Monthly treatment volumes for passive treatment (gallons)

Site size (acres)	1.9	3.8	6.0	8.5	12.0	17.0	23.0	34.0	46.0	69.0	85.1	145.0
Alabama	84,331	168,662	266,308	377,270	532,617	754,540	1,020,849	1,509,081	2,041,697	3,062,546	3,777,140	6,435,785
Alaska	60,638	121,275	191,487	271,273	382,974	542,546	734,033	1,085,092	1,468,066	2,202,099	2,715,922	4,627,600
Arizona	13,309	26,617	42,028	59,539	84,055	119,078	161,106	238,156	322,212	483,317	596,091	1,015,667
Arkansas	81,888	163,775	258,593	366,340	517,185	732,679	991,272	1,465,359	1,982,544	2,973,816	3,667,707	6,249,324
California	31,628	63,256	99,878	141,494	199,756	282,988	382,866	565,976	765,732	1,148,598	1,416,604	2,413,720
Colorado	22,885	45,770	72,269	102,381	144,537	204,761	277,030	409,522	554,060	831,089	1,025,010	1,746,492
Connecticut	76,378	152,755	241,193	341,690	482,385	683,379	924,572	1,366,758	1,849,143	2,773,715	3,420,915	5,828,821
Delaware	73,984	147,968	233,634	330,981	467,267	661,962	895,596	1,323,924	1,791,191	2,686,787	3,313,704	5,646,147
District of Columbia	72,714	145,427	229,622	325,298	459,245	650,597	880,219	1,301,193	1,760,438	2,640,657	3,256,810	5,549,206
Florida	106,642	213,284	336,764	477,083	673,528	954,165	1,290,930	1,908,331	2,581,859	3,872,789	4,776,440	8,138,469
Georgia	87,456	174,911	276,176	391,249	552,352	782,499	1,058,674	1,564,997	2,117,349	3,176,023	3,917,096	6,674,252
Hawaii	31,452	62,905	99,323	140,708	198,647	281,417	380,740	562,833	761,480	1,142,220	1,408,738	2,400,317
Idaho	19,491	38,983	61,552	87,198	123,104	174,397	235,949	348,794	471,897	707,846	873,010	1,487,503
Illinois	56,824	113,648	179,444	254,213	358,888	508,425	687,869	1,016,850	1,375,739	2,063,608	2,545,117	4,336,568
Indiana	68,246	136,492	215,514	305,312	431,028	610,623	826,137	1,221,247	1,652,275	2,478,412	3,056,709	5,208,258
Iowa	54,449	108,899	171,945	243,589	343,891	487,178	659,124	974,357	1,318,248	1,977,371	2,438,758	4,155,346
Kansas	63,087	126,174	199,222	282,231	398,443	564,462	763,683	1,128,923	1,527,367	2,291,050	2,825,628	4,814,525
Kentucky	77,407	154,815	244,445	346,297	488,889	692,593	937,038	1,385,186	1,874,076	2,811,113	3,467,040	5,907,412
Louisiana	101,070	202,140	319,168	452,155	638,336	904,309	1,223,478	1,808,619	2,446,955	3,670,433	4,526,867	7,713,228
Maine	71,652	143,304	226,269	320,548	452,538	641,095	867,364	1,282,190	1,734,728	2,602,092	3,209,247	5,468,165
Maryland	72,714	145,427	229,622	325,298	459,245	650,597	880,219	1,301,193	1,760,438	2,640,657	3,256,810	5,549,206
Massachusetts	72,921	145,842	230,277	326,226	460,554	652,451	882,728	1,304,902	1,765,456	2,648,184	3,266,093	5,565,024
Michigan	52,076	104,152	164,451	232,972	328,902	465,944	630,395	931,888	1,260,789	1,891,184	2,332,460	3,974,228
Minnesota	49,451	98,902	156,161	221,228	312,322	442,456	598,617	884,912	1,197,234	1,795,850	2,214,882	3,773,888
Mississippi	90,244	180,489	284,982	403,724	569,964	807,449	1,092,431	1,614,898	2,184,862	3,277,293	4,041,994	6,887,064
Missouri	63,161	126,323	199,457	282,564	398,914	565,129	764,586	1,130,257	1,529,172	2,293,758	2,828,968	4,820,216
Montana	20,256	40,513	63,968	90,621	127,935	181,242	245,209	362,484	490,419	735,628	907,275	1,545,886
Nebraska	48,692	97,383	153,763	217,831	307,526	435,661	589,424	871,323	1,178,848	1,768,273	2,180,870	3,715,935
Nevada	6,567	13,134	20,738	29,378	41,475	58,757	79,495	117,514	158,989	238,484	294,130	501,161
New Hampshire	69,179	138,357	218,459	309,483	436,917	618,966	837,425	1,237,932	1,674,849	2,512,274	3,098,471	5,279,416
New Jersey	80,817	161,633	255,210	361,548	510,421	723,096	978,307	1,446,193	1,956,613	2,934,920	3,619,735	6,167,586

Site size (acres)	1.9	3.8	6.0	8.5	12.0	17.0	23.0	34.0	46.0	69.0	85.1	145.0
New Mexico	26,580	53,160	83,937	118,911	167,875	237,823	321,760	475,645	643,520	965,281	1,190,513	2,028,488
New York	63,472	126,943	200,437	283,953	400,874	567,905	768,342	1,135,810	1,536,684	2,305,027	2,842,866	4,843,896
North Carolina	74,271	148,541	234,539	332,263	469,077	664,526	899,065	1,329,052	1,798,129	2,697,194	3,326,539	5,668,016
North Dakota	27,663	55,327	87,358	123,757	174,715	247,513	334,871	495,027	669,742	1,004,613	1,239,023	2,111,144
Ohio	64,983	129,967	205,211	290,715	410,421	581,430	786,641	1,162,860	1,573,282	2,359,922	2,910,571	4,959,257
Oklahoma	56,430	112,861	178,201	252,451	356,402	504,903	683,104	1,009,805	1,366,207	2,049,311	2,527,484	4,306,523
Oregon	70,026	140,052	221,135	313,274	442,270	626,549	847,684	1,253,098	1,695,368	2,543,051	3,136,430	5,344,094
Pennsylvania	71,565	143,130	225,994	320,158	451,988	640,316	866,310	1,280,633	1,732,621	2,598,931	3,205,348	5,461,521
Rhode Island	76,941	153,883	242,973	344,211	485,945	688,423	931,395	1,376,845	1,862,790	2,794,185	3,446,162	5,871,839
South Carolina	78,161	156,322	246,824	349,668	493,649	699,336	946,160	1,398,672	1,892,321	2,838,481	3,500,793	5,964,924
South Dakota	27,679	55,358	87,407	123,826	174,813	247,652	335,059	495,305	670,118	1,005,177	1,239,718	2,112,329
Tennessee	79,292	158,584	250,396	354,727	500,791	709,454	959,850	1,418,908	1,919,700	2,879,549	3,551,444	6,051,227
Texas	55,927	111,855	176,613	250,201	353,225	500,403	677,015	1,000,805	1,354,030	2,031,046	2,504,956	4,268,139
Utah	25,034	50,068	79,055	111,994	158,110	223,989	303,043	447,977	606,087	909,130	1,121,261	1,910,491
Vermont	58,475	116,950	184,657	261,598	369,315	523,196	707,854	1,046,392	1,415,707	2,123,561	2,619,058	4,462,555
Virginia	69,392	138,784	219,132	310,438	438,265	620,875	840,007	1,241,750	1,680,015	2,520,022	3,108,027	5,295,699
Washington	60,638	121,275	191,487	271,273	382,974	542,546	734,033	1,085,092	1,468,066	2,202,099	2,715,922	4,627,600
West Virginia	73,641	147,283	232,552	329,449	465,104	658,897	891,449	1,317,794	1,782,898	2,674,347	3,298,361	5,620,004
Wisconsin	54,119	108,239	170,903	242,113	341,807	484,226	655,130	968,453	1,310,260	1,965,390	2,423,981	4,130,167
Wyoming	25,340	50,679	80,020	113,361	160,040	226,723	306,743	453,446	613,485	920,228	1,134,948	1,933,812

Table 9-21. Monthly chemical cost for passive treatment

Site size (acres)	1.9	3.8	6.0	8.5	12.0	17.0	23.0	34.0	46.0	69.0	85.1	145.0
Alabama	$84	$169	$266	$377	$533	$755	$1,021	$1,509	$2,042	$3,063	$3,777	$6,436
Alaska	$61	$121	$191	$271	$383	$543	$734	$1,085	$1,468	$2,202	$2,716	$4,628
Arizona	$13	$27	$42	$60	$84	$119	$161	$238	$322	$483	$596	$1,016
Arkansas	$82	$164	$259	$366	$517	$733	$991	$1,465	$1,983	$2,974	$3,668	$6,249
California	$32	$63	$100	$141	$200	$283	$383	$566	$766	$1,149	$1,417	$2,414
Colorado	$23	$46	$72	$102	$145	$205	$277	$410	$554	$831	$1,025	$1,746
Connecticut	$76	$153	$241	$342	$482	$683	$925	$1,367	$1,849	$2,774	$3,421	$5,829
Delaware	$74	$148	$234	$331	$467	$662	$896	$1,324	$1,791	$2,687	$3,314	$5,646
District of Columbia	$73	$145	$230	$325	$459	$651	$880	$1,301	$1,760	$2,641	$3,257	$5,549
Florida	$107	$213	$337	$477	$674	$954	$1,291	$1,908	$2,582	$3,873	$4,776	$8,138
Georgia	$87	$175	$276	$391	$552	$782	$1,059	$1,565	$2,117	$3,176	$3,917	$6,674
Hawaii	$31	$63	$99	$141	$199	$281	$381	$563	$761	$1,142	$1,409	$2,400
Idaho	$19	$39	$62	$87	$123	$174	$236	$349	$472	$708	$873	$1,488
Illinois	$57	$114	$179	$254	$359	$508	$688	$1,017	$1,376	$2,064	$2,545	$4,337
Indiana	$68	$136	$216	$305	$431	$611	$826	$1,221	$1,652	$2,478	$3,057	$5,208
Iowa	$54	$109	$172	$244	$344	$487	$659	$974	$1,318	$1,977	$2,439	$4,155
Kansas	$63	$126	$199	$282	$398	$564	$764	$1,129	$1,527	$2,291	$2,826	$4,815
Kentucky	$77	$155	$244	$346	$489	$693	$937	$1,385	$1,874	$2,811	$3,467	$5,907
Louisiana	$101	$202	$319	$452	$638	$904	$1,223	$1,809	$2,447	$3,670	$4,527	$7,713
Maine	$72	$143	$226	$321	$453	$641	$867	$1,282	$1,735	$2,602	$3,209	$5,468
Maryland	$73	$145	$230	$325	$459	$651	$880	$1,301	$1,760	$2,641	$3,257	$5,549
Massachusetts	$73	$146	$230	$326	$461	$652	$883	$1,305	$1,765	$2,648	$3,266	$5,565
Michigan	$52	$104	$164	$233	$329	$466	$630	$932	$1,261	$1,891	$2,332	$3,974
Minnesota	$49	$99	$156	$221	$312	$442	$599	$885	$1,197	$1,796	$2,215	$3,774
Mississippi	$90	$180	$285	$404	$570	$807	$1,092	$1,615	$2,185	$3,277	$4,042	$6,887
Missouri	$63	$126	$199	$283	$399	$565	$765	$1,130	$1,529	$2,294	$2,829	$4,820
Montana	$20	$41	$64	$91	$128	$181	$245	$362	$490	$736	$907	$1,546
Nebraska	$49	$97	$154	$218	$308	$436	$589	$871	$1,179	$1,768	$2,181	$3,716
Nevada	$7	$13	$21	$29	$41	$59	$79	$118	$159	$238	$294	$501
New Hampshire	$69	$138	$218	$309	$437	$619	$837	$1,238	$1,675	$2,512	$3,098	$5,279
New Jersey	$81	$162	$255	$362	$510	$723	$978	$1,446	$1,957	$2,935	$3,620	$6,168
New Mexico	$27	$53	$84	$119	$168	$238	$322	$476	$644	$965	$1,191	$2,028

Site size (acres)	1.9	3.8	6.0	8.5	12.0	17.0	23.0	34.0	46.0	69.0	85.1	145.0
New York	$63	$127	$200	$284	$401	$568	$768	$1,136	$1,537	$2,305	$2,843	$4,844
North Carolina	$74	$149	$235	$332	$469	$665	$899	$1,329	$1,798	$2,697	$3,327	$5,668
North Dakota	$28	$55	$87	$124	$175	$248	$335	$495	$670	$1,005	$1,239	$2,111
Ohio	$65	$130	$205	$291	$410	$581	$787	$1,163	$1,573	$2,360	$2,911	$4,959
Oklahoma	$56	$113	$178	$252	$356	$505	$683	$1,010	$1,366	$2,049	$2,527	$4,307
Oregon	$70	$140	$221	$313	$442	$627	$848	$1,253	$1,695	$2,543	$3,136	$5,344
Pennsylvania	$72	$143	$226	$320	$452	$640	$866	$1,281	$1,733	$2,599	$3,205	$5,462
Rhode Island	$77	$154	$243	$344	$486	$688	$931	$1,377	$1,863	$2,794	$3,446	$5,872
South Carolina	$78	$156	$247	$350	$494	$699	$946	$1,399	$1,892	$2,838	$3,501	$5,965
South Dakota	$28	$55	$87	$124	$175	$248	$335	$495	$670	$1,005	$1,240	$2,112
Tennessee	$79	$159	$250	$355	$501	$709	$960	$1,419	$1,920	$2,880	$3,551	$6,051
Texas	$56	$112	$177	$250	$353	$500	$677	$1,001	$1,354	$2,031	$2,505	$4,268
Utah	$25	$50	$79	$112	$158	$224	$303	$448	$606	$909	$1,121	$1,910
Vermont	$58	$117	$185	$262	$369	$523	$708	$1,046	$1,416	$2,124	$2,619	$4,463
Virginia	$69	$139	$219	$310	$438	$621	$840	$1,242	$1,680	$2,520	$3,108	$5,296
Washington	$61	$121	$191	$271	$383	$543	$734	$1,085	$1,468	$2,202	$2,716	$4,628
West Virginia	$74	$147	$233	$329	$465	$659	$891	$1,318	$1,783	$2,674	$3,298	$5,620
Wisconsin	$54	$108	$171	$242	$342	$484	$655	$968	$1,310	$1,965	$2,424	$4,130
Wyoming	$25	$51	$80	$113	$160	$227	$307	$453	$613	$920	$1,135	$1,934

Table 9-22. Total monthly cost for passive treatment

Site Size (acres)	1.9	3.8	6.0	8.5	12.0	17.0	23.0	34.0	46.0	69.0	85.1	145.0
Alabama	$324	$909	$1,006	$1,117	$1,273	$1,495	$2,261	$2,749	$3,522	$5,043	$5,757	$9,156
Alaska	$301	$861	$931	$1,011	$1,123	$1,283	$1,974	$2,325	$2,948	$4,182	$4,696	$7,348
Arizona	$253	$767	$782	$800	$824	$859	$1,401	$1,478	$1,802	$2,463	$2,576	$3,736
Arkansas	$322	$904	$999	$1,106	$1,257	$1,473	$2,231	$2,705	$3,463	$4,954	$5,648	$8,969
California	$272	$803	$840	$881	$940	$1,023	$1,623	$1,806	$2,246	$3,129	$3,397	$5,134
Colorado	$263	$786	$812	$842	$885	$945	$1,517	$1,650	$2,034	$2,811	$3,005	$4,466
Connecticut	$316	$893	$981	$1,082	$1,222	$1,423	$2,165	$2,607	$3,329	$4,754	$5,401	$8,549
Delaware	$314	$888	$974	$1,071	$1,207	$1,402	$2,136	$2,564	$3,271	$4,667	$5,294	$8,366
District of Columbia	$313	$885	$970	$1,065	$1,199	$1,391	$2,120	$2,541	$3,240	$4,621	$5,237	$8,269
Florida	$347	$953	$1,077	$1,217	$1,414	$1,694	$2,531	$3,148	$4,062	$5,853	$6,756	$10,858
Georgia	$327	$915	$1,016	$1,131	$1,292	$1,522	$2,299	$2,805	$3,597	$5,156	$5,897	$9,394
Hawaii	$271	$803	$839	$881	$939	$1,021	$1,621	$1,803	$2,241	$3,122	$3,389	$5,120
Idaho	$259	$779	$802	$827	$863	$914	$1,476	$1,589	$1,952	$2,688	$2,853	$4,208
Illinois	$297	$854	$919	$994	$1,099	$1,248	$1,928	$2,257	$2,856	$4,044	$4,525	$7,057
Indiana	$308	$876	$956	$1,045	$1,171	$1,351	$2,066	$2,461	$3,132	$4,458	$5,037	$7,928
Iowa	$294	$849	$912	$984	$1,084	$1,227	$1,899	$2,214	$2,798	$3,957	$4,419	$6,875
Kansas	$303	$866	$939	$1,022	$1,138	$1,304	$2,004	$2,369	$3,007	$4,271	$4,806	$7,535
Kentucky	$317	$895	$984	$1,086	$1,229	$1,433	$2,177	$2,625	$3,354	$4,791	$5,447	$8,627
Louisiana	$341	$942	$1,059	$1,192	$1,378	$1,644	$2,463	$3,049	$3,927	$5,650	$6,507	$10,433
Maine	$312	$883	$966	$1,061	$1,193	$1,381	$2,107	$2,522	$3,215	$4,582	$5,189	$8,188
Maryland	$313	$885	$970	$1,065	$1,199	$1,391	$2,120	$2,541	$3,240	$4,621	$5,237	$8,269
Massachusetts	$313	$886	$970	$1,066	$1,201	$1,392	$2,123	$2,545	$3,245	$4,628	$5,246	$8,285
Michigan	$292	$844	$904	$973	$1,069	$1,206	$1,870	$2,172	$2,741	$3,871	$4,312	$6,694
Minnesota	$289	$839	$896	$961	$1,052	$1,182	$1,839	$2,125	$2,677	$3,776	$4,195	$6,494
Mississippi	$330	$920	$1,025	$1,144	$1,310	$1,547	$2,332	$2,855	$3,665	$5,257	$6,022	$9,607
Missouri	$303	$866	$939	$1,023	$1,139	$1,305	$2,005	$2,370	$3,009	$4,274	$4,809	$7,540
Montana	$260	$781	$804	$831	$868	$921	$1,485	$1,602	$1,970	$2,716	$2,887	$4,266
Nebraska	$289	$837	$894	$958	$1,048	$1,176	$1,829	$2,111	$2,659	$3,748	$4,161	$6,436
Nevada	$247	$753	$761	$769	$781	$799	$1,319	$1,358	$1,639	$2,218	$2,274	$3,221
New Hampshire	$309	$878	$958	$1,049	$1,177	$1,359	$2,077	$2,478	$3,155	$4,492	$5,078	$7,999
New Jersey	$321	$902	$995	$1,102	$1,250	$1,463	$2,218	$2,686	$3,437	$4,915	$5,600	$8,888
New Mexico	$267	$793	$824	$859	$908	$978	$1,562	$1,716	$2,124	$2,945	$3,171	$4,748

Site Size (acres)	**1.9**	**3.8**	**6.0**	**8.5**	**12.0**	**17.0**	**23.0**	**34.0**	**46.0**	**69.0**	**85.1**	**145.0**
New York	$303	$867	$940	$1,024	$1,141	$1,308	$2,008	$2,376	$3,017	$4,285	$4,823	$7,564
North Carolina	$314	$889	$975	$1,072	$1,209	$1,405	$2,139	$2,569	$3,278	$4,677	$5,307	$8,388
North Dakota	$268	$795	$827	$864	$915	$988	$1,575	$1,735	$2,150	$2,985	$3,219	$4,831
Ohio	$305	$870	$945	$1,031	$1,150	$1,321	$2,027	$2,403	$3,053	$4,340	$4,891	$7,679
Oklahoma	$296	$853	$918	$992	$1,096	$1,245	$1,923	$2,250	$2,846	$4,029	$4,507	$7,027
Oregon	$310	$880	$961	$1,053	$1,182	$1,367	$2,088	$2,493	$3,175	$4,523	$5,116	$8,064
Pennsylvania	$312	$883	$966	$1,060	$1,192	$1,380	$2,106	$2,521	$3,213	$4,579	$5,185	$8,182
Rhode Island	$317	$894	$983	$1,084	$1,226	$1,428	$2,171	$2,617	$3,343	$4,774	$5,426	$8,592
South Carolina	$318	$896	$987	$1,090	$1,234	$1,439	$2,186	$2,639	$3,372	$4,818	$5,481	$8,685
South Dakota	$268	$795	$827	$864	$915	$988	$1,575	$1,735	$2,150	$2,985	$3,220	$4,832
Tennessee	$319	$899	$990	$1,095	$1,241	$1,449	$2,200	$2,659	$3,400	$4,860	$5,531	$8,771
Texas	$296	$852	$917	$990	$1,093	$1,240	$1,917	$2,241	$2,834	$4,011	$4,485	$6,988
Utah	$265	$790	$819	$852	$898	$964	$1,543	$1,688	$2,086	$2,889	$3,101	$4,630
Vermont	$298	$857	$925	$1,002	$1,109	$1,263	$1,948	$2,286	$2,896	$4,104	$4,599	$7,183
Virginia	$309	$879	$959	$1,050	$1,178	$1,361	$2,080	$2,482	$3,160	$4,500	$5,088	$8,016
Washington	$301	$861	$931	$1,011	$1,123	$1,283	$1,974	$2,325	$2,948	$4,182	$4,696	$7,348
West Virginia	$314	$887	$973	$1,069	$1,205	$1,399	$2,131	$2,558	$3,263	$4,654	$5,278	$8,340
Wisconsin	$294	$848	$911	$982	$1,082	$1,224	$1,895	$2,208	$2,790	$3,945	$4,404	$6,850
Wyoming	$265	$791	$820	$853	$900	$967	$1,547	$1,693	$2,093	$2,900	$3,115	$4,654

9.3.3. ATS COSTS

EPA estimated costs for ATS using a combination of one-time costs, which accounts for items such as site preparation and installing storage, as well as recurring costs that account for items such as equipment rental, operator labor, and treatment chemicals. EPA estimates the size of the ATS system needed in each state for each model projects size on the basis of the system design flowrates in Table 9-9. On the basis of system flowrate, EPA estimated monthly equipment rental costs provided in vendor quotes (see Table 7-26) by scaling up the unit costs for a 500-gpm system to the desired system flowrate. EPA notes that this is a conservative assumption, because there are economies of scale that are not captured in this approach. For example, for a 1,000-gpm system, it might be more economical to rent one larger pump instead of two smaller pumps. However, the approach does provide reasonable, albeit conservative, estimates of costs. For labor and treatment chemical, the system run-time was estimated on the basis of the monthly treatment volumes (including an additional 10 percent for system startup and shutdown) and the associated chemical dosage rate and pump and generator fuel consumption. Operator labor was also included. For storage, EPA estimated basin storage volumes to impound runoff from the 2-year, 24-hour storm. If that volume was larger than the incremental sediment basin storage requirements contained in existing state permits, additional costs for storage were also calculated using the same methodology for estimating sediment basin costs described above. Costs were also estimated for periodic equipment servicing and for providing a stabilized pad consisting of crushed stone.

Table 9-23 shows the cost assumptions used for an ATS system for a flowrate of 500 gpm. For larger systems, costs were estimated as multiples of the values found in Table 9-24. For the 100-gpm system, it was assumed that a trailer-mounted system would be used with a rental cost of $10,000 per month.

Tables 9-24 and 9-25 show the one-time ATS and monthly ATS costs for the 12 model project sizes. Additional details of the costing approach are in the C&D Cost Spreadsheet Models. The ATS Cost Spreadsheet Model (DCN 43119) was used to estimate ATS treatment costs and storage costs, while the Unit Cost Spreadsheet Model (DCN 43120) was used to estimate ESC and passive treatment costs. The per-project costs under each of the regulatory options are in Appendix I. Model project costs were scaled to the national level using the distribution of projects described earlier. National compliance costs are described in the *Economic Analysis for Final Effluent Guidelines and Standards for the Construction and Development Category* (USEPA 2009).

Table 9-23. ATS costs: 500-gpm system

Equipment rental	**$/month**	**Quantity**	**Total $/mo**
Filter	$4,000	1	$4,000
System	$4,000	1	$4,000
Pump	$1,650	2	$3,300
Hose	$98	4	$392
Elbow	$36	2	$72
Genset	$1,050	1	$1,050
Tanks	$1,260	2	$2,520
Total Monthly Costs			**$15,334**
One-Time Costs			
Delivery	$1,485		
Pick-up	$1,485		
Stabilized pad (1600 SF @ $0.50/SF)	$800		
Calibration	$1,300		
Pipes, valves, electrical	$6,000		
Installation	$7,500		
Misc. lab equipment & supplies	$4,250		
Sand and gravel	$1,222		
Total One-Time Costs	**$24,042**		
Labor, O&M and Materials			
# Laborers	1		
Labor rate ($/hr)	$75		
Fuel ($/hr)	$30	3 units @ 10 GPH per unit	
Total labor + fuel ($/hr)	$105		
	$/service	# units	Total
Equipment servicing (every 250 hrs)	$300	3	$900
Chitosan ($/Mgal)	$982		

Table 9-24. One-time ATS costs model projects

Site size (acres)	1.9	3.8	6.0	8.5	12.0	17.0	23.0	34.0	46.0	69.0	85.1	145.0
Alabama	$21,886	$34,380	$63,497	$79,937	$102,952	$135,831	$175,286	$267,412	$346,322	$517,359	$643,022	$1,080,748
Alaska	$13,220	$17,047	$21,479	$26,516	$33,567	$58,290	$70,377	$92,538	$116,713	$163,048	$215,275	$340,198
Arizona	$9,392	$9,392	$9,392	$9,392	$9,392	$9,392	$9,392	$24,042	$24,042	$24,042	$24,042	$48,084
Arkansas	$18,863	$28,334	$53,951	$66,413	$83,860	$108,784	$138,693	$213,318	$273,136	$407,579	$507,626	$850,052
California	$10,029	$10,665	$11,403	$12,240	$13,413	$29,739	$31,749	$35,435	$39,457	$47,164	$72,351	$96,674
Colorado	$11,748	$14,103	$16,831	$19,930	$24,270	$45,118	$52,557	$66,195	$81,072	$109,588	$149,340	$227,854
Connecticut	$13,695	$17,997	$22,979	$43,290	$51,216	$62,539	$76,126	$101,035	$148,002	$200,085	$256,336	$416,022
Delaware	$14,249	$19,107	$24,731	$45,773	$54,720	$67,503	$82,842	$110,964	$161,435	$220,235	$281,187	$458,366
District of Columbia	$14,082	$18,772	$24,202	$45,023	$53,663	$66,005	$80,815	$107,968	$157,381	$214,154	$273,687	$445,586
Florida	$21,602	$33,813	$62,601	$78,668	$101,160	$133,293	$191,644	$262,336	$359,247	$526,849	$630,316	$1,098,684
Georgia	$18,413	$27,435	$37,880	$64,400	$81,019	$104,759	$133,247	$205,268	$262,244	$391,241	$467,685	$815,718
Hawaii	$20,974	$32,556	$60,616	$75,855	$97,190	$127,669	$184,035	$251,088	$344,028	$504,022	$602,162	$1,050,712
Idaho	$9,392	$9,392	$9,392	$9,392	$9,392	$9,392	$9,392	$9,392	$24,042	$24,042	$24,042	$48,084
Illinois	$13,130	$16,867	$21,195	$26,113	$47,649	$57,485	$69,288	$90,928	$134,326	$179,573	$211,245	$372,916
Indiana	$15,850	$22,308	$29,786	$52,934	$64,831	$81,826	$102,221	$139,610	$200,191	$278,370	$352,887	$580,534
Iowa	$14,311	$19,229	$24,925	$46,047	$55,107	$68,051	$83,584	$112,060	$162,917	$222,459	$283,930	$463,040
Kansas	$15,312	$21,231	$28,086	$50,525	$61,429	$77,007	$95,701	$129,972	$187,151	$258,810	$328,763	$579,014
Kentucky	$13,646	$17,900	$22,825	$43,072	$50,908	$62,103	$75,536	$100,163	$146,822	$198,315	$254,153	$412,302
Louisiana	$24,435	$54,129	$71,547	$91,341	$119,053	$158,641	$225,938	$313,032	$427,834	$629,731	$776,996	$1,314,884
Maine	$13,321	$17,250	$21,799	$26,969	$48,856	$59,196	$71,603	$94,349	$138,955	$186,516	$219,809	$387,508
Maryland	$14,082	$18,772	$24,202	$45,023	$53,663	$66,005	$80,815	$107,968	$157,381	$214,154	$273,687	$445,586
Massachusetts	$13,612	$17,832	$22,719	$42,921	$50,695	$61,801	$75,127	$99,560	$146,005	$197,090	$252,642	$409,728
Michigan	$10,554	$11,716	$13,062	$14,591	$16,732	$34,440	$38,111	$44,839	$52,179	$86,040	$95,888	$176,360
Minnesota	$12,700	$16,008	$19,838	$24,190	$44,934	$53,639	$64,084	$83,235	$104,127	$163,961	$191,991	$340,108
Mississippi	$20,073	$30,754	$57,771	$71,825	$91,500	$119,607	$153,336	$234,965	$302,423	$451,509	$561,807	$981,952
Missouri	$15,608	$21,824	$29,021	$51,850	$63,300	$79,657	$99,286	$155,064	$194,322	$289,358	$342,028	$601,616
Montana	$9,577	$9,762	$9,976	$10,219	$10,560	$11,047	$11,631	$27,352	$28,520	$30,759	$32,326	$62,198
Nebraska	$14,241	$19,089	$24,704	$31,083	$54,665	$67,425	$82,736	$110,808	$141,431	$219,917	$261,004	$457,698
Nevada	$9,392	$9,392	$9,392	$9,392	$9,392	$9,392	$9,392	$9,392	$24,042	$24,042	$24,042	$48,084
New Hampshire	$12,471	$15,550	$19,116	$23,167	$43,489	$51,592	$61,316	$79,143	$98,590	$155,656	$181,748	$322,656

Site size (acres)	1.9	3.8	6.0	8.5	12.0	17.0	23.0	34.0	46.0	69.0	85.1	145.0
New Jersey	$16,997	$24,603	$33,409	$58,066	$72,076	$92,091	$116,108	$160,139	$227,965	$320,031	$404,269	$668,082
New Mexico	$9,392	$9,392	$9,392	$9,392	$9,392	$9,392	$24,042	$24,042	$24,042	$24,042	$24,042	$48,084
New York	$13,361	$17,330	$21,925	$27,148	$49,109	$59,553	$72,087	$95,065	$139,924	$187,968	$221,600	$390,558
North Carolina	$16,995	$24,598	$33,401	$58,055	$72,060	$92,068	$116,077	$160,094	$227,905	$319,940	$404,157	$667,892
North Dakota	$9,392	$9,392	$9,392	$9,392	$9,392	$9,392	$24,042	$24,042	$24,042	$24,042	$24,042	$48,084
Ohio	$14,967	$20,541	$26,996	$34,332	$59,251	$73,921	$91,526	$123,800	$159,009	$246,285	$293,523	$513,108
Oklahoma	$16,370	$23,348	$31,428	$55,260	$68,114	$86,478	$108,514	$168,705	$212,777	$317,041	$376,171	$659,790
Oregon	$11,760	$14,128	$16,870	$19,986	$38,998	$45,230	$52,709	$66,419	$81,375	$129,834	$149,900	$268,392
Pennsylvania	$12,834	$16,275	$20,260	$39,438	$45,778	$54,835	$65,703	$85,628	$127,156	$168,817	$217,772	$350,314
Rhode Island	$16,189	$22,986	$30,856	$54,449	$66,970	$84,856	$106,320	$145,671	$208,390	$290,669	$368,055	$606,378
South Carolina	$15,835	$22,278	$29,739	$52,867	$64,736	$81,692	$102,039	$159,134	$199,828	$297,617	$352,215	$618,972
South Dakota	$10,823	$12,254	$13,911	$15,793	$18,429	$36,844	$41,363	$49,647	$58,684	$95,797	$107,921	$196,866
Tennessee	$15,009	$20,626	$27,131	$49,172	$59,519	$74,301	$92,040	$124,561	$179,830	$247,828	$315,218	$555,934
Texas	$17,893	$26,395	$50,889	$62,075	$77,735	$100,107	$126,954	$195,965	$249,658	$372,362	$464,192	$776,046
Utah	$9,392	$9,392	$9,392	$9,392	$9,392	$9,392	$9,392	$24,042	$24,042	$24,042	$24,042	$48,084
Vermont	$13,822	$18,252	$23,382	$29,211	$52,021	$63,679	$77,669	$103,316	$131,296	$204,714	$242,253	$425,750
Virginia	$13,817	$18,242	$23,366	$43,838	$51,990	$63,634	$77,608	$103,227	$150,967	$204,533	$261,821	$425,368
Washington	$13,220	$17,047	$21,479	$26,516	$33,567	$58,290	$70,377	$92,538	$116,713	$163,048	$215,275	$340,198
West Virginia	$11,990	$14,588	$17,596	$21,015	$40,451	$47,288	$55,492	$70,533	$86,942	$138,184	$160,199	$285,940
Wisconsin	$14,496	$19,599	$25,509	$32,224	$56,275	$69,706	$85,822	$115,370	$147,603	$229,175	$272,422	$477,154
Wyoming	$10,604	$11,816	$13,220	$14,815	$17,048	$20,238	$38,716	$45,733	$53,389	$68,063	$78,334	$140,592

Table 9-25. Monthly ATS costs for model projects

Site size (acres)	1.9	3.8	6.0	8.5	12.0	17.0	23.0	34.0	46.0	69.0	85.1	145.0
Alabama	$11,503	$12,956	$16,594	$17,194	$17,929	$18,979	$20,315	$34,209	$36,122	$54,737	$69,516	$110,658
Alaska	$11,045	$12,140	$13,400	$14,775	$16,749	$17,976	$18,882	$20,619	$22,431	$26,054	$38,385	$53,166
Arizona	$10,229	$10,459	$10,724	$11,026	$11,498	$12,102	$12,826	$16,461	$16,934	$17,696	$18,230	$35,624
Arkansas	$11,461	$12,872	$16,558	$17,143	$17,856	$18,876	$20,175	$34,062	$35,923	$54,398	$68,923	$109,948
California	$10,545	$11,140	$11,771	$12,488	$13,542	$16,673	$17,221	$18,087	$19,032	$20,919	$33,899	$42,390
Colorado	$10,394	$10,789	$11,295	$11,814	$12,541	$16,303	$16,645	$17,347	$18,031	$19,342	$32,584	$39,082
Connecticut	$11,366	$12,682	$14,256	$17,026	$17,692	$18,643	$19,784	$21,951	$35,351	$38,579	$56,104	$78,104
Delaware	$11,325	$12,600	$14,126	$16,975	$17,620	$18,541	$19,647	$21,749	$35,156	$38,288	$55,695	$77,490
District of Columbia	$11,287	$12,524	$14,006	$16,929	$17,554	$18,448	$19,521	$21,562	$34,977	$38,019	$55,318	$76,926
Florida	$11,888	$13,775	$17,003	$17,667	$18,596	$19,999	$33,477	$35,674	$52,728	$69,837	$72,871	$140,992
Georgia	$11,557	$13,064	$14,859	$17,260	$18,023	$19,112	$20,494	$34,397	$36,376	$55,170	$57,997	$111,568
Hawaii	$10,542	$11,134	$15,804	$16,000	$16,274	$16,666	$30,296	$30,907	$45,607	$60,220	$61,340	$120,830
Idaho	$10,336	$10,672	$11,061	$11,553	$12,171	$13,055	$14,166	$16,160	$17,642	$18,759	$19,540	$37,856
Illinois	$10,979	$12,008	$13,142	$14,481	$17,107	$17,815	$18,664	$20,296	$33,761	$36,196	$37,812	$73,094
Indiana	$11,226	$12,402	$13,814	$16,779	$17,449	$18,298	$19,318	$21,263	$34,690	$37,588	$54,714	$76,020
Iowa	$10,938	$11,927	$13,013	$16,487	$17,036	$17,714	$18,528	$20,095	$33,568	$35,906	$52,182	$72,486
Kansas	$11,137	$12,224	$13,533	$16,670	$17,294	$18,080	$19,023	$20,826	$34,270	$36,959	$53,833	$104,124
Kentucky	$11,384	$12,718	$14,312	$17,048	$17,722	$18,686	$19,843	$22,039	$35,434	$38,705	$56,280	$78,368
Louisiana	$11,792	$16,291	$16,919	$17,549	$18,430	$19,688	$33,250	$35,215	$52,213	$68,933	$86,787	$139,566
Maine	$11,285	$12,519	$13,999	$15,674	$17,550	$18,443	$19,513	$21,551	$34,966	$38,003	$40,166	$76,892
Maryland	$11,303	$12,556	$14,057	$16,948	$17,582	$18,488	$19,574	$21,641	$35,053	$38,133	$55,478	$77,164
Massachusetts	$11,307	$12,563	$14,068	$16,953	$17,588	$18,496	$19,586	$21,659	$35,070	$38,158	$55,513	$77,218
Michigan	$10,897	$11,845	$12,884	$14,115	$15,818	$17,614	$18,392	$19,819	$21,450	$35,617	$37,098	$71,878
Minnesota	$10,852	$11,754	$12,741	$13,912	$16,812	$17,503	$18,242	$19,596	$21,149	$35,172	$36,703	$71,204
Mississippi	$11,605	$13,160	$16,683	$17,319	$18,106	$19,230	$20,653	$34,564	$36,603	$55,556	$70,405	$136,342
Missouri	$11,138	$12,227	$13,537	$16,671	$17,297	$18,083	$19,027	$32,937	$34,276	$51,628	$53,845	$104,144
Montana	$10,349	$10,698	$11,152	$11,612	$12,255	$13,173	$14,325	$17,124	$17,730	$18,890	$19,702	$38,134
Nebraska	$10,839	$11,728	$12,700	$13,854	$16,789	$17,471	$18,198	$19,532	$21,062	$35,079	$36,589	$70,760
Nevada	$10,113	$10,226	$10,357	$10,506	$10,715	$11,012	$11,420	$12,075	$16,086	$16,463	$16,726	$33,040
New Hampshire	$11,242	$12,434	$13,864	$15,433	$17,476	$18,338	$19,372	$21,342	$23,484	$37,702	$39,670	$76,258
New Jersey	$11,443	$12,835	$14,498	$17,120	$17,824	$18,831	$20,113	$22,327	$35,836	$39,121	$56,862	$79,240

Site size (acres)	1.9	3.8	6.0	8.5	12.0	17.0	23.0	34.0	46.0	69.0	85.1	145.0
New Mexico	$10,458	$10,916	$11,496	$12,099	$12,943	$14,198	$16,932	$17,660	$18,454	$20,052	$21,118	$40,566
New York	$11,144	$12,237	$13,554	$14,993	$17,306	$18,096	$19,045	$20,859	$34,302	$37,006	$38,812	$74,796
North Carolina	$11,330	$12,610	$14,142	$16,981	$17,629	$18,554	$19,663	$21,773	$35,179	$38,322	$55,744	$77,564
North Dakota	$10,477	$10,953	$11,555	$12,183	$13,061	$14,365	$16,994	$17,751	$18,578	$20,238	$21,347	$40,958
Ohio	$11,170	$12,290	$13,636	$15,110	$17,351	$18,160	$19,131	$20,987	$23,004	$37,190	$39,039	$75,184
Oklahoma	$10,972	$11,995	$13,121	$16,529	$17,095	$17,798	$18,641	$32,533	$33,729	$50,696	$52,520	$102,184
Oregon	$11,257	$12,463	$13,911	$15,548	$17,502	$18,374	$19,420	$21,414	$23,581	$37,805	$39,922	$76,476
Pennsylvania	$11,283	$12,516	$13,994	$16,924	$17,548	$18,439	$19,508	$21,544	$34,959	$37,993	$55,281	$76,870
Rhode Island	$11,376	$12,702	$14,287	$17,038	$17,708	$18,667	$19,816	$21,999	$35,396	$38,648	$56,200	$78,248
South Carolina	$11,397	$12,744	$14,353	$17,064	$17,745	$18,718	$19,961	$33,838	$35,621	$53,882	$56,409	$108,862
South Dakota	$10,477	$10,954	$11,556	$12,184	$13,062	$16,506	$16,994	$17,753	$18,580	$32,517	$33,305	$65,378
Tennessee	$11,416	$12,783	$14,415	$17,088	$17,779	$18,766	$20,026	$22,198	$35,712	$38,935	$56,602	$109,192
Texas	$10,964	$11,977	$16,170	$16,518	$17,080	$17,777	$18,613	$32,503	$33,688	$50,626	$65,020	$102,038
Utah	$10,431	$10,863	$11,412	$11,980	$12,775	$13,960	$15,322	$17,529	$18,277	$19,711	$20,790	$40,008
Vermont	$11,008	$12,065	$13,232	$14,608	$17,157	$17,885	$18,759	$20,436	$22,183	$36,397	$38,060	$73,516
Virginia	$11,246	$12,442	$13,876	$16,803	$17,483	$18,347	$19,384	$21,360	$34,783	$37,728	$54,910	$76,314
Washington	$11,045	$12,140	$13,400	$14,775	$16,749	$17,976	$18,882	$20,619	$22,431	$26,054	$38,385	$53,166
West Virginia	$11,319	$12,588	$14,107	$15,827	$17,610	$18,527	$19,627	$21,720	$23,996	$38,246	$40,466	$77,402
Wisconsin	$10,933	$11,915	$12,995	$14,272	$17,026	$17,700	$18,509	$20,067	$21,684	$35,866	$37,405	$72,400
Wyoming	$10,437	$10,873	$11,429	$12,003	$12,808	$14,007	$16,786	$17,555	$18,312	$19,764	$20,855	$40,118

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10. ESTIMATING POLLUTANT LOAD REDUCTIONS

10.1. OVERVIEW OF APPROACH

Estimating the performance of the variety of erosion and sediment controls (ESCs) likely to be employed at construction sites, given the array of site conditions, site geometries, soil types and rainfall conditions nationally is an extremely complicated undertaking. Models do exist (such as SEDCAD and SEDIMOT III) that can be used to estimate, for a given set of site conditions and for a given storm event, the sediment generation, sediment transport, and sediment removals through BMPs. However, a significant amount of data regarding site conditions, watershed parameters and design features of various control structures is needed. Given the range of possible conditions nationally, U.S. Environmental Protection Agency (EPA) determined that basing a national loading reductions estimate on an input parameter-intensive model such as SEDCAD was not feasible for this analysis. Therefore, EPA developed a relatively straightforward approach to estimate loading reductions estimates for the regulatory options considered.

EPA used a model site approach to estimate baseline sediment loads and to estimate loading reductions for the Construction and Development (C&D) industry under the regulatory options evaluated. EPA used the Revised Universal Soil Loss Equation (RUSLE) to estimate loads and load reductions at the Reach File Version 1.0 (RF1) scale. This approach consisted of the following steps:

1. Developing a series of model projects of differing sizes, durations, and project types on the basis of analysis of Notice of Intent (NOI) data.
2. Determining RF1-level estimates for RUSLE and hydrologic parameters using national geographic information system (GIS) data layers, supplemented with best professional judgment (BPJ) estimates for parameters for which data were not available.
3. Estimating baseline and option-specific estimates of sediment loads for each RF1. For Option 1, estimates were developed according to changes in the RUSLE P- and C factors from baseline. For Options 2, 3, and 4, estimates were developed first using the change in RUSLE P- and C-factors for all sites to account for the effects of the enhanced erosion and sediment control requirements, and second a concentration approach for acres subject to turbidity limits.
4. Summing RF1 loads to the national level.

The following sections describe these steps in detail.

10.2. MODEL PROJECT ANALYSIS

EPA evaluated NOI data from four states and developed a distribution of projects by site size, project duration, and project type (see Appendix C). EPA categorized NOI data into three main project types: residential, nonresidential, and transportation. On the basis of the NOI data evaluation, EPA developed the distribution shown in Table 10-1. For the loads analysis, it was not necessary to maintain the breakout by project durations because longer duration projects are calculated using the same methodology as shorter duration projects. Therefore, one project duration was calculated for each of the 12 model project sizes within each of the three project type categories (residential, nonresidential, and transportation), yielding a total of 36 individual model projects (12 site size categories times 3 project types). As with the cost analysis, it was assumed that the duration of land disturbance would be less than the project duration according to the NOIs. Therefore, the duration of each model project was determined using BPJ, and the duration for each of the 36 site size categories were determined by collapsing the model project matrix. Table 10-2 shows the collapsed distribution and the duration of both the NOIs as well as the calculated project duration for each of the 36 model project size categories used for the loading estimates.

10.3. MODEL PARAMETER AND LOADS ESTIMATION

Sediment loads were estimated using the RUSLE. RUSLE is an empirical relationship that can be used to estimate soil erosion rates from various land uses. RUSLE calculates soil loss, A (in tons/acre/year), on the basis of six parameters using the following relationship:

$$A = R \times K \times L \times S \times C \times P$$

The parameters in RUSLE are

A = Average annual soil loss (tons/acre/year)
R = rainfall-runoff erosivity factor
K = soil erodibility factor
L = slope length factor
S = slope steepness factor
C = cover-management factor
P = support practice factor

EPA used a combination of data sources as well as BPJ in selecting RUSLE parameters. EPA's load estimation methodology calculates soil loss at the RF1 scale. Therefore, EPA used national databases, where available, to determine some parameters that are geographically based. Other parameters are site-specific. Therefore, EPA estimated the parameters by applying BPJ to various data sources. EPA assumed a delivery ration of 1 (i.e., all estimates by RUSLE were assumed to be discharged from the construction site). That assumption does not account for losses that could occur if, for example, sediment were to be deposited between the construction site and the storm drain or receiving water. This is a reasonable assumption, however, because discharges from construction sites (particularly larger sites that comprise the bulk of the acres affected) are typically discharged via a pipe or channel directly to a storm drain network or to receiving water. In addition, the SPARROW model accounts for some potential losses as sediment is delivered to the RF1 stream network.

Table 10-1. Model project matrix

RESIDENTIAL													
Project size (acres)	Duration (days)												Total by site size
	0–46	47–91	92–182	183–274	275–365	366–456	457–547	549–639	640–730	731–912	913–1,095	> 1,096	
1.9	124	147	632	571	1,111	926	283	293	222	450	98	57	4,914
3.8	68	100	351	341	703	657	312	213	249	397	125	177	3,693
6	44	28	242	168	444	301	81	110	169	220	76	109	1,992
8.5	22	26	187	172	318	309	52	70	109	180	68	167	1,680
12	23	14	195	218	506	388	139	78	72	430	75	283	2,421
17	18	2	84	174	209	219	95	107	74	360	77	137	1,556
23	1	28	107	133	239	303	73	90	103	325	101	307	1,810
3	1	--	48	59	182	143	23	42	18	214	69	185	984
46	11	--	33	84	126	114	11	24	70	155	101	192	921
69	--	--	1	38	38	54	17	19	18	60	11	117	373
85	--	--	--	2	17	36	--	7	7	43	27	103	242
145	--	--	8	11	45	50	15	12	37	50	39	77	344
Total Residential	312	345	1,888	1,971	3,938	3,500	1,101	1,065	1,148	2,884	867	1,911	20,930
NONRESIDENTIAL													
Project size (acres)	Duration (days)												Total by site size
	0–46	47–91	92–182	183–274	275–365	366–456	457–547	549–639	640–730	731–912	913–1,095	> 1,096	
1.9	558	1,359	4,910	5,334	4,806	3,276	940	685	442	592	180	155	23,237
3.8	219	547	1,990	2,973	2,643	1,715	910	461	199	465	140	148	12,410
6	150	206	996	1,368	1,516	1,059	513	285	240	188	89	99	6,709
8.5	55	97	578	736	616	617	165	152	144	274	49	96	3,579
12	77	73	493	660	950	741	347	178	162	291	41	71	4,084
17	13	82	246	261	505	419	203	60	114	131	29	39	2,102
23	38	59	166	264	542	250	215	208	135	142	25	34	2,078
3	3	27	78	164	176	126	48	72	29	101	5	36	865
46	--	17	49	65	129	150	57	152	12	131	51	34	847
69	2	2	29	50	33	30	30	87	16	71	2	14	366
85	--	--	10	1	86	22	11	21	--	51	--	11	213
145	--	8	25	46	124	25	10	11	5	58	29	15	356
Total Nonresidential	1,115	2,477	9,570	11,922	12,126	8,430	3,449	2,372	1,498	2,495	640	752	56,846

TRANSPORTATION													
Project size (acres)	Duration (days)												Total by site size
	0–46	47–91	92–182	183–274	275–365	366–456	457–547	549–639	640–730	731–912	913–1,095	> 1,096	
1.9	82	210	629	418	308	323	136	55	132	117	7	--	2,417
3.8	25	87	277	255	246	146	81	60	34	58	22	7	1,298
6	16	23	184	138	170	53	45	26	--	78	15	22	770
8.5	7	15	70	73	78	78	33	89	17	7	21	6	494
12	8	21	70	109	39	95	52	43	17	36	13	45	548
17	--	3	63	49	13	15	21	2	8	64	6	28	272
23	5	2	31	36	6	76	40	27	14	95	16	15	363
3	--	--	1	26	17	6	16	4	9	5	42	2	128
46	--	1	2	19	9	25	21	15	9	24	4	51	180
69	--	--	--	--	3	9	10	4	-	5	21	--	52
85	--	--	7	--	--	3	--	--	2	4	12	28	56
145	--	--	--	1	3	4	1	9	11	24	35	30	118
Total Transportation	143	362	1,334	1,124	892	833	456	334	253	517	214	234	6,696
NATIONAL TOTAL	1,570	3,184	12,792	15,017	16,956	12,763	5,006	3,771	2,899	5,896	1,721	2,897	84,472

Table 10-2. Project matrix for loads analysis

	Residential		Nonresidential		Transportation	
Project size (acres)	**NOI duration (months)**	**Duration for loads estimation (months)**	**NOI duration (months)**	**Duration for loads estimation (months)**	**NOI duration (months)**	**Duration for loads estimation (months)**
1.9	13	10	9	8	9	8
3.8	15	12	10	8	10	8
6	15	12	11	9	11	9
8.5	16	13	12	10	13	10
12	17	14	12	10	14	11
17	18	15	12	10	16	13
23	20	16	13	11	18	14
34	21	17	14	11	20	16
46	22	17	17	14	22	18
69	23	19	17	13	23	18
85.1	28	22	17	13	29	24
145	23	18	15	12	29	23
Average	**16**	**13**	**11**	**9**	**12**	**10**

Table 10-3 summarizes sources used by EPA for each RUSLE factor. As discussed in Section 3.5.4, EPA used CONUS-SOIL soil database (Miller and White 1998) to evaluate soil and physical parameter values at the RF1 level. The loads analysis evaluated only RF1 watersheds that contained new developed land between 1992 and 2001 as indicated by the National Land Cover Dataset (NLCD). EPA developed a procedure (called masking) that would use only the parameter values for the geographic areas that were developed between 1992 and 2001.

Table 10-3. Data sources used to obtain RUSLE factors

RUSLE term	Definition	Source of information	Method for determining RF1-level values
C	Cover-management Factor	Literature review and BPJ	EPA calculated an average annual value that is based on assumptions about how cover, and associated C factors, are likely to be employed over the duration of a typical project. These values were determined by applying BPJ to various sources in the literature and did not vary geographically or across regulatory option.
P	Support Practice Factor	Literature review and BPJ	EPA assigned values on the basis of a literature review and BPJ. Values varied by assumptions about how practices were likely to change under the regulatory options.
K	Soil Erodibility Factor	CONUS-SOIL Database	EPA determined the spatially averaged value from soils data for each RF1 watershed, weighted toward areas where development occurred between 1992 and 2001 using NLCD data.
R	Rainfall-Runoff Erosivity Factor	GIS layer prepared for the EPA LEW Calculator	EPA determined the spatially averaged value from soils data for each RF1 watershed, weighted toward areas where development occurred between 1992 and 2001 using NLCD data.
LS	Slope Length Factor	BPJ	EPA assumed an average slope of 4% and a slope length of 80 feet across all model projects.

The array of surface conditions at constructions sites varies as construction advances from clearing/grubbing, to earth moving/contouring, followed by the installation of structures and final landscaping. Given the large number of construction sites commencing annually and the large variation in construction sequences and construction activities occurring across the country, determining site-specific RUSLE parameters for C, P, L, and S is extremely challenging. Therefore, EPA applied BPJ to estimate values for these parameters. EPA selected values that are expected to be typical across the entire country and, on average, could be considered typical of conditions over the duration of the project. To evaluate the sensitivity of the loading estimates under the primary analysis (which were used to estimate national water quality changes in the SPARROW model and subsequent environmental benefits), EPA chose to vary the assumptions for one parameter, P. RF1 and national loads were estimated using three assumptions for P, with the middle (called average) value used for water quality modeling. The results for the other two scenarios (called low and high) are included in the discussion below; however, SPARROW model runs were not conducted for those scenarios.

10.3.1. LS FACTOR

As suggested by its name, the RUSLE slope length parameter is composed of a slope component and a length component. In combination, the two components express the influence of the path taken by runoff as it travels across a construction site to the point of discharge. The steeper and longer the pathway, the greater the amount of erosion the RUSLE predicts .

While the LS factor is one of the most important RUSLE parameters, it is also one of the more difficult values to determine at the national scale. The STATSGO data used by EPA reports land slope only in terms of a low value and a high value. Therefore, determining a representative slope for specific geographic areas is not possible using that data set. While more detailed data sets are available, the resources required to analyze preexisting slopes at the national scale made the use of more detailed data sets infeasible for this analysis.

Table 10-4 indicates per-state, spatially averaged, lowest-reported, and highest-reported slope data extracted from the STATSGO data. The values generated through this process are relatively high (e.g., greater than 5 percent). Therefore, EPA elected not to use these data for modeling purposes, but instead assumed a 4 percent land slope across all model sites, acknowledging that slopes present on actual construction sites can be much lower (such as if a corn field is converted to a big-box store) or much higher (such as on a highway road cut). The value of 4 percent falls toward the bottom of the ranges reported in Table 10-4.

Table 10-4. Slope ranges from STATSGO (percent)

State	Average of lowest reported slopes	Average of highest reported slopes	State	Average of lowest reported slopes	Average of highest reported slopes
AL	4.71	11.96	NC	5.37	11.53
AR	4.71	11.91	ND	2.49	6.98
AZ	1.66	8.24	NE	2.95	7.29
CA	6.83	17.37	NH	6.25	14.93
CO	1.50	11.33	NJ	2.16	6.42
CT	5.21	11.89	NM	1.60	10.99
DC	6.69	14.05	NV	2.14	8.99

State	Average of lowest reported slopes	Average of highest reported slopes	State	Average of lowest reported slopes	Average of highest reported slopes
DE	0.93	3.66	NY	4.37	11.61
FL	0.32	3.24	OH	3.99	9.90
GA	4.49	10.40	OK	2.25	7.08
IA	3.60	6.95	OR	9.82	24.08
ID	2.88	10.83	PA	6.86	17.27
IL	2.79	6.80	RI	3.69	10.64
IN	2.12	5.96	SC	2.72	6.40
KS	1.71	5.31	SD	1.99	6.83
KY	11.04	24.63	TN	8.00	17.73
LA	1.36	4.78	TX	0.89	5.05
MA	4.82	12.55	UT	3.19	14.80
MD	4.89	11.66	VA	7.51	17.13
ME	4.04	11.48	VT	9.19	21.79
MI	2.11	7.80	WA	8.13	21.46
MN	2.24	6.60	WI	3.25	9.01
MO	5.25	12.71	WV	15.79	31.27
MS	5.15	12.52	WY	1.32	11.00
MT	3.07	13.50	National	3.65	10.18

EPA assumed a relatively short distance of 80 feet across all its model sites for the slope length. That distance is intended to represent the typical density of channels for a 4 percent slope used to facilitate drainage on the site before the permanent drainage network is installed, or the length before some sort of slope break would be provided. In general, the permanent drainage infrastructure is installed early in the construction process, and it is available to drain the construction footprint around individual structures at some point during construction.

For its analysis of construction site erosion, EPA computed LS on the basis of a high rill-to-interrill erosion ratio. That assumption is generally considered the most appropriate assumption for construction site conditions (USDA 1997).

10.3.2. P FACTOR

To represent the influence of various ESC technologies, EPA used the RUSLE practice factor (P). Examination of the literature indicates that P factors for sediment controls at construction sites can vary from between 0.1 to 0.9 (see Table 10-5). This means that sediment controls can vary from between 10 percent to 90 percent effective in removing sediment. In reality, the performance of a given sediment control is dependent on a number of factors, including design, size, frequency, and duration of rainfall and runoff events; particle size distribution of sediment particles; the presence of particle surface charge; influent sediment concentration; the degree of sediment accumulation; and the extent to which maintenance has been performed. To estimate loads for the national estimates, EPA chose to assign a P factor of 0.4 to characterize baseline sediment control performance. This means that 60 percent of the sediment estimated to be produced at the site is removed through sediment controls such as sediment traps, sediment basins, silt fences, and check dams. The value is intended to be typical of the range of practices used at sites nationwide, recognizing that different sites employ a mix of sediment control practices. To evaluate the influence of the ESC requirements under Options 1 through 4, EPA reduced the P factor to 0.3. That accounts for using surface outlets on all basins, which is the major change to sediment controls from existing requirements contained in the nonnumeric effluent limitations of the regulatory options. EPA also assumed that filter berms will be used in place of silt fence, which has an associated improvement in sediment removal. As a sensitivity analysis, EPA varied the baseline P factor assumption. EPA assumed a baseline P factor of 0.3 as the low-value and 0.5 as the high-value in the sensitivity analysis. As with the primary case, EPA assumed that the regulatory options would reduce the P factor by 0.1 units. Table 10-6 summarizes the P factor assumptions.

Table 10-5. P factors for construction site practices

Practice	P factor
Sediment Containment Systems	0.1–0.9
Bale or Sandbag Barriers	0.9
Rock Barriers at Sump Locations	0.8
Silt Fence Barrier	0.6
Grass Buffer Strips	
0% to 10% Slope	0.6
11% to 24% Slope	0.8

Table 10-6. P factors used for load estimation

Scenario	Low value	Average value	High value
Baseline	0.3	0.4	0.5
Regulatory Options	0.2	0.3	0.4

10.3.3. C FACTOR

EPA used the RUSLE cover factor (C) to represent various cover conditions present on the model sites under baseline conditions and under the regulatory options. Table 10-7 shows C factors for various construction site controls. Permittees are likely to implement various types of cover practices on the site. During clearing and grading, substantial portions of the site can be disturbed and bare soil can be prevalent. As portions of the site reach final grade, permittees usually install some sort of temporary cover, such as straw mulch or temporary seeding. As construction progresses, temporarily stabilized areas could be exposed again during excavation activities, and eventually the site is stabilized at the end of construction. However, such practices vary widely nationwide and even within states.

To determine an appropriate C factor for use in the national modeling, EPA developed an average annual C factor for sites nationwide. The average C factor was determined by making assumptions about the types of cover present on construction sites during different periods of construction. For a 1-year duration project under baseline conditions, EPA assumed that the site would have bare soil that is loose for a period of 1 month during initial clearing and grading, followed by a 1-month period where soil is bare and compacted. Straw mulch would then be applied at a rate of 2 tons per acre for a period of 9 months during the vertical construction phase. The remaining 1 month would be seeded and mulched with grasses established. That gives an average C factor of 0.26 for the year.

Under Options 1, 2, 3, and 4, EPA assumed that the period of compacted, bare soil would be reduced from 1 month to 2 weeks and that the period when the site is covered in straw mulch would increase from 9 months to 9.5 months. That change is intended to reflect the effect of the enhanced soil cover requirement of the options, meaning that permittees would install temporary cover on average 2 weeks earlier than under baseline conditions. That gives an average C factor for the year of 0.23.

Table 10-8 shows the assumptions used under baseline conditions and under the regulatory options and the value of the average annual C factors.

Table 10-7. C factors for construction site controls

Treatment		**C factor value**
Bare soil conditions		
	Freshly disked to 6–8 inches	1
	After one rain	0.89
	Loose to 12 inches, smooth	0.9
	Loose to 12 inches, rough	0.8
	Compacted root rake	1.2
	Compacted bulldozer scraped across slope	1.2
	Same except root raked across	0.9
	Rough irregular tracked all directions	0.9
	Seed and fertilized, fresh unprepared seedbed	0.64
	Same except after 6 months	0.54
	Seed, fertilized after 12 months	0.38
	Undisturbed except scraped	0.66-1.30
	Scarified only	0.76-1.31
Asphalt/Concrete Pavement		0.01
Asphalt emulsion		
	1,210 gal/acre	0.01–0.019
	605 gal/acre	0.14–0.57
Gravel (diameter = 25–50 mm) at 90 tons/acre		0.05
Dust binder		
	605 gal/acre	1.05
	1,210 gal/acre	0.29–0.78
Other chemicals		
	Aquatain	0.68
	Aerospray 70, 10% cover	0.94
	PVA	0.71–0.90
	Tera-Tack	0.66
Straw Mulch		
	1 ton/acre (slopes less than 10%)	0.2
	1.5 ton/acre (slopes less than 10%)	0.12
Seeding		
	Temporary, 0–60 days	0.4
	Temporary, after 60 days	0.05
	Permanent, 2 to 12 months	0.05

Treatment		**C factor value**
Grass Seeding and Mulch		
	20% coverage by treatment	0.20
	40% coverage by treatment	0.10
	60% coverage by treatment	0.042
Brush		0.35

Wischmeier and Smith 1978; URS 2008

Table 10-8. C factors used for loads estimation

Cover	**C factor**	**Duration (months)**	**C factor × fraction of year**
Baseline			
Bare soil, loose to 12 inches, rough	0.8	1	0.067
Bare soil, compacted	1.2	1	0.1
Straw mulch, 1.5 tons/acre, 1–5% slope	0.12	9	0.09
Grass with mulch, 60% cover	0.042	1	0.0035
		Total for Year	*0.26*
Options 1, 2, 3, and 4			
Bare soil, loose to 12 inches, rough	0.8	0.5	0.033
Bare soil, compacted	1.2	1	0.1
Straw mulch, 1.5 tons/acre, 1–5% slope	0.12	9.5	0.095
Grass with mulch, 60% cover	0.042	1	0.0035
		Total for Year	*0.23*

10.3.4. RUNOFF VOLUME ESTIMATES

EPA estimated runoff volumes within each RF1 watershed to calculate removals for options that incorporated a numeric discharge standard. EPA computed runoff coefficients on the basis of the long-term meteorological record for 11 indicator cities. The values were then assigned to RF1 watersheds for those states. For other states that do not contain an indicator city, values from the nearest state were used as an approximation. Table 10-9 lists the states/commonwealths represented by each of the indicator cities. Note that the loading analysis does not include consideration of construction activities in Hawaii and Alaska, and does not include any of the U.S. territories.

Table 10-9. Allocation of states/commonwealths/territories to representative indicator city

State	**Indicator city**	**State**	**Indicator city**
Alabama	Atlanta, GA	New Jersey	Albany, NY
Arizona	Las Vegas, NV	New Mexico	Dallas, TX
Arkansas	Dallas, TX	New York	Albany, NY
California	Las Vegas, NV	North Carolina	Atlanta, GA
Colorado	Denver, CO	North Dakota	Denver, CO
Connecticut	Manchester, NH	Ohio	Chicago, IL
Delaware	Washington, DC	Oklahoma	Dallas, TX
Florida	Atlanta, GA	Oregon	Seattle, WA
Georgia	Atlanta, GA	Pennsylvania	Washington, DC
Idaho	Boise, Id	Rhode Island	Manchester, NH
Illinois	Chicago, IL	South Carolina	Atlanta, GA

State	Indicator city	State	Indicator city
Indiana	Chicago, IL	South Dakota	Denver, CO
Iowa	Kansas City, KS	Tennessee	Atlanta, GA
Kansas	Kansas City, KS	Texas	Dallas, TX
Kentucky	Atlanta, GA	Utah	Denver, CO
Louisiana	Dallas, TX	Vermont	Manchester, NH
Maine	Manchester, NH	Virginia	Washington, DC
Maryland	Washington, DC	Washington	Seattle, WA
Massachusetts	Manchester, NH	West Virginia	Washington, DC
Michigan	Chicago, IL	Wisconsin	Chicago, IL
Minnesota	Chicago, IL	Wyoming	Denver, CO
Mississippi	Atlanta, GA	Alaska	Not analyzed
Missouri	Kansas City, KS	Hawaii	Not analyzed
Montana	Denver, CO	Puerto Rico	Not analyzed
Nebraska	Kansas City, KS	Virgin Islands	Not analyzed
Nevada	Las Vegas, NV	Pacific Islands	Not analyzed
New Hampshire	Manchester, NH	District of Columbia	Washington, DC

EPA used the CONUS-SOIL data on hydrologic soil groups (HSG) to estimate runoff volumes from the model construction sites. HSG is presented in terms of the percent of land area that is made up of soils characterized as type A, B, C, or D. Those four soil hydrologic classifications are correlated to the soil Curve Number, used with the SCS Curve Number methods to convert inches of rainfall into inches of runoff.

Eleven indicator cities were used to evaluate runoff coefficients, and those values were assigned to surrounding states using the relationships in Table 10-9. The NRCS Curve Number procedure (TxDOT 2009) was used to estimate runoff coefficients and associated runoff volumes, considering the Curve Number for each of the four HSGs and the distribution of HSGs within each geographic area.

The hourly rainfall record was then evaluated for a single year's meteorological record to determine runoff amounts for each hour's precipitation, for each HSG. The rainfall year selected for each indicator city was judged to be typical or a year that did not contain rainfall events with greater than a 2-year return period.

For simplicity, the total runoff volume from all the individual rainfall events was divided by the total annual rainfall amount. The result is a runoff coefficient that can be used to convert annual precipitation into annual runoff. Table 10-10 indicates the runoff coefficients for each HSG, for each indicator city.

EPA used values in Table 10-10 to estimate the annual runoff amount for developed acres within each RF1 watershed. For example, if an RF1 watershed near Albany New York, has equal amounts of A, B, C, and D soils, its effective runoff coefficient is estimated as the sum of 25 percent of each of the Albany HSG values. ($0.25 \times (0.12 + 0.23 + 0.34 + 0.45)$ or 0.285). Multiplying the total annual precipitation associated with each RF1 watershed by the customized per-RF1 runoff coefficient, yields the estimated annual runoff amount. Additional information on EPA's processing hydrologic data and developing Table 10-10 values is in Appendix H.

Appendix H also contains information on EPA's assessment of indicator city meteorological data to establish the number of rainfall events expected in a construction period and the duration of discharge monitoring for runoff events.

Table 10-10 Estimated runoff coefficients by HSG for indicator regions

City	EPA Region*	A soil	B soil	C soil	D soil
Manchester, NH	1	0.15	0.26	0.36	0.46
Albany, NY	2	0.12	0.23	0.34	0.45
Washington, DC	3	0.15	0.27	0.39	0.49
Atlanta, GA	4	0.17	0.30	0.41	0.52
Chicago, IL	5	0.14	0.26	0.37	0.47
Dallas, TX	6	0.14	0.28	0.41	0.52
Kansas City, KS	7	0.13	0.25	0.37	0.47
Denver, CO	8	0.04	0.10	0.18	0.27
Las Vegas, NV	9	0.03	0.10	0.18	0.26
Boise, ID	10a	0.01	0.04	0.09	0.16
Seattle, WA	10b	0.13	0.22	0.32	0.42

* EPA Region 10 was divided into two portions to help account for differences in rainfall patterns.

To obtain annual precipitation for each RF1 watershed, EPA performed a spatial analysis using the 1-km resolution U.S. Average Monthly or Annual Precipitation (1971–2000) PRISM Group raster data coverage (PRISM Group 2006). The annual rainfall for the urbanized acres within each RF1 watershed boundary was averaged and used to estimate the per-RF1 annual rainfall value.

10.4. LOAD ESTIMATION

EPA estimated loads under baseline as well as under the regulatory options evaluated. All calculations were done at the RF1 level. Using NLCD data, EPA estimated the amount of new development occurring in each RF1 watershed (for a description of this analysis, see the proposed rule development document). That analysis indicates that approximately 590,545 acres per year were developed nationally over the period of 1992 to 2001. EPA then scaled these estimates up to account for growth in the industry since the 1992–2001 period. EPA's revised estimate of national developed acreage is 852,650 acres. EPA then scaled up the RF1-level estimates of developed acres using the ratio between these two values.

Using the RF1-level parameters for K and R, and the C, P, and LS assumptions described above, EPA calculated the baseline sediment loading for all developed acres with each RF1 watershed on an annual basis. There were 42,288 unique RF1 watersheds in the analysis (approximately 4 percent of watersheds crossed state boundaries, so those RF1 watersheds were broken into smaller sections to conform with the RF1/state combinations and were later recombined). All RF1 watersheds that did not have development between 1992 and 2001 were not analyzed. The annual values were then used to estimate the loads for each model project category on the basis of the number of acres within each category and the duration of construction activity for the entire national model project matrix. For model construction sites with a duration of less than 1 year, the load was calculated using the fraction of the year modeled, with no consideration for the actual time of year that construction occurred. Because parameters such as R vary during the year, the soil loss during any fraction of a year can be calculated if the start and end dates of the project are known. However, because of the large number of model projects in the analysis, it is simply assumed that the projects are evenly distributed over the course of the year. In addition, all loads from projects longer than 1 year were estimated by scaling up the annual values. For example, if a construction duration was 13 months, the total load from that model construction site would consist of the annual load from RUSLE (12 months), plus 1/12 the annual load to account for the 1-month incremental load.

Options 2, 3, and 4 contain site size thresholds whereby specific requirement for meeting a numeric turbidity limit apply according to site size (10 acres for Options 3 and 4 and 30 acres for Option 2). As with Option 1, EPA applied the changes in C and P factors to determine the influence of the enhanced ESCs. EPA then determined if any additional removals would result from the turbidity limits using a concentration approach. That was done by dividing the sediment load by the calculated runoff volume from developed acres within each RF1 watershed. For Options 2 and 3, it was assumed that the average total suspended solids (TSS) concentration for discharges subject to the numeric limit would be 25 milligrams per liter (mg/L). For Option 4, it was assumed that the average TSS concentration of discharges would be 250 mg/L. For each RF1 watershed, the discharge load was calculated on the basis of the difference between the concentration after application of BMPs and either 25 mg/L (Options 2 and 3) or 250 mg/L. If the baseline concentration was less than either 25 mg/L or 250 mg/L, no removals were associated with the numeric limit for that RF1 watershed. From the distribution of site sizes and durations, loads were then calculated on the basis of the quantity of acres within each site size category and the duration of construction activity for each model project category within the national model project matrix, using the same procedure described above for Option 1.

Load reductions were summed for each RF1 watershed and then summed to the state and national level. RF1-level estimates were used for subsequent water quality modeling using the SPARROW model.

10.5. RESULTS

Table 10-11 provides estimates of sediment discharges under baseline conditions and the regulatory options for the primary analysis case. Tables 10-12 and 10-13 provide estimates of sediment discharges for the low and high scenarios, respectively. Table 10-14 provides the estimated sediment removals by regulatory option for the primary analysis case. Tables 10-15 and 10-16 provide estimated removals for the low and high scenarios, respectively. All values presented in these tables are after full implementation.

Table 10-11. Discharged loads—primary analysis case

State	Tons per year				
	Baseline	Option 1	Option 2	Option 3	Option 4
AL	120,513	79,956	36,218	15,419	25,945
AK	--	--	--	--	--
AR	78,969	52,393	23,660	9,996	15,925
AZ	10,813	7,174	3,225	1,348	1,970
CA	24,516	16,266	7,414	3,204	5,944
CO	12,222	8,109	3,684	1,580	2,785
CT	2,878	1,910	886	399	925
DC	1,403	931	422	180	311
DE	3,459	2,295	1,049	457	884
FL	150,699	99,983	46,575	21,177	51,377
GA	180,561	119,795	54,635	23,648	44,336
HI	--	--	--	--	--
IA	39,324	26,090	11,840	5,063	8,783
ID	1,812	1,202	547	236	427
IL	89,672	59,494	27,040	11,606	20,640
IN	53,875	35,744	16,293	7,044	13,109
KS	101,100	67,076	30,325	12,849	20,906
KY	51,628	34,253	15,639	6,786	12,925
LA	196,969	130,682	58,732	24,518	35,571
MA	6,258	4,152	1,965	925	2,588
MD	29,790	19,765	8,997	3,877	7,068
ME	7,376	4,894	2,358	1,153	3,673
MI	31,647	20,997	9,833	4,524	11,515
MN	17,639	11,703	5,402	2,405	5,276
MO	86,647	57,487	25,941	10,940	17,191
MS	145,295	96,397	43,421	18,228	27,665
MT	3,657	2,426	1,111	486	965
NC	92,858	61,608	28,141	12,227	23,428
ND	8,576	5,690	2,566	1,080	1,674
NE	14,553	9,655	4,376	1,865	3,166
NH	3,246	2,154	1,016	476	1,303
NJ	14,378	9,540	4,383	1,930	3,971
NM	2,665	1,768	829	382	957
NV	2,225	1,476	676	296	591
NY	17,302	11,479	5,340	2,421	5,789
OH	62,997	41,796	19,176	8,419	17,149
OK	101,097	67,074	30,270	12,768	20,103
OR	9,119	6,050	2,903	1,406	4,251
PA	53,686	35,619	16,418	7,288	15,750
RI	965	640	298	135	327
SC	79,666	52,855	24,163	10,519	20,410
SD	15,388	10,209	4,589	1,917	2,796
TN	88,740	58,876	26,754	11,478	20,350
TX	460,238	305,350	137,702	57,978	90,021
UT	2,631	1,746	821	381	996
VA	63,323	42,012	19,199	8,351	16,128
VT	1,209	802	376	173	446
WA	15,752	10,451	4,996	2,402	7,090
WI	17,363	11,520	5,289	2,326	4,777

State	Tons per year				
	Baseline	Option 1	Option 2	Option 3	Option 4
WY	1,146	760	349	153	310
WV	11,729	7,782	3,593	1,600	3,521
NATIONAL	**2,589,577**	**1,718,085**	**781,433**	**336,018**	**604,009**

Table 10-12. Discharged loads—low sensitivity analysis case

State	Tons per year				
	Baseline	Option 1	Option 2	Option 3	Option 4
AL	90,385	53,304	24,409	10,669	21,195
AK	--	--	--	--	--
AR	59,227	34,929	15,922	6,884	12,813
AZ	8,109	4,783	2,166	922	1,542
CA	18,387	10,844	5,011	2,238	4,954
CO	9,166	5,406	2,487	1,098	2,276
CT	2,159	1,273	604	285	812
DC	1,052	621	285	125	256
DE	2,594	1,530	710	320	746
FL	113,024	66,655	31,808	15,237	44,876
GA	135,420	79,863	36,942	16,532	37,219
HI	--	--	--	--	--
IA	29,493	17,393	7,987	3,513	7,233
ID	1,359	801	370	164	355
IL	67,254	39,662	18,253	8,072	17,105
IN	40,406	23,829	11,015	4,921	10,986
KS	75,825	44,717	20,419	8,864	16,921
KY	38,721	22,836	10,580	4,752	10,890
LA	147,727	87,121	39,432	16,755	27,806
MA	4,694	2,768	1,352	678	2,333
MD	22,343	13,176	6,078	2,703	5,892
ME	5,532	3,263	1,636	862	3,153
MI	23,735	13,998	6,732	3,277	10,127
MN	13,229	7,802	3,673	1,710	4,562
MO	64,986	38,325	17,451	7,525	13,776
MS	108,971	64,265	29,184	12,501	21,939
MT	2,743	1,618	753	342	813
NC	69,644	41,072	19,043	8,567	19,757
ND	6,432	3,793	1,725	742	1,336
NE	10,915	6,437	2,950	1,292	2,593
NH	2,434	1,436	698	348	1,174
NJ	10,784	6,360	2,974	1,363	3,381
NM	1,999	1,179	568	277	812
NV	1,669	984	458	208	502
NY	12,976	7,653	3,645	1,739	5,074
OH	47,248	27,864	13,003	5,936	14,666
OK	75,823	44,716	20,364	8,784	16,118
OR	6,839	4,033	2,009	1,046	3,582
PA	40,265	23,746	11,158	5,172	13,631
RI	723	427	203	97	288
SC	59,750	35,237	16,357	7,379	17,271
SD	11,541	6,806	3,082	1,311	2,189

State	Tons per year				
	Baseline	Option 1	Option 2	Option 3	Option 4
TN	66,555	39,251	18,058	7,981	16,852
TX	345,178	203,567	92,605	39,839	71,855
UT	1,973	1,164	563	277	855
VA	47,492	28,008	12,995	5,855	13,632
VT	907	535	258	126	397
WA	11,814	6,967	3,452	1,781	5,914
WI	13,023	7,680	3,587	1,641	4,086
WY	859	507	237	108	261
WV	8,797	5,188	2,443	1,138	3,056
NATIONAL	**1,942,181**	**1,145,390**	**527,695**	**233,956**	**499,863**

Table 10-13. Discharged loads—high sensitivity analysis case

State	Tons per year				
	Baseline	Option 1	Option 2	Option 3	Option 4
AL	150,642	106,608	48,026	20,168	30,695
AK	--	--	--	--	--
AR	98,711	69,857	31,397	13,108	19,037
AZ	13,516	9,565	4,285	1,774	2,397
CA	30,645	21,688	9,816	4,170	6,916
CO	15,278	10,812	4,882	2,062	3,275
CT	3,598	2,546	1,168	512	1,039
DC	1,754	1,241	560	236	367
DE	4,324	3,060	1,388	593	1,021
FL	188,374	133,311	61,341	27,116	57,339
GA	225,701	159,727	72,327	30,765	51,453
HI	--	--	--	--	--
IA	49,155	34,787	15,693	6,613	10,333
ID	2,265	1,603	725	307	499
IL	112,090	79,325	35,826	15,141	24,175
IN	67,343	47,658	21,572	9,167	15,232
KS	126,376	89,435	40,232	16,834	24,890
KY	64,536	45,671	20,697	8,821	14,959
LA	246,212	174,242	78,032	32,281	43,335
MA	7,823	5,536	2,578	1,171	2,835
MD	37,238	26,353	11,916	5,051	8,244
ME	9,220	6,525	3,081	1,443	3,967
MI	39,559	27,996	12,934	5,771	12,786
MN	22,048	15,603	7,130	3,100	5,973
MO	108,309	76,649	34,431	14,355	20,606
MS	181,618	128,530	57,657	23,954	33,391
MT	4,571	3,235	1,470	630	1,111
NC	116,073	82,144	37,240	15,886	27,093
ND	10,720	7,586	3,406	1,418	2,012
NE	18,191	12,874	5,802	2,439	3,740
NH	4,057	2,871	1,335	604	1,431
NJ	17,973	12,719	5,791	2,497	4,552
NM	3,332	2,358	1,090	487	1,076
NV	2,781	1,968	894	384	679
NY	21,627	15,305	7,035	3,103	6,475

State	Tons per year				
	Baseline	Option 1	Option 2	Option 3	Option 4
OH	78,746	55,728	25,348	10,902	19,632
OK	126,372	89,432	40,176	16,753	24,087
OR	11,398	8,067	3,796	1,765	4,683
PA	67,108	47,492	21,679	9,404	17,866
RI	1,206	853	392	173	365
SC	99,583	70,474	31,969	13,658	23,550
SD	19,235	13,612	6,097	2,524	3,402
TN	110,926	78,501	35,449	14,976	23,847
TX	575,297	407,134	182,798	76,117	108,163
UT	3,289	2,328	1,079	485	1,108
VA	79,153	56,016	25,404	10,847	18,624
VT	1,512	1,070	495	221	494
WA	19,690	13,934	6,539	3,023	7,817
WI	21,704	15,360	6,990	3,010	5,462
WY	1,432	1,014	461	199	358
WV	14,662	10,376	4,742	2,063	3,985
NATIONAL	**3,236,971**	**2,290,780**	**1,035,172**	**438,079**	**706,378**

Table 10-14. Sediment removals—primary analysis case

State	Tons per year			
	Option 1	Option 2	Option 3	Option 4
AL	40,557	84,295	105,094	94,568
AK	--	--	--	--
AR	26,576	55,309	68,973	63,044
AZ	3,639	7,587	9,465	8,842
CA	8,251	17,103	21,312	18,572
CO	4,113	8,538	10,642	9,437
CT	969	1,993	2,479	1,953
DC	472	981	1,222	1,092
DE	1,164	2,410	3,002	2,575
FL	50,716	104,125	129,523	99,323
GA	60,766	125,926	156,912	136,224
HI	--	--	--	--
IA	13,234	27,485	34,261	30,541
ID	610	1,265	1,576	1,385
IL	30,178	62,632	78,065	69,031
IN	18,131	37,581	46,831	40,766
KS	34,024	70,775	88,251	80,195
KY	17,375	35,990	44,842	38,704
LA	66,288	138,237	172,452	161,398
MA	2,106	4,294	5,334	3,671
MD	10,026	20,793	25,913	22,722
ME	2,482	5,018	6,224	3,703
MI	10,651	21,814	27,123	20,132
MN	5,936	12,237	15,233	12,363
MO	29,160	60,706	75,708	69,456
MS	48,897	101,874	127,067	117,630
MT	1,231	2,546	3,171	2,692
NC	31,250	64,717	80,632	69,431

State	Tons per year			
	Option 1	Option 2	Option 3	Option 4
ND	2,886	6,010	7,496	6,901
NE	4,898	10,177	12,688	11,387
NH	1,092	2,230	2,770	1,943
NJ	4,839	9,996	12,448	10,408
NM	897	1,837	2,283	1,709
NV	749	1,549	1,929	1,634
NY	5,823	11,962	14,881	11,513
OH	21,201	43,821	54,578	45,848
OK	34,023	70,827	88,329	80,995
OR	3,069	6,216	7,713	4,868
PA	18,067	37,268	46,398	37,936
RI	325	667	829	638
SC	26,811	55,503	69,147	59,256
SD	5,179	10,798	13,471	12,592
TN	29,865	61,987	77,262	68,391
TX	154,888	322,536	402,260	370,217
UT	886	1,811	2,251	1,635
VA	21,311	44,123	54,971	47,195
VT	407	833	1,036	763
WA	5,301	10,756	13,350	8,662
WI	5,844	12,075	15,038	12,586
WY	386	797	992	835
WV	3,947	8,137	10,129	8,209
NATIONAL	**871,492**	**1,808,143**	**2,253,559**	**1,985,567**

Table 10-15. Sediment removals—low sensitivity analysis case

State	Tons per year			
	Option 1	Option 2	Option 3	Option 4
AL	37,081	65,975	79,716	69,190
AK	--	--	--	--
AR	24,298	43,305	52,343	46,414
AZ	3,327	5,944	7,188	6,568
CA	7,543	13,376	16,149	13,433
CO	3,761	6,680	8,068	6,890
CT	886	1,555	1,873	1,347
DC	432	767	927	796
DE	1,064	1,884	2,274	1,848
FL	46,369	81,216	97,787	68,149
GA	55,557	98,478	118,889	98,202
HI	--	--	--	--
IA	12,100	21,507	25,980	22,260
ID	557	989	1,194	1,004
IL	27,591	49,001	59,182	50,148
IN	16,577	29,392	35,485	29,420
KS	31,108	55,406	66,961	58,904
KY	15,886	28,141	33,970	27,832
LA	60,606	108,295	130,972	119,921
MA	1,926	3,342	4,016	2,361
MD	9,166	16,264	19,640	16,450
ME	2,269	3,896	4,670	2,379

State	Tons per year			
	Option 1	Option 2	Option 3	Option 4
MI	9,738	17,004	20,459	13,609
MN	5,427	9,556	11,519	8,667
MO	26,661	47,535	57,461	51,209
MS	44,706	79,787	96,470	87,032
MT	1,125	1,990	2,401	1,930
NC	28,572	50,601	61,077	49,887
ND	2,639	4,706	5,690	5,095
NE	4,478	7,965	9,623	8,322
NH	999	1,736	2,087	1,261
NJ	4,424	7,810	9,420	7,402
NM	820	1,431	1,722	1,187
NV	685	1,210	1,461	1,167
NY	5,324	9,331	11,237	7,902
OH	19,384	34,245	41,312	32,581
OK	31,107	55,459	67,039	59,705
OR	2,806	4,830	5,792	3,257
PA	16,519	29,107	35,093	26,634
RI	297	520	626	435
SC	24,513	43,393	52,371	42,479
SD	4,735	8,459	10,230	9,352
TN	27,305	48,497	58,575	49,703
TX	141,612	252,573	305,340	273,323
UT	810	1,410	1,696	1,118
VA	19,484	34,497	41,637	33,860
VT	372	650	781	511
WA	4,847	8,362	10,033	5,900
WI	5,343	9,435	11,381	8,936
WY	352	622	751	598
WV	3,609	6,354	7,659	5,741
NATIONAL	**796,791**	**1,414,486**	**1,708,225**	**1,442,318**

Table 10-16. Sediment removals—high sensitivity analysis case

State	Tons per year			
	Option 1	Option 2	Option 3	Option 4
AL	44,034	102,615	130,473	119,947
AK	--	--	--	--
AR	28,854	67,314	85,603	79,674
AZ	3,951	9,231	11,742	11,119
CA	8,958	20,830	26,475	23,729
CO	4,466	10,396	13,216	12,002
CT	1,052	2,430	3,086	2,559
DC	513	1,194	1,518	1,387
DE	1,264	2,936	3,731	3,302
FL	55,063	127,033	161,258	131,035
GA	65,974	153,374	194,936	174,247
HI	--	--	--	--
IA	14,369	33,463	42,543	38,822
ID	662	1,540	1,958	1,766
IL	32,765	76,264	96,949	87,915
IN	19,685	45,771	58,176	52,111
KS	36,941	86,144	109,542	101,485

State	Tons per year			
	Option 1	Option 2	Option 3	Option 4
KY	18,864	43,838	55,714	49,576
LA	71,970	168,179	213,931	202,876
MA	2,287	5,245	6,652	4,988
MD	10,885	25,321	32,186	28,994
ME	2,695	6,139	7,777	5,253
MI	11,563	26,625	33,788	26,773
MN	6,445	14,918	18,948	16,075
MO	31,659	73,878	93,954	87,703
MS	53,088	123,961	157,664	148,227
MT	1,336	3,102	3,941	3,461
NC	33,929	78,833	100,187	88,980
ND	3,133	7,314	9,302	8,707
NE	5,317	12,389	15,752	14,451
NH	1,186	2,723	3,454	2,627
NJ	5,254	12,182	15,476	13,421
NM	974	2,242	2,845	2,256
NV	813	1,887	2,398	2,102
NY	6,322	14,592	18,524	15,152
OH	23,018	53,398	67,845	59,114
OK	36,939	86,195	109,619	102,284
OR	3,332	7,602	9,633	6,716
PA	19,616	45,429	57,704	49,242
RI	352	813	1,032	841
SC	29,109	67,614	85,924	76,032
SD	5,622	13,138	16,711	15,833
TN	32,425	75,477	95,950	87,079
TX	168,164	392,499	499,180	467,135
UT	961	2,211	2,805	2,182
VA	23,137	53,749	68,306	60,530
VT	442	1,017	1,291	1,018
WA	5,756	13,151	16,667	11,873
WI	6,344	14,714	18,694	16,242
WY	419	971	1,233	1,074
WV	4,286	9,920	12,599	10,677
NATIONAL	**946,192**	**2,201,800**	**2,798,892**	**2,530,594**

Table 10-17 provides the reductions of sediment discharged for the nation under each regulatory option, the percent reduction for the primary analysis, and the sensitivity analysis, after full implementation.

Table 10-17. National sediment reductions for regulatory options

	Load reduction (tons)		
	Low-end estimate	Average estimate	High-end estimate
Option 1	796,791	871,492	946,192
Option 2	1,414,486	1,808,143	2,201,800
Option 3	1,708,225	2,253,559	2,798,892
Option 4	1,442,318	1,985,567	2,530,594

Load reduction (billion pounds)			
	Low-end estimate	**Average estimate**	**High-end estimate**
Option 1	1.594	1.743	1.892
Option 2	2.829	3.616	4.404
Option 3	3.416	4.507	5.598
Option 4	2.885	3.971	5.061
Percent load reduction			
	Low-end estimate	**Average estimate**	**High-end estimate**
Option 1	41%	34%	29%
Option 2	73%	70%	68%
Option 3	88%	87%	86%
Option 4	74%	77%	78%

The RF1-level estimates of baseline discharges and discharges under the regulatory options were used as inputs to the SPARROW model to estimate changes in sediment flux in the nation's RF1 river network. EPA used, as inputs to the SPARROW model, only the set of RF1s watersheds that have 1 or more acres of annual development. Of the 42,288 state/RF1 combinations in the model, there were 40,591 individual RF1 watersheds. Of those, 33,083 had 1 or more acres of development. The total loads modeled in SPARROW are as shown in Table 10-18. The total number of acres represented in the SPARROW loads is 848,986, which represents 99.6 percent of the total annual acres estimated to be developed (852,650).

Table 10-18. Total discharge loads and loads modeled in SPARROW

	All RF1s	RF1s modeled in SPARROW
Baseline	2,589,577	2,582,272
Option 1	1,718,085	1,713,238
Option 2	781,433	779,217
Option 3	336,018	335,053
Option 4	604,009	602,164

Results of the SPARROW modeling are in *The Environmental Impact and Benefits Assessment for Final Effluent Guidelines and Standards for the Construction and Development Category* (EPA 2009b), which discusses the results of the SPARROW modeling and the monetized benefits of the regulatory options. The entire loading analysis is in the C&D Load Spreadsheet Model (DCN 43121).

10.6. REFERENCES

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11. NON-WATER QUALITY ENVIRONMENTAL IMPACTS

Sections 304(b) and 306(b) of the Clean Water Act require the U.S. Environmental Protection Agency (EPA) to consider non-water quality environmental impacts (including energy requirements) associated with effluent limitations guidelines and standards. In accordance with those requirements, EPA has considered the potential impacts of the options on energy consumption, solid waste generation, and air emissions. The estimates of the impacts for the construction and development (C&D) industry are summarized in Sections 11.1, 11.2, and 11.3. Additional information on the calculation of the estimates is in DCN 43111 in the Administrative Record.

11.1. ENERGY REQUIREMENTS

EPA considered the additional energy requirements attributable to the regulatory options (Section 11.1.1) and the production of treatment chemicals (Section 11.1.2) and compared the option energy requirements with the energy requirements of the C&D industry (Section 11.1.3).

11.1.1. ENERGY REQUIREMENTS ATTRIBUTABLE TO THE REGULATORY OPTIONS

EPA estimates that additional energy requirements attributable to the regulatory options being considered are the result of the additional sediment removed from basins, traps, and other areas of accumulation. In addition, Options 2 and 3, which rely on the use of active treatment systems (ATS), would have additional energy requirements for operating pumps and generators. EPA assumes that diesel powered generators and pumps would be used to operate ATS. For a 500-gallon-per-minute (gpm) system, fuel consumption is approximately 10 gallons per hour (Rain for Rent 2008). Table 11-1 presents estimates of energy usage by regulatory option considered. Under Option 4, a small amount of energy could be required if metering pumps are used for introducing liquid polymer. EPA has not quantified energy usage for the pumps, but the amount of energy usage is expected to be minimal. The passive treatment technologies of Option 4 generally rely on gravity, so can be configured so as to utilize gravity flow of water through channels and basins, so the significant use of pumps and generators is not anticipated. However, permittees may utilize pumping to move water around construction sites and for dewatering trenches and excavations, but EPA has not quantified potential energy usage for pumping as the need for pumping would be highly site-specific.

Table 11-1. Estimated energy consumption by regulatory option

Option	Sediment removal (tons/year)	Sediment excavation		On-site trucking		Active treatment			Total fuel consumption (gallons)
		Equipment run time for excavation (hours/year)	Excavator fuel consumption (gallons/year)	# of truckloads	Truck fuel consumption (gallons/year)	Water volume treated (billion gallons/ year)	Equipment run time (hours/year @ 500 gpm)	Fuel consumption (gallons @ 10 gallons/hr)	
1	871,492	3,320	28,552	24,900	4,980	N/A	N/A	N/A	33,532
2	1,808,143	6,888	59,238	51,661	10,332	180	5,989,567	59,895,567	59,965,244
3	2,253,559	8,585	73,831	64,387	12,877	273	9,090,525	90,905,253	90,991,961
4	1,985,567	7,564	65,051	56,730	11,346	N/A	N/A	N/A	76,397

11.1.2. TREATMENT CHEMICAL PRODUCTION

EPA considered the availability and additional energy consumption from treatment chemicals. Section 11.1.2.1 describes chitosan and Section 11.1.2.2 describes polyacrylamides (PAMs). EPA expects that under Options 2 and 3, chitosan would primarily be used. Under Option 4, EPA anticipates a mix of both chitosan and PAMs. Results for both 100 percent chitosan use and 100 percent PAM use are presented for Option 4.

11.1.2.1. Chitosan

Chitosan is derived from chitin, the major component of crustacean shells and is a cationic polyelecrolyte. Chitosan (poly-D-glucosamine) is one of the most common polymers found in nature (USEPA 2003). Chitin is the second-most abundant natural fiber after cellulose and is similar to cellulose in many respects (Hennen 1996). Global Industry Analysts, Inc., estimates that the global chitin market will exceed 51.4 thousand metric tons (113 million pounds) by 2012 (Global Industry Analysts, Inc. 2008). The United States could produce approximately 30 percent of the worldwide shellfish harvest each year (Hennen 1996). Therefore, EPA estimates that the U.S. chitin market could approach 34 million pounds by 2012.

Minton (2006) reports an average chitosan acetate dose rate of 2 milligrams per liter (mg/L). Minton (2006) notes that the Washington State Department of Ecology specifies a maximum dosage of 1 mg/L but that variances are granted for turbidities greater than 600 nephelometric turbidity units (NTUs). Minton (2006) reports chitosan acetate dosages as high as 3 mg/L. Table 11-2 presents the amount of chitosan acetate required from applying a 2 mg/L chitosan acetate dosage to the stormwater volumes (from Section 11.1.1, Table 11-1) requiring treatment. Note that under Option 4, it is not likely that chitosan acetate would be used to treat all stormwater generated. Nonetheless, EPA has included estimates here. The option 4 volumes are the same as Option 3, because the acreage threshold (10 acres) is the same.

Table 11-2. Maximum chitosan acetate required under EPA options

Option	Stormwater treated (billions of gallons)	Chitosan acetate required (pounds)
2	180	3,000,000
3	273	4,560,000
4	273	4,560,000

The amount of chitosan acetate in Table 11-2 represents a fraction of the total chitin market. In addition, EPA expects the amount of chitosan would be less than the amount presented in Table 11-2 because many construction sites would use other treatment chemical alternatives, including PAMs, described in Section 11.1.2.2.

Because chitosan is manufactured from crustacean shells and not petroleum products, additional energy consumption from chitosan production and use is expected to be minimal.

11.1.2.2. Polyacrylamides (PAMs)

PAMs are a broad class of compounds that include cationic (positively charged) and anionic (negatively charged) PAM. PAMs are water soluble over a wide pH range and exhibit a high affinity for suspended sediment. PAMs are derived from acrylamide, of which 94 percent is used as PAMs (ICIS Chemical Business 2008). U.S. demand for PAMs is presented in Table 11-3.

Table 11-3. U.S. acrylamide/PAMs demand*

Year	Acrylamide demand (million lbs)	PAM demand (million lbs)
2007	253	238
2011(projected)	290	273

Source: ICIS Chemical Business 2008

* U.S. demand equals production plus imports less exports

Polymers such as PAMs are produced from petroleum, so additional PAMs consumption to treat construction site stormwater runoff would result in increased petroleum consumption. However, consumption on construction sites is not expected to significantly increase demand for acrylamide. EPA estimates that total treatment volumes under Option 4 are 273 million gallons per year. Assuming a PAMs dosage of 2 mg/L to all stormwater generated, incremental PAM use under Option 4 would be 4,560,000 pounds per year.

11.1.3. COMPARISON OF OPTION ENERGY REQUIREMENTS TO CONSTRUCTION INDUSTRY

Table 11-4 presents an estimate for construction industry fuel consumption based on the 2002 census.

Table 11-4. 2002 Energy use in NAICS Category 23

Census category	NAICS category 23	2002 unit cost	NAICS category 23 energy use (millions of gallons)
Gasoline and diesel fuel	$10,953,670,000[a]	$1.32/gallon[b]	8,300

[a] U.S. Census Bureau 2002.

[b] Energy Information Administration 2002.

Table 11-5 presents estimates of energy usage by regulatory option considered, compared to the total annual diesel and gasoline consumption in NAICS Category 23 (Construction).

Table 11-5. Estimated incremental energy usage by regulatory option

Option	Option diesel consumption (gallons)	Fraction of NAICS category 23 energy (gallons)
Option 1	33,532	0.000004
Option 2	59,965,244	0.007
Option 3	90,991,961	0.011
Option 4	76,397	0.000009

EPA does not expect any adverse effects to occur as a result of the small incremental energy requirements for the regulation.

11.2. AIR EMISSIONS IMPACTS

The Agency believes that none of the regulatory options for this rule would generate significant air emissions.

According to the Construction Industry Compliance Assistance Compliance Summary Tool (http://www.cicacenter.org/cs.cfm) no federal Clean Air Act (CAA) requirements apply to the C&D industry. CAA requirements are implemented primarily by states through their State Implementation Plans (SIPs). Following are examples of construction-related emissions that might require a state permit under an SIP:

- Nitrogen oxides (NOx) and fine particulates from construction equipment diesel engines
- Dust from vehicle traffic, from loading and unloading of construction materials at transfer points, and from conveyor systems transporting building materials
- Visible stack emissions from off-road equipment
- Volatile organic compounds (VOCs) from paint and cleaning solvents

To the extent that use of heavy construction equipments would be expected to increase from removing accumulated sediment, or portable generators or diesel powered pumps are used to power ATS, there would be an increase in fine particulate matter, VOCs, and NOx, and other pollutants, as well as increased CO_2 emissions, as estimated below.

EPA estimates air emissions on the basis of emission factors from diesel generators, the primary source of construction site air emissions, and excavators and trucks to remove accumulated sediment. A 135-kilowatt generator (210 horsepower [hp]) generator would consume approximately 10 gallons of diesel per hour (Diesel Supply and Service, No date). EPA multiplied the total system run times presented in Section 11.1 by the emission factors from the California South Coast Air Quality Management District (SC AQMD 2008)). Table 11-6 presents the estimated incremental air emissions by regulatory option.

Table 11-6. Estimated incremental air emissions by regulatory option (pounds/year)

Option	Reactive organic gases (ROG)	Carbon monoxide (CO)	Nitrogen oxides (NOx)	Sulfuric oxides (SOx)	Particulate matter (PM)	Carbon dioxide (CO_2)	Methane (CH_4)
Option 1	2,066	6,731	19,299	20	794	1,829,303	186
Option 2	1,116,150	3,997,266	11,595,274	11,860	442,759	1,052,768,276	100,692
Option 3	1,692,847	6,062,967	17,587,588	17,989	671,540	1,596,784,327	152,718
Option 4	4,707	15,335	43,970	45	1,809	4,167,800	424

Because construction air emissions are primarily from fuel combustion, EPA estimates that the increase in air emissions relative to the construction industry air emissions would be similar to the estimates for the fraction of construction industry fuel consumption presented in Table 11-5.

11.3. SOLID WASTE GENERATION

Solid waste generated at C&D sites include treatment residuals generated as part of coagulation and flocculation from ATS, and sediment that accumulates in channels, basins, and traps that are used as part of passive treatment systems. If ATS are used, solid waste can include spent cartridge or bag filters, or filter media (usually sand). EPA did not quantify solid waste generated from spent cartridge or bag filters because it is not clear whether permittees would require cartridge or bag filters as a final finishing step after ATS. Sediment removed from sediment basins and ATS, including sediment-containing polymers, can generally be used as fill material on the construction site. Therefore, EPA expects that solid waste generation would be minimal under any of the options.

11.4. REFERENCES

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