TURBIDITY REDUCTION AND MONITORING STRATEGIES FOR HIGHWAY CONSTRUCTION PROJECTS

Prepared for:

American Association of State Highway and Transportation Officials
Standing Committee on Environment

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AASHTO	American Association of State Highway and Transportation Officials
AC	Alternating Current
ALDOT	Alabama Department of Transportation
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
ATS	Active Treatment System
BFM	Bonded Fiber Matrices
BILS	Bottom Inlet Level Spreader
BMP	Best Management Practices
BPT	Best Practicable Control Technology
C&D	Construction and Development
Caltrans	California Department of Transportation
CDOT	Colorado Department of Transportation
CESCL	Certified Erosion and Sediment Control Lead
CESF	Chitosan Enhanced Sand Filtration
CFR	Code of Federal Regulations
CGP	Construction general permit
CPESC	Certified Professional in Erosion and Sediment Control
CPSWQ	Certified Professional in Stormwater Quality
CTAPE	Chemical Technology Assessment Protocol - Ecology
DADMAC	Diallyldimethyl ammonium chloride
DC	Direct Current
DOT	Department of Transportation
EC50	Effects Concentration for 50% of population
ECS	Erosion Control Supervisor
ECTC	Erosion Control Technology Council
EMC	Event Mean Concentration
ESC	Erosion and Sediment Control
ESCP	Erosion and Sediment Control Plan
FCD	Fiber Check Dam
FNU	Formazin Nephelometric Units
FRM	Fiber Reinforced Matrices
GLI-2	Great Lakes Instruments - Method 2
GPM	Gallons Per Minute
GULD	General Use Level Designation
HDPE	High Density Polyethylene
HPV	High Production Volume
IDT	Idaho Department of Transportation
ISO	International Organization for Standardization
LC50	Lethal Concentration for 50% of population
LED	Light Emitting Diode
LOD	Limits Of Disturbance
LOEC	Lowest Observed Effect Concentration
MATC	Maximum Allowable Threshold Concentration
MCTT	Multi-Chamber Treatment Train
MDE	Maryland Department of the Environment
MDSHA	Maryland State Highway Administration
MnDOT	Minnesota Department of Transportation

MoDOT	Missouri Department of Transportation
MS4	Municipal Storm Sewer System
NAL	Numeric Action Level
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program
NEL	Numeric Effluent Limit
NHDOT	New Hampshire Department of Transportation
NOEC	No Observed Effect Concentration
NOV	Notice of Violation
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NSF	National Sanitation Foundation
NTU	Nephelometric Turbidity Units
NYSDOT	New York State Department of Transportation
O&M	Operations and Maintenance
OCS	Oxide Coated Sand
OMB	Office of Management and Budget
OSHA	Occupational Safety and Health Administration
PAC	Polyaluminum Chloride
PAM	Polyacrylamide
PE	Professional Engineer
PVC	Polyvinyl Chloride
QA/QC	Quality Assurance/Quality Control
RUSLE2	Revised Universal Soil Loss Equation 2
SCADA	Supervisory Control and Data Acquisition
SCDOT	South Carolina Department of Transportation
SM2130	Standard Method 2130
SMM	Stabilized Mulch Matrices
SSC	Suspended Sediment Concentration
SWMP	Stormwater Management Plan
SWPPP	Stormwater Pollution Prevention Plan
TDOT	Tennessee Department of Transportation
TMDL	Total Maximum Daily Load
TP90	Technical Publication 90
TRM	Turf Reinforcement Mattress
TSS	Total Suspended Solids
TxDOT	Texas Department of Transportation
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WDNR	Wisconsin Department of Natural Resources
WET	Whole Effluent Toxicity
WisDOT	Wisconsin Department of Transportation
WQ	Water Quality
WSDOT	Washington Department of Transportation

Executive Summary

In 2009, the USEPA promulgated the Effluent Limitations Guidelines and Standards for the Construction and Development Point Source Category (40 CFR Part 450), known and the “C&D Rule”, requiring turbidity monitoring for larger construction sites and establishing a numeric effluent limitation of 280 NTU. Due to subsequent legal challenges, the numeric effluent limitation and monitoring requirements were stayed. Monitoring requirements were included in the USEPA’s 2011 proposed construction general permit, but were stricken from the finalized permit. Nevertheless, in January 2012, the USEPA solicited data and information on turbidity monitoring, implying that it is considering a potential future revision and reinstatement of some kind that would require turbidity monitoring that may be subject to a numeric effluent limitation or numeric action level.

This report seeks to prepare DOTs and others planning and implementing transportation-related construction projects for this potential eventuality by providing them with information on traditional and state-of-the-art turbidity reduction and monitoring practices. Two surveys were sent to state DOTs in an effort to gain information on the current state of the practice. Survey questions covered current erosion and sediment control practices, as well as turbidity monitoring practices in use in each state. These surveys provided detailed information for DOTs desiring to compare their programs to those of other states. An analysis of these surveys is included in Appendix A. This appendix includes a number of references to documents produced by state DOTs that may assist others in the development of their programs.

Turbidity Reduction

The turbidity of stormwater runoff from active construction sites is a function of many factors such as soil type, slope, extent of disturbed soils, precipitation patterns, and the BMPs implemented. Construction stormwater BMPs include erosion prevention practices that are used to minimize the initial mobilization and entrainment of sediment particles as well as sediment control practices that capture and treat sediment-laden stormwater runoff. Preventative measures, such as diverting flows around exposed soils, scheduling site activities to minimize the duration and area of exposed soils during rainfall, and using temporary mulch and erosion control blankets, are typically more cost-effective than removal of particles already entrained in stormwater runoff.

Research on turbidity reduction practices and technologies indicates that conventional erosion and sediment control BMPs, such as fiber mulch, silt fences, and sediment traps, can be effective at reducing the initial mobilization and transport of sediment particles, but generally will not reliably meet low turbidity effluent limits for construction sites. More rigorous and seemingly redundant application of conventional BMPs may be effective for some sites, but even these “enhanced” controls in combination may not consistently achieve turbidities below 280 NTU, especially for sites with steep slopes, highly erodible soils, and high intensity precipitation (or rapid snowmelt) events. For some sites with challenging circumstances, the use of chemical coagulants or electrocoagulation would likely be necessary to meet turbidity limits consistently.

The most common chemicals used as coagulants and flocculants in stormwater treatment systems are natural and synthetic polymers. While a variety of polymeric blends have been considered for stormwater treatment, the most popular include:

- Chitosan – very popular and widely accepted natural polymer for stormwater treatment derived from shellfish exoskeletons.
- DADMAC (diallyldimethyl ammonium chloride) a.k.a. polyDADMAC – is less expensive, but may have some toxicity concerns. Not as widely used as others.
- PAC (polyaluminum chloride) – Less impacts to pH than alum when alkalinity is low.
- PAM (polyacrylamide) – often copolymerized to vary the electrostatic charge. Differing chain lengths and charges mean there are a significant number of different formulations for PAM. Generally, should avoid small molecular sizes and cationic formulations. Extensively used in agriculture for decades. Generally used in erosion control and passive chemical treatment scenarios rather than active treatment.

Chemical coagulants and flocculants may be added to stormwater either actively or passively. Passive chemical dosing systems deliver liquid coagulants/flocculants via gravity or by dissolution of solid coagulants/flocculants directly into the flow stream. The "New Zealand" method is a rainfall-driven gravitational dosing method where the quantity of liquid chemical is based on the rainfall volume collected by a catchment tray. Dissolution methods include the use of coagulant powders or solid blocks added to catch basins, conveyances, check dams, or other in-stream locations. The chemical dose for this approach is less controlled than the New Zealand method because the rate of dissolution depends on wetting time, the level of turbulence, and water quality characteristics of the runoff rather than by the quantity of rainfall.

Active treatment systems may be configured as batch systems or flow-through systems. Batch systems store water until the pH is adjusted and then chemicals are added in a batch treatment cell. Flow-through systems continuously monitor turbidity and flow and then chemicals for coagulation/flocculation and pH adjustment are added accordingly en route to a filtration system. Electrocoagulation is a special type of active treatment system that introduces charged metal hydroxides (typically aluminum or iron) through electrolysis, which neutralize charged particles similar to chemical coagulants. The costs and effectiveness for electrocoagulation appear to be similar to those of other active treatment methods employing chemical coagulants.

The cost and reliability of implementing turbidity reduction practices at construction sites depends on a number of factors including, but certainly not limited to: soil type, precipitation and drainage characteristics, vegetation establishment/extent of disturbed area, duration of project, treatment system type and configuration, and level of monitoring and maintenance. In general, the active treatment systems are much more expensive to install and operate than passive dosing methods, but they can be expected to be significantly more consistent at achieving low effluent turbidity (usually below 10 NTU) at a variety of flow rates whereas the performance of passive systems is much less certain, particularly when flow rates are highly variable.

Besides site specific factors, treatment costs for active treatment depend on availability of materials, energy costs, and whether the system is rented or purchased. Costs per gallon of stormwater treated are also highly dependent on the utilization of the equipment, which in turn, is dependent on 1) amount of storage available for equalization, 2) size and imperviousness of the drainage area, and 3) the precipitation patterns during the construction period. The O&M costs will be higher for a system that runs for long durations; however, more stormwater will be treated, so the capital expense relative to the volume treated is less than for a system that sits idle for long periods of time. Due to these many considerations it is not surprising that 6-month treatment costs for these systems appear to range from as low as $4 to as high as $83 per thousand gallons treated. Passive treatment systems are expected to be considerably lower in cost because there are no energy costs, limited (if any) mechanical equipment, and lower operation and maintenance requirements. Based on estimates produced by the USEPA (2009a), the total monthly costs for a 17-acre model site treated using the New Zealand treatment method would range from approximately $1.80 to $13 per thousand gallons treated..

Very few studies have conducted side-by-side comparisons of the various technologies so direct comparisons of costs and performance of available data are tenuous, at best. Nonetheless, based on the available information gathered during the course of this study, some general comparisons of the four major classes of turbidity reduction technologies are possible, as indicated in Table ES-1. The turbidity ranges are approximate and are roughly based on the performance studies and data reviewed. They are intended to provide relative comparisons of what may be expected from these sediment control technologies.

Table ES-1. Summary Comparison of Major Classes of Turbidity Reduction Technologies.

Sediment Control Method	Expected Achievable Turbidity Range	Reliability	Monitoring & Maintenance Required	Relative Cost
Conventional BMPs	500-2,000 NTU	Low	Low	Low
Enhanced Conventional BMPs	100-500 NTU	Low	Low	Moderate
Passive Coagulation	20-500 NTU	Moderate	Moderate	Moderate
Active Treatment	1-20 NTU	High	High	High

Turbidity Monitoring

Obtaining an accurate turbidity measurement for construction site runoff can be difficult and is complicated by the challenges associated with collecting representative samples and differences in turbidity measurement equipment. More than one standard method for turbidity measurement exists, and within each method, tolerances in the standards contribute to variability of meters. While formazin is primary calibration standard and provides a basis for comparison of meters to a correct value, this chemical has very different light scattering characteristics than construction site runoff. Therefore, properly calibrated meters from different manufacturers may obtain significantly different readings for the same runoff sample. If turbidity results are to be compared or are used for enforcement, measurement, equipment and calibrations should be standardized. Some states, such as Washington, have begun to do this already.

Compositing is the practice of combining samples before turbidity is analyzed to obtain a more representative measurement of the event mean turbidity at a site. It can be done by taking samples at regular time intervals or by taking samples at regular runoff flow/volume intervals. This latter technique, referred to as flow-weighted compositing, requires continuous flow measurements, but delivers the most representative turbidity for a given storm. Choosing this option in part depends on the desired level of confidence in obtaining a representative measurement and the potential consequences of exceeding a numeric threshold (e.g., NEL or NAL).

Each of the sampling methods discussed in this report (manual grab sampling, stage sampling, simple and fully automatic sampling, and sampling by in-situ water quality probe) have strengths and weaknesses, which will, in turn, influence how it is best used. Each method's strengths, weaknesses, and most preferred application is summarized as follows:

- Manual grab samples benefit from low capital, training, and maintenance costs, but complicate compositing and require crews to be at each sampling location with short notice. These strengths and weaknesses make manual sampling the preferred method for most projects, but especially for low budget projects of shorter duration, or those with fewer or changing discharge locations.
- Stage sampling was originally designed for remote stream sampling, and has significant limitations, such as poor control over (and no record of) when a sample is taken and inability to sample during the falling leg of the hydrograph. Although it is specifically allowed in one state (Georgia), it was only discussed briefly in this report and not compared to other methods due to the inherent limitations.
- Automatic samplers can take and composite samples without crews onsite at sampling time, and can be controlled remotely with additional equipment, but have large capital, training, and O & M costs. These criteria make them a good fit for projects of long duration with consistent sampling locations, those requiring compositing to determine the most accurate assessment of a rainfall event's average discharge turbidity, and those for which it is difficult for crews to reach all locations in a timely and safe manner.
- In-situ water quality probes can record turbidity in near-continuous fashion and send this information electronically to e-mail or websites for wider accessibility in real-time, if interfaced with communication equipment. They avoid sample transportation and analysis costs, but have high capital costs and require careful installation and maintenance to ensure that readings are not biased by fouling, excessive sedimentation, partially submerged sensors, or calibration drift. This makes them best suited to receiving water monitoring and projects in which there are strong needs for real-time or near-continuous feedback on erosion control and treatment practices. Continuous data can also be mathematically composited to assess average discharge turbidity.

Regardless of the technique chosen, accuracy is strongly affected by proper sample collection, handling, and analysis methods.

Several state DOTs have developed significant experience in turbidity monitoring and have published guidance manuals in this area, most notably California and Washington. This information is a valuable resource for states starting to develop their own turbidity monitoring programs.

Due to the inherent and extensive variability from site to site in construction projects, there is no simple prescriptive formula for developing an appropriate sampling program for a linear construction project. Several subjective decisions must be made when selecting sampling methods and equipment.

The first choice is to determine the sampling frequency and method to be used. The majority of linear construction projects will likely implement the regulatory minimum (if the site requires sampling), which is anticipated to be manual grab sampling at discharge locations three times per storm event during normal business hours, and will likely implement reactive measures, as stipulated by permits, if discharge turbidity exceeds numeric limitations. In the event that a site has chosen to implement a minimal sampling program in accordance with regulations, it is recommended to incorporate provisions for modifying the program with the inclusion of additional grab samples, or transitioning to an automated program if violations of turbidity standards are noted.

While automated sampling with flow-weighted averaging of turbidity is more costly than grab sampling, this approach decreases the likelihood of “false positive” violations of effluent limitations and reduces the chances of “false negatives” that hinder proper response to inadequate source or treatment controls on the site. Automated sampling programs are well suited for large and long-term construction projects that span multiple rainy seasons. Projects that discharge to sensitive receiving waters or cross multiple receiving waters should consider in-situ water quality probes. Remote communication equipment with these probes can enable a much faster response to turbidity problems in streams than can be accomplished with any other method. This combination should be applied in situations where repercussions for high turbidity in receiving waters are especially serious.

It is expected that regulators will continue to incentivize construction phasing that minimizes exposure of disturbed soils, as well as non-channelized discharge of stormwater through vegetated buffers. DOTs may be able to reduce or eliminate monitoring locations by using distributed erosion and sediment controls that prevent concentrated flow conditions. These distributed controls, when properly installed and combined with source controls, are typically more effective than “end of pipe” controls because flow depths, velocities, and erosive forces are reduced and the ability to infiltrate and filter surface flows is increased. Linear DOT construction sites, particularly in lower slope/grade areas may be conducive to using controls that produce diffuse discharges when the majority of down-gradient site boundaries are oriented along somewhat level ground and when sufficient right-of-way space exists.

Finally, it is likely that regulations will continue to allow sampling of a subset of outfalls that are representative of the whole site, particularly for linear construction sites. While the regulatory criteria for accepting representative sites is limited, the key similarities between drainage areas that should be considered include the percent of exposed soils, type of construction activities, type and extent of erosion and sediment controls, the sites topography and soil characteristics and the expected stormwater flow rates. The ability of a DOT to utilize representative sites to reduce monitoring requirements may depend largely on how well this site information is presented to the permitting authority.

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Chapter 1. Introduction

1.1 Background

In December 2009, the U.S. Environmental Protection Agency (USEPA) published the new Effluent Limitations Guidelines and Standards for the Construction and Development Point Source Category (40 CFR Part 450), known as the “C&D rule” (USEPA, 2009b). This rule would impose Numeric Effluent Limitations (NELs) for turbidity on construction site dischargers over a certain size threshold and was to take effect in August 2011 (for 20+ acre sites) and in Feb 2014 (for 10+ acre sites). However, on November 5, 2010 the USEPA issued a stay of the turbidity limit due to legal challenges and data analysis problems in developing the limits (USEPA, 2010). In December 2010, the USEPA submitted a proposal to the Office of Management and Budget (OMB) to revise the turbidity limit, but this proposal was withdrawn in order to seek additional treatment performance data from construction sites before proposing a new turbidity limit (USEPA, 2011a, 2011b).

Monitoring requirements were part of the USEPA’s 2011 proposed construction general permit (USEPA, 2011c), but were stricken from the finalized permit (USEPA, 2012a). Nevertheless, in January 2012, the USEPA solicited data and information on turbidity monitoring, implying that it is considering a potential revision and reinstatement of some monitoring provisions that could require turbidity monitoring subject to a numeric threshold. The threshold could either be a NEL where exceedance triggers a permit violation, or a numeric action level (NAL) where exceedance triggers required action, but is not a violation. It is unknown at this time if USEPA will revise the original NEL value of 280 nephelometric turbidity units (NTUs), or if they do, whether it would be raised or lowered based on data reevaluation. Regardless of the final number, it is prudent for construction site dischargers to evaluate their current erosion and sediment control practices in light of these new and evolving regulations, and begin considering turbidity monitoring methods in preparation for potential future NELs or NALs.

Adherence to numeric effluent limits for turbidity for construction site discharges has already been required of construction site dischargers in states such as California and Georgia, or for discharges in high quality watersheds and/or those with Endangered Species Act violation concerns (salmonids in Washington State for example). However, a reinstatement of USEPA’s rule would require all states to implement the USEPA criteria in their construction general permit(s), at a minimum, within their next permit renewal cycle. Table 1-1 below describes some of the already existing turbidity limits in construction general permits.

Table 1-1. USEPA Numeric Effluent Limit in Comparison to Selected States

State	Turbidity Limit	Qualifier(s)
CA	250 NTU	Numeric action limit for Risk Level 2 and 3 sites (Risk levels based on potential for sediment generation and sensitivity of receiving water)
CA	500 NTU	Numeric effluent limit for Risk Level 3 discharges only
GA	20—750 NTU	Turbidity limit based on numerous factors, including site size, watershed size (highly dependent), and warm/cold water designation.
VT	25 NTU	Reportable benchmark (not effluent limit). Sampling is only required if discolored stormwater is flowing to a water of the State.
WA	25 NTU	Reportable benchmark (not effluent limit)
Federal	280 NTU (withdrawn)	10 acre and larger sites (once fully implemented)

One of the challenges of meeting turbidity effluent limits is that measured turbidity is not always a true indicator of the water quality impairment condition that it is intended to reflect. Turbidity is used as a surrogate measurement for quantifying entrained sediment. Sediment entrainment can vary by several orders of magnitude, depending on the storm, soil conditions, slope, treatment methods, etc. In addition, the correlation between turbidity measurement and suspended sediment can be affected by particle size, color, and dissolved organic compounds in the water sampled. Measurements can vary significantly from one turbidity meter to another, even with identical samples. A better understanding of these dynamics can be helpful in implementing turbidity control and monitoring programs, especially for DOTs, which often have construction projects that can traverse many types of geologic and vegetative conditions over large areas.

DOTs face an additional significant challenge in that many of their construction projects are atypical of sites covered under construction general permits, as they are typically much more linear in nature. Linear construction projects are recognized by some states where they have issued separate general construction permits for DOTs. Linear projects can potentially have more issues with channelization of runoff and very often have numerous outfalls for one project. Regulations often allow the implementation of strategies to reduce sampling requirements. The use of "representative" sampling locations instead of sampling every discharge location is one example of this. However, sampling regulations are vague in this regard and it is essentially up to the discharger to establish a defensible plan for characterizing site turbidity.

Two surveys were sent to state departments of transportation in 2011 to assess their readiness for upcoming NELs, facilitate knowledge transfer, and support this research effort (see Appendix A for details). Less than 30% of states reported that sampling of construction site discharge turbidity is currently required of their DOTs and just over 90% of responding DOTs said their agency had not initiated or completed any studies or research to facilitate the transition to NELs. These results confirm the need for additional guidance in this area. In addition, the following results show more specific needs:

- Just over a third of responding states have developed or started to develop policy or guidance for erosion or sediment control practices to meet NELs for turbidity on construction site discharges.
- When asked what hurdles must be overcome before their agency is able to utilize turbidity reduction technologies, of responding states:
    - 74% said that they needed to develop standard specifications.
    - 83% said that they needed guidance for design and maintenance.
- Less than a third of respondents had approved or developed any specifications for usage or conducted research related to use of flocculants or polyacrylamides (PAMs) at construction sites
- Just over 40% of respondents said that their state DOT had conducted studies, implemented organizational practices, or prepared reports that evaluate the effectiveness, efficiency, or performance of turbidity reduction technologies or conventional erosion and sediment controls at DOT facilities.

1.2 Goals and Objectives

With numeric effluent limits and action levels for turbidity increasingly more common in state construction general permits and the potential for future federal adoption of such limits, many DOTs are finding themselves in need of guidance on managing and monitoring turbidity at highway construction sites. In an effort to assist DOTs in making this transition to more stringent turbidity standards, this report seeks to provide guidance on:

1) Selection and implementation of enhanced traditional erosion control and treatment control BMPs
2) Identification of projects that may require more advanced treatment practices (including passive dosing of chemicals and active treatment techniques)
3) Selection and implementation of chemical treatment techniques in the most challenging situations
4) Selection and implementation of turbidity monitoring equipment
5) Implementation of monitoring programs in ways that provide the most value for the expenditure of effort

In addition, this report should help facilitate the exchange of information between DOTs on existing programs and research in the areas of turbidity sampling and advanced turbidity treatment.

1.3 Document Organization

Chapter 2 of this document focuses on current regulations and practices for controlling erosion and sediment, and thereby reducing turbidity, from linear construction sites. Standard erosion control and standard BMP practices are discussed, along with enhanced conventional BMPs. These BMPs are compared to passive dosing of chemical coagulants and flocculants, as well as active treatment systems. Each method is described in detail, with an evaluation of its effectiveness and cost.

Chapter 3 discusses construction effluent monitoring methods. It starts with lessons learned from state DOTs. Then it proceeds to cover compositing and the different methods of obtaining turbidity samples: manual grab samples, stage samplers, simple and fully automatic samplers, and in-situ turbidity probes. Standard methods of turbidity analysis and their differences are also discussed. Finally, a comparison of these various sampling methods is provided.

Chapter 4 is a higher-level overview of turbidity sampling, with a focus on strategies for employing sampling on linear construction sites. Since sampling frequency is an important driver in the choice of a sampling method, a discussion of when more frequent sampling may be desirable is provided and an overview is presented on drivers for the choice of one sampling method over another. Ways of minimizing sampling (using representative sampling locations, construction phasing, and diffuse discharge of stormwater to natural buffers) is then discussed. Finally, recommendations are given on the development and implementation of a monitoring plan.

Chapter 5 is a summary of the report with a focus on conclusions drawn from the material discussed in earlier chapters.

Appendix A provides a summary and analysis of the results of survey questions given to state DOTs in 2011. Survey questions are provided in Attachments 1 and 2 of Appendix A.

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Chapter 2. Turbidity Reduction Practices and Technologies

Turbidity reduction practices and technologies include both erosion controls to minimize entrainment of sediment (which can also reduce sources of organic matter that can also cause turbidity) and structural treatment controls to reduce sediment concentrations after particles become entrained in stormwater runoff. Some of the fundamental principles underlying the selection of these practices and technologies for a particular site include:

- Minimizing the footprint of disturbance and retaining natural vegetation to the extent practical;
- Scheduling construction to minimize soil exposure during the wet season or to limit exposure times overall;
- Promptly stabilizing denuded areas that are not actively being worked;
- Designing site drainage features to minimize the development of concentrated flows;
- Diverting runoff away from steep slopes, highly erosive soils, and sensitive habitat areas;
- Minimizing the steepness and length of cut slopes by using benches, terraces, contour furrows, or diversion ditches;
- Utilizing channel linings or temporary structures in drainage channels to slow discharge velocities and avoid channel downcutting;
- Retaining sediment on site by using sediment trapping devices (e.g., silt fences, basins, traps, etc.) and equipment tracking controls (e.g., stabilized gravel entrances/exits, shaker plates, wheel wash facilities, etc.);
- Regularly maintaining all site controls; and
- Inspecting sites frequently and correcting problems promptly.

To consistently achieve low turbidity concentrations in construction site discharges these principles must be strictly adhered to. Even then, depending on site soils, slopes, weather patterns, and a number of other factors, enhancements to the design of basic sediment retention structures, building redundancy into the system of sediment controls such as using baffles, floating inlets, and skimmers prior to filtration systems, and the addition of coagulation/flocculation agents may still be necessary to meet increasingly strict requirements.

This chapter discusses a wide range of turbidity reduction practices and technologies. Following a brief overview of current requirements and standard practices for controlling construction site stormwater runoff, enhanced erosion and sediment controls are discussed. Coagulation and flocculation technologies are then presented followed by a comparison of costs, effectiveness, and operations and maintenance of conventional and more advanced practices and technologies. This chapter is concluded with a summary of existing data gaps and research needs.

2.1 Current Requirements and Standard Practices

In March 2003, Phase II of the NPDES stormwater program went into effect, thereby requiring an NPDES permit for any construction activity that will disturb one or more acres, or is part of a "common plan" of development or sale that will disturb one or more acres. The permit requires operators to plan and implement appropriate pollution prevention and control practices for stormwater runoff during the construction period. As opposed to turbidity regulations associated with in-water work permitted by the U.S. Army Corps of Engineers under Section 404 (and certified by the state under Section 401) of the Clean Water Act, this permitting process focuses on managing sediment that may erode and be delivered to waters of the state.

Most states are authorized to implement the stormwater NPDES permitting program and therefore have state specific construction general permits (CGPs) that they issue and enforce. However, USEPA is the permitting authority in Massachusetts, New Hampshire, New Mexico, Idaho, Washington D.C., Puerto Rico, the territories, and Indian Country lands. In areas where USEPA is the permitting authority, operators must meet the requirements of the USEPA Construction General Permit (CGP). Otherwise, operators must meet the requirements of the USEPA-approved CGP for the authorized state. CGPs typically include requirements to:

- Prepare a stormwater pollution prevention plan (SWPPP);
- Implement and maintain erosion and sediment control BMPs during construction;
- Conduct self-inspections and perform site maintenance;
- Stabilize site soils after construction activities have temporarily or permanently ceased; and
- Document compliance activities.

Many states simply follow the guidance of USEPA CGP. However, a number of municipalities and states have additional or more stringent requirements.

2.1.1 Stormwater Pollution Prevention Plan (SWPPP)

For all construction projects requiring a stormwater permit, a SWPPP must be prepared and approved by the permitting authority before any groundbreaking activity begins. The SWPPP must include (Pitt, Clark, & Lake, 2007):

- A narrative that describes the major construction activities and sequence of earth disturbing activities;
- A general location map and a site map with depictions of drainage patterns, slopes, disturbed areas, erosion and sediment controls, and discharge locations;
- Descriptions of soil types, pollutant discharge controls, and timing of control implementation relative to the construction schedule;
- Estimates of the existing and post-construction runoff coefficients;
- Name(s) of receiving waters;
- Identification of SWPPP implementation responsibilities; and
- Summary of available data that describes existing stormwater runoff characteristics.

If during the course of the construction project there is a change in the planned activities or the implementation erosion and sediment controls, then an amendment to the SWPPP is required. The SWPPP must also be updated if any of the controls are found to be ineffective at eliminating or minimizing the discharge of pollutants.

2.1.2 Low Erosivity Waivers

The NPDES Stormwater Phase II Rule allows NPDES permitting authorities to accept "low erosivity waivers" for small construction sites. The waiver process exempts small construction sites (disturbing under five acres) from NPDES permitting requirements when the construction activity takes place during a relatively short time in arid or semi-arid areas. Consequently, most states have adopted the erosivity waiver process into their state CGPs for sites disturbing less than 5 acres if the project's rainfall erosivity factor ("R" Factor in the Universal Soil Loss Equation) is less than five during the entire period of construction. In some cases, states will also only approve a waiver certification if the entire period of construction activity occurs within the dry months as defined in their CGP for different regions of the state.

The "R" factor is a measure of the average erosive force of rainfall at a particular location. It is computed from the sum of the product of the total storm energy and maximum 30-minute intensity for all storms during an average year. The USEPA provides an online calculator for computing the "R" factor for any particular site as defined by the latitude/longitude or street address and the period of construction. The USEPA online tool can be found here: http://cfpub.epa.gov/npdes/stormwater/lew/lewcalculator.cfm.

2.1.3 Construction General Permits and the C&D Rule (40 CFR Part 450)

In February 2012, the USEPA issued its 2012 CGP. This CGP, and all new or reissued state CGPs, must include the requirements of the C&D rule. Since the NEL of 280 NTU and turbidity monitoring requirements in the C&D rule have been stayed indefinitely, these are not required to be included in new state CGPs and are not mentioned in the 2012 USEPA CGP. Other aspects of this rule, however, are still valid. For instance, the C&D rule requires construction site operators to apply the best practicable control technology currently available (BPT) for controlling erosion and sediment discharges, stabilizing disturbed areas, and dewatering. Specifically, erosion and sediment controls must, at a minimum, be designed, installed, and maintained to:

1) Control stormwater volume and velocity within the site to minimize soil erosion;
2) Control stormwater discharges, including both peak flow rates and total stormwater volume, to minimize erosion at outlets and to minimize downstream channel and streambank erosion;
3) Minimize the amount of soil exposed during construction activity;
4) Minimize the disturbance of steep slopes;
5) Minimize sediment discharges by addressing factors such as amount, frequency, intensity, and duration of precipitation, the nature of resulting runoff, and soil characteristics including the range of soil particle sizes expected to be present on the site;
6) Provide and maintain nature buffers around surface waters and direct stormwater to vegetated areas to increase sediment removal and maximize stormwater infiltration, unless infeasible; and
7) Minimize soil compaction and preserve topsoil as feasible.

Soil stabilization must be initiated immediately whenever earth-disturbing activities have ceased on any portion of the site and will not resume for more than 14 days. The C&D rule also includes additional requirements for controlling discharges from dewatering activities and preventing pollution from vehicle wash waters, building materials, construction waste, detergents, sanitary wastes, landscape materials, and spills and leaks. Unless infeasible, outlet structures from basins and impoundments must withdraw water from the surface.

The 2009 C&D rule also included a daily numeric turbidity limit of 280 NTUs applicable to construction sites disturbing more than 20 acres (after August 1, 2011) or 10 acres (after February 2, 2014) at one time for all runoff-producing storm events less than or equal to the 2-year, 24-hour storm. These effluent limits (and timelines) were to be applied to all individual NPDES permits issued after those dates or in construction general permits issued after the rule was promulgated (February 2, 2010). However, due to an error identified in the computation of the numeric turbidity limit, USEPA stayed the numeric limitation and associated monitoring requirements on January 4, 2011 that were published in the December 1, 2009 rule. USEPA has stated that it intends to propose a revised turbidity effluent limit in a future rulemaking.

2.2 Erosion Control Planning and Implementation

Erosion control practices are techniques used to minimize the initial mobilization and entrainment of sediment particles from active construction sites. Sediment particles can become mobilized due to raindrop impact forces, the force of flowing water particularly in concentrated flows, and wind forces. This mobilization results in erosion, water pollution, and soil loss. Stormwater runoff management plans or stormwater pollution prevention plans are used for construction sites as required by the governing regulatory agencies to implement practices for limiting the off-site discharge of sediment, sediment-laden water, and other pollutants associated with sediment particles and stormwater runoff. A variety of controls and management practices can be used to reduce erosive forces and create a physical barrier so that soil particles do not discharge from the construction site. A brief overview of traditional erosion controls is provided below. These practices are essential in minimizing soil loss and improving the water quality of stormwater runoff from construction sites. Implementation of these controls and practices should be initiated prior to and during major earth disturbing activities such as initial clearing and grubbing. Furthermore, erosion control planning is necessary to facilitate drainage controls throughout construction as well as manage stormwater runoff from adjacent off-site areas. Additional structural erosion and sedimentation controls to be used throughout construction are described in Section 2.2.5.

2.2.1 Minimization of Disturbance

The minimization of disturbed or denuded areas is one of the most important and beneficial erosion control management practices. Phasing a project in an attempt to disturb the minimum area is useful in limiting soil erosion. In addition, most regulatory agencies require the construction of a temporary sediment basin for disturbed areas greater than 10 acres. Permanent stabilization can be achieved as work progresses to limit the amount of disturbed area in order to take advantage of these erosion control benefits. Both the short-term and long-term weather forecasts should be taken into account as phasing progresses.

2.2.2 Site Drainage Planning

Site grading plans should follow the existing drainage patterns as much as possible in order to minimize the cut and fill quantities and required grading activities. Grading plans should consider drainage patterns during construction to minimize the number of site outfalls. In appropriate situations, this may include allowing stormwater runoff to be conveyed to a common location, such as a temporary sediment basin, thereby minimizing the number of monitoring locations and the number of stormwater outfalls requiring treatment. In some cases, it may be more appropriate to not concentrate flows and instead disperse runoff into adjacent vegetated buffer strips with no discernible outfall. The topographic low point on a site should be reserved for the placement of temporary sediment basins where applicable. Grading activities and site drainage should be designed, as feasible, such that dewatering activities are not necessary to remove stormwater runoff from the site. Dewatering activities may be required for excavations where groundwater is shallow, but dewatering of sediment basins can often be avoided with proper site drainage planning.

Highway construction projects often traverse slopes and intersect natural drainage courses. Conventional grading practices applied to these locations result in rectilinear surfaces with constant planar slopes that tend to concentrate flows at the toe of the slope. Hardened slopes and conveyances are then often needed to avoid rill, gully, and channel erosion. Contour grading and slope rounding is an alternative grading approach that blends the linear transportation facility into adjacent landforms to preserve existing slopes and drainage courses (Caltrans, n.d.). This approach reduces the potential for erosion by dispersing runoff and directs the flow of water to gully soils where deep-rooted plants may survive. Figure 2-1 compares rectilinear grading with contour grading.

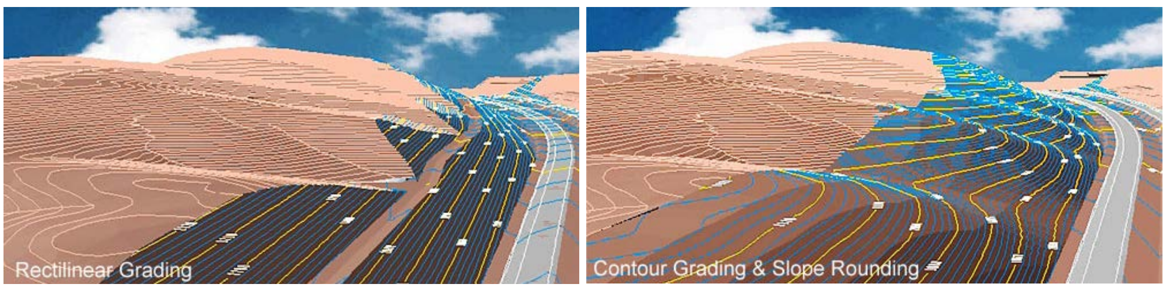

Figure 2-1. Comparison of Rectilinear and Contour Grading Designs (Caltrans, n.d.)

2.2.3 Soil Stabilization

Temporary or permanent soil stabilization practices are important to reduce the amount of soil lost to raindrop impact and wind forces. A variety of soil stabilization practices can be used depending on the current stage of construction and site-specific conditions. Regulatory agencies typically require temporary soil stabilization on all denuded areas that will be inactive for 14 days or more. The following soil stabilization practices can be implemented to minimize soil erosion:

- <u>Hydroseeding</u> – Hydroseed containing hydraulic mulch together with fast-germinating seed is useful for temporary stabilization. The hydraulic mulch helps prevent soil erosion immediately and provides a source of moisture to allow the seed to germinate. Fast-germinating annual grass or grain varieties can be used and should be based on local climate conditions. However, temporary stabilization is not achieved simply through seeding. Stabilization occurs once the seed has germinated and establishes an adequate vegetative density.

- Straw or hay mulch – Straw/hay mulch should be tackified or crimped by disc or other machinery in order to prevent the mulch from floating during runoff events. Typical application rates are 2-3 tons of anchored mulch per disturbed acre. Straw mulch is generally preferred to hay mulch, as the straw is thicker and heavier and does not contain unwanted hay seed.

Figure 2-2. Straw Mulch Cover at a Construction Site.

- Erosion control blankets – Rolled erosion control products such as blankets, netting, or plastic liners can reduce raindrop impact forces and decrease soil erosion. Products must be installed per manufacturer recommendations regarding staple spacing and edge treatments. The edges of rolled erosion control product may be trenched into the ground to keep the product in place and force runoff to flow over the top of the blanket instead of beneath it.

- Wood mulch – Wood cellulose fibers, wood chips, or wood mulch can be useful in minimizing soil erosion. Wood can be recycled from clearing and grubbing activities. Small particles or finely shredded wood material is not desirable in locations of concentrated flow due to the potential for flotation during runoff events.

- Gravel – In some cases, gravel may be allowed for temporary or permanent soil stabilization. Crushed or decomposed granite can be used for stabilization particularly in arid climates where vegetative cover is difficult to achieve.

- Soil roughening – Denuded soil can be left in a roughened state along slopes to minimize soil erosion potential. Soil roughening should be conducted perpendicular to the fall line of the slope. The roughened state will reduce erosive forces and flow velocities down the slope. If seed is applied to the slope, the roughened areas will help encourage seed germination. Improper soil roughening (i.e., parallel to the fall line of the slope) will enhance soil erosion and should be avoided.

2.2.4 Perimeter Controls

Perimeter controls are structural controls installed along the site perimeter to minimize the potential for sediment and pollutants to leave the site. Perimeter controls can either slow down the flow of stormwater resulting in settlement of suspended solids before discharging off-site or can intercept stormwater flows and route them to a centralized control such as a sediment basin for treatment. The following perimeter control practices are common for reducing the off-site discharge of pollutants:

- Construction entrance/exit – A stabilized construction entrance/exit is designed to restrict vehicle and equipment access to the construction site from the public street. Construction entrances/exits typically consist of course stone which creates a rough texture and aids in removing soil and sediment from vehicle tires. Alternatively, for sites with existing pavement, rumble strips or pipes such as cattle guards may also be used. The construction entrance/exit creates a vibration and jarring of the vehicle as it passes over the rough surface, which allows soil to be retained on-site and reduces track out onto public streets. Because sediment will be deposited on the construction entrance/exit, the voids in the stones will become clogged over time. Therefore, periodic top dressing or additional stone may be required for maintenance. All site access must be confined to the construction entrance/exit. In addition, wheel wash facilities may be required for additional cleaning. In this case, the wash water must be retained on site and is typically not allowed to discharge off site.

Figure 2-3. Double Silt Fence with Safety Fence Between.

- Silt fence, fiber rolls, silt dike – Perimeter controls designed to retain sediment-laden stormwater and allow for settlement of suspended solids can be come in a variety of forms. The most commonly used controls are silt fence, fiber rolls or straw wattles, silt dikes, or other devices that impede the flow of stormwater. Silt fence consists of a synthetic permeable filter fabric attached to support posts and, in some cases, wire backing for additional support. The support posts and wire backing are designed to support the filter fabric, stormwater, and sediment retained by the fence. The filter fabric should be trenched in to the surrounding soil and adequately compacted to prevent undermining of the fence. Drainage areas to silt fence are typically restricted to 0.5 acre per 100 feet of fence for slopes less than 2%. Fiber rolls or straw wattles generally consist of a geotextile fabric tube filled with reusable materials such as straw mulch, shredded tires, or wood chips. The weight of the fiber roll is generally sufficient to minimize undermining, but lightweight rolls may need to be staked as recommended by the manufacturer. Therefore, minimal earth disturbance is needed for the installation of fiber rolls. However, due to the low profile of most fiber rolls, the application is generally restricted to areas of very small stormwater runoff. Silt dike consists of filter fabric placed on a triangular wire frame or triangular foam material. Silt dike is generally applied on existing pavement and can be adhered to the pavement. Flocculant chemicals can be applied to many fiber roll devices to allow for additional or improved settlement of suspended solids as stormwater passes through the roll. Silt fences or fiber rolls should be installed on fairly level ground, parallel to the contour and should not be installed along a concentrated flow path. When installed along slopes, the ends should be flared up towards a higher contour such that water can pond behind it. "Smile" shapes or J-hooks should be periodically installed to provide additional ponding capacity and filtration of runoff. Figure 2-4 shows a J-hook and silt fence smiles being applied at construction sites.

- Berms or diversion ditches – Berms and diversion ditches can be constructed to intercept overland flows and divert stormwater to a sediment basin or other structural control for treatment. Berms or dikes consist of the build-up and compaction of surface soils to create a physical barrier. Diversion ditches or swales consist of an excavated area with the excavated soil placed on the down-gradient edge of the ditch for additional capacity. For both berms and ditches, the soil should be stabilized immediately upon completion of construction. Concentrated flows will be conveyed through these structures and soil stabilization will reduce the potential for erosion and suspension of additional sediment. Berms or ditches constructed at the site perimeter can be used to route on-site stormwater runoff to a structural control for treatment or can be used as run-on control to prevent stormwater from entering the disturbed portions of the construction site.

Figure 2-4. J-hook (left) and Smile (right) (Carpenter, 2006)

- Buffer strips – Preservation of existing trees and mature vegetation for buffer strips can be used as an effective non-structural perimeter control. The vegetation in buffer strips can trap sediment by slowing down sheet flow runoff. Although the preservation of existing vegetation is encouraged, in most cases, the use of buffer strips alone should not be used as the sole perimeter control for large disturbed areas.

2.2.5 Structural Sediment Controls

Structural sediment controls are practices and techniques used during construction to control runoff in addition to and in conjunction with the erosion control planning and implementation practices described above. Structural controls are expected to change and be modified as construction activities progress, grading and drainage patterns change, and permanent stormwater management systems are installed, such as underground storm drainpipes.

Conveyance of stormwater provides an opportunity to provide partial sediment control while collecting and routing the runoff to a common point for detention and additional treatment. Conveyance can be accomplished either below grade in ditches or above grade with berms. Both methods can be used to prevent stormwater from leaving the construction site prior to treatment.

Swales and Trenches

Diversion ditches, channels, swales, and trenches are construction site stormwater conveyance practices useful for collecting sheet flow runoff and routing flows to a common discharge point. All conveyance practices should be stabilized using vegetation or temporary soil stabilization products to prevent additional erosion from occurring due to concentrated flow velocities. Furthermore, check dams can be installed to reduce velocities and capture additional sediment. Check dams can be constructed of rock, wood, fiber rolls, or other manufactured product that impedes the flow of water to allow settlement of suspended solids as water flows over and through the check dam. A series of dams can be placed along a ditch or swale with the bottom of the upper check dam at the same elevation as the top of the dam below it to allow for maximum ponding capacity. In addition, the center of the check dam should be constructed with a low point such that during high flow events, water will flow over the center of the dam as opposed to around the edges of the dam where erosion is likely to occur. Silt fences should not be used as check dams. Additional stabilization, such as riprap or channel lining, may be beneficial particularly at the ditch outfall to prevent soil erosion. Rock riprap is useful to prevent the migration of soil particles due to high velocity flows.

Berms and Flow Spreaders

Above grade conveyance practices can also be used to collect sheet flow runoff and route the flows to a common discharge point. Berms are useful for providing a physical barrier to prevent runoff from leaving the construction site. Above grade conveyance systems should be stabilized upon installation to prevent additional erosion due to concentrated flows, particularly at the toe of a berm. However, additional check dams along the length of a berm are difficult to install properly. Another above ground conveyance practice can be used to spread shallow concentrated flows back to sheet flow conditions. Flow spreaders are stabilized berms at a constant elevation that allow water to pond behind the spreader and flow over the spreader in sheet flow conditions. This not only reduces flow velocities and minimizes erosion, but also allows for settlement of suspended solids and helps prevent erosion down-gradient.

Inlet Protection

A variety of inlet protection devices are used to remove pollutants from stormwater runoff prior to entering the inlet structure. Controls are placed within the flow path in order to slow the flow of water and allow for settlement of suspended solids. Inlet protection devices can consist of a variety of physical barriers including, fiber rolls, block and aggregate sediment filters, and manufactured devices such as covers or filter bags. It is expected that as construction progresses, inlet protection devices will be modified. For example, when an inlet is initially installed, the site may not be paved. Once paving is added, the inlet protection device may change due to the surrounding paved area. Furthermore, all inlet protection devices are expected to create ponding of stormwater, which can result in localized flooding or bypass conditions. Inlet protection should be installed and maintained such that undesired ponding conditions do not occur.

Sediment Traps and Basins

Temporary sediment basins or sediment traps are depressions installed down-gradient from construction activities and designed to detain stormwater runoff and allow for settlement of suspended sediment. State construction general permits often require sediment basins for disturbed areas greater than 10 acres. An overflow pipe or outfall structure is included in the sediment basin design to allow for discharge of stormwater at a controlled rate. Sediment traps are typically constructed for contributing areas less than 5 acres. Sediment traps should have an overflow structure but typically allow for infiltration or evaporation of detained stormwater. For both sediment basins and sediment traps, soil stabilization should be achieved immediately upon installation. Stabilization is particularly critical along the slopes of the basin or trap to prevent rill or gully erosion from forming. Sediment basins and sediment traps are usually constructed in conjunction with other conveyance practices, such as diversion ditches, to route runoff to the basin for additional treatment.

Filtration Systems

Filtration systems such as gravity sand filters are useful for filtering suspended sediment from stormwater runoff. These systems are typically reserved for stabilized sites or used as permanent stormwater management features. If large sediment loads are expected during construction, filtration systems may become clogged over time and require additional maintenance or become ineffective. A combined sedimentation/filtration system may be useful for large sediment loads. The majority of sediment settles out within the sedimentation chamber of the system and further treatment occurs in the filtration chamber. Smaller filtration systems such as filter bags or pressurized filtration vessels are particularly useful for dewatering activities where stormwater is pumped through the filtration devices prior to being discharge off-site.

2.2.6 Site Inspections and Corrective Actions

At active or unstabilized construction sites sediment can quickly build-up behind silt fences and check dams and within swales, inlet filters, sediment traps and basins. These BMPs can then become a source of sediment if the device fails or captured material becomes resuspended during subsequent storm events. The failure of a silt fence or berm may cause a catastrophic release of sediment, thereby negating much of the benefits of installing the BMP in the first place. Therefore, regular maintenance and corrective actions are needed to ensure stormwater BMPs continue to perform as intended.

All erosion and sediment controls should be inspected during periods of runoff or within 24 hours after any significant rainfall event (>0.5 inches). Many construction general permits require inspections once every 14 calendar days and within 24 hours of the end of a rainfall event greater than 0.5 inches. As an alternative, inspections must be conducted once every 7 calendar days on a specifically designated day.

To minimize the potential for resuspension, deposited sediment should be removed or stabilized. Stabilization may include covering the captured sediment with coarse aggregate, erosion control blankets, sod, or mulch. However, sediment should be removed if accumulation is excessive such that the structural integrity or performance of the BMP may become compromised during the next storm. For silt fences and temporary berms, if the sediment accumulates to 1/3rd of the barrier height then the material should be removed (Oregon DEQ, 2005) or an additional upgradient fence or berm should be installed until construction activities are completed. For sediment traps and basins, the accumulation of sediment should be considered in the design and should be removed *before* it reaches half (i.e., 50%) of the designed sediment storage capacity. Whenever possible, sediment material that is removed should be incorporated into fill soils at the site or moved to a stable location that is not prone to erosion.

Modifications to the stormwater management plan and the addition, relocation, or modification of stormwater controls to prevent pollutants from leaving the site through stormwater runoff should be based on findings during regular site inspections. When maintenance of erosion controls is required, the control should be restored to its original condition. In addition to inspecting erosion and sediment control practices, non-stormwater management practices must be inspected as well.

2.3 Enhanced Erosion and Sediment Controls

Enhanced erosion and sediment controls include standard practices that are implemented more rigorously or are enhanced in some manner to improve their performance. For example, augmenting mulch and seed with tackifiers to improve soil stabilization is an enhancement often applied at agricultural and construction sites. This section describes approaches to implement more rigorous and redundant controls followed by the application and effectiveness of tackifiers in erosion control. Several design enhancements for improving the performance of sedimentation facilities are then discussed. While the use of coagulants and flocculants within sedimentation facilities is another type of enhancement, these technologies are still not commonly used at construction sites and the implications of their use deserves further consideration than the more commonly applied enhancements. Consequently, coagulation/flocculation technologies are discussed separately in Section 2.4.

2.3.1 Effectiveness of More Rigorous Implementation of Standard Controls

Depending on site soils, slopes, climate, and sensitivity of receiving waters, a more advanced level of erosion and sediment control may be necessary at a site to achieve low turbidity effluent. This may include implementing multiple and perhaps seemingly redundant measures, such as placing an erosion control blanket over hydroseed or lining drainage ditches while also installing check dams to minimize sediment migration. Stormwater BMPs typically work better when implemented in combinations. For example, slope stabilization should be employed for erosion control and silt fencing should be used as a backup sediment control should erosion occur.

Slope Stabilization

Stabilizing soils to prevent erosion will usually be more cost-effective than removing sediment already entrained in stormwater runoff. In addition, erosion mitigation can be very expensive. As described above in Section 2.2.3, there are multiple types of soil coverings with varying abilities to protect soils from raindrop and rill erosion. Some coverings, such as manure or compost, may reduce erosion, but may still contribute to turbidity by releasing humic substances, tannins, and lignins. However, note that eroding soils, particularly in areas of historic wetlands, can also release these organic substances that reduce water clarity.

Horner et al. (1990) investigated different slope treatments including straw and wood fiber mulch and various erosion control blankets including jute, excelsior (wood shavings), woven straw, and synthetic fiber mats. Composite runoff samples were collected at the bottom of test plot slopes (2.5:1) and analyzed for flow rate, turbidity, and settleable solids. While all slope treatments provided moderate control of settleable solids, only the straw mulch provided consistent control of turbidity (Horner et al., 1990). The average turbidity of the straw mulch treatments (2.75-4 tons/acre) for five storm events in 1987-88 was below 50 NTU, while the average of the other treatments ranged from 75 to 190 NTU. The control plot averaged greater than 400 NTU.

The thickness of the straw mulch covering is a key factor in reducing erosion. Most erosion and sediment control manuals recommend 2-3 inches of mulch covering. For sites with highly erodible soils and high intensity rainfalls, the mulch covering may need to be 4 inches or greater to provide significant benefits. Thick mulch not only reduces impact erosion, it will tend to stay in place better than thin mulch when subjected to sheet flow because of the added weight and binding of the material.

Silt Fences

Silt fences are among the most common sediment controls implemented at construction sites. They are installed perpendicular to the flow line along the contour of a slope, and unlike sediment traps and basins, silt fences do not require disruption of additional off-site space. They are designed to retain sediment entrained in shallow overland flow from small drainage areas (< 1/2 acre per 100 ft of fence) and should not be installed across drainage ways, swales, gullies, ditches or other areas of concentrated water flow (NRCS, 2011). Despite their widespread use and ample guidance on proper design and installation techniques, silt fences have been shown to be ineffective at significantly reducing fine sediment and turbidity (Stevens, Barfield, Britton, & Hayes, 2004; Barrett, Kearney, McCoy, & Malina, 1995). Common causes of poor performance include:

1. Under-runs due to inadequate toe-ins or excessive erosion caused from concentrated flow created by cross contour installations;

2. Failure to trap fines due to inadequate detention time to allow for upstream settling;
3. Inadequate fabric splicing;
4. Tears and punctures in fabric due to inadequate strength or damage caused from construction activities;
5. Breaking or overturning of support posts;
6. Overtopping caused by sagging of fence or excessive drainage area; and
7. Lack of maintenance

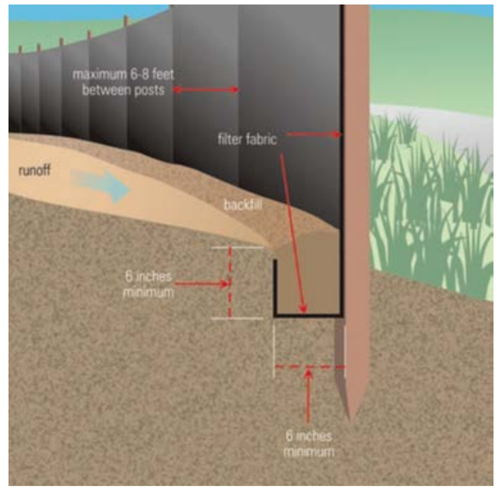

Figure 2-5. Proper Silt Fence installation Details (USEPA, 2007).

Soil type and installation technique can greatly influence silt fence performance. Barrett et al. (1995) evaluated six Texas DOT constructions sites incorporating silt fences, including two installations of non-woven fabric and four installations of woven fabric. Samples were collected above and below the silt fences and analyzed for TSS, turbidity, and suspended particle size. With a median TSS removal of 0% and a median turbidity removal of 2%, the field results indicated that silt fences were ineffective at significantly reducing TSS or turbidity. The median TSS concentration discharged from the silt fence controls was approximately 500 mg/L. The poor field performance was attributed to a high percentage of silt and clay size particles (92% of the TSS), as well as installation and maintenance deficiencies. Holes in the fabric and inadequate toe-ins that resulted in under-runs were among the major deficiencies noted. These field results contradicted the performance of silt fences observed during controlled flume experiments where the same researchers reported mean TSS removal efficiencies of 68-90%. The improved performance was believed to be primarily caused by a coarser particle size distribution and a larger ponded area behind the controls in the flume experiments, which allowed for longer detention times and significant particle settling. This research indicates that because the pore size of silt fences are typically too large to contain clay and silt-sized particles they are not very effective at physical screening and will do little to reduce turbidity unless adequate detention time is provided upstream of the fence to promote sedimentation.

Techniques for improving performance of silt fences are summarized below (NRCS, 2011; Stevens et al., 2004; USEPA, 2007).

- <u>Siting</u> – Drainage areas should be restricted such that the maximum design depth of ponding behind the fence does not exceed 6 inches. The fence should be installed along the contour as closely as possible with the ends of the fence flared upslope to create a bowl shape (“smile” or J-hook) capable of storing the design storm without overtopping. Silt fences should not be used as a check dam for swales and ditches.
- <u>Installation</u> – The fabric should be buried to a depth of at least 6 inches and thoroughly compacted so the toe of the fence cannot be eroded or pulled from the ground when the soil is saturated. Posts should be driven to at least 16 inches below the ground surface and be designed with adequate

strength to stay erect during full impoundment (beyond the design storm). If the bearing strength of soils is insufficient for the posts to stay erect during saturated conditions, the use of fins, deeper burial depths, or other post anchoring designs should be employed. To avoid excessive stretching or sagging of the fence, posts should have less than 8 foot spacing and either a high strength geotextile grid or a metal web fence backing.

- <u>Maintenance</u> – Fences should be inspected after every rainfall event greater than 0.5 inches to look for excessive sediment accumulation, undercutting, punctures or tears, toppled posts, any signs of overtopping or sagging. Even without significant rainfall, regular inspections and preventative maintenance should occur at least weekly to identify and correct for any damage caused by construction operations or vandalism. Sediment accumulated behind the fence should be removed if sediment has accumulated to half the height of the silt fence fabric.

A modification to the standard silt fence is the "super silt fence" where a chain link fence is installed as backing to the woven geotextile fabric (MDE, 2009). This design provides a barrier that can collect and hold debris and soil with less potential for failure than the standard silt fence and has been recommended for projects adjacent to sensitive streams or critical habitat areas or where physical failures are more likely.

Stabilized Conveyances and Check Dams

For linear construction projects, ditches are often used to convey stormwater runoff to acceptable discharge points. To minimize erosion of these ditches they must be stabilized with mulch, an erosion blanket, rock, coarse gravel, or grass. Grass-lined channels should only be used where longitudinal slopes are less than 5% and should be designed with a parabolic or trapezoidal cross-section with side slopes not exceeding 3:1. If grass seed is used, straw mulch or an erosion control blanket or netting may be required until grass becomes established. Rock-lined channels can be used to convey flows down slopes up to 10%, but steeper slopes may require more stable materials such as concrete or rock gabions with additional outlet stabilization structures.

To provide sediment control within temporary and permanent conveyances, check dams should be installed to slow flow velocities and promote settling and infiltration. The performance of check dams at capturing sediment is largely dependent on the particle size distribution of the suspended sediment and the design, placement, and type of material used for the check dam.

Wanielista et al. (1986) recommend that check dams be designed to detain the entire water quality design storm to allow for infiltration through the swale bottom rather than be designed as flow-through filters. As such, the researchers recommend that check dam materials be constructed out of clayey sand that is mechanically compacted and covered with sod. Sod is recommended for immediate as well as long-term stabilization. Additional design recommendations include a 3-foot separation distance between the top of the check dam and the road sub-base material and a slope of the flow line between check dams of 10:1 – although shallower slopes are generally recommended where possible. With this type of design, the check dams are essentially being used to create sequential sedimentation basins. For narrow, linear construction projects adequate space may not be available to provide significant storage volume along the conveyance ditch. Instead, a flow-through design may be needed where the check dams are smaller or more permeable materials are used. Rock check dams can be used to slow the flow and promote sedimentation. However, check dams constructed out of large rock are inefficient at capturing fine sediment and will not significantly reduce turbidity (McLaughlin, King, & Jennings, 2009). This statement agrees with Barrett et al. (1995) where the researchers reported a mean TSS removal efficiency of 7% for rock check dams installed in flume experiments. The short detention times and large pore sizes are the suspected cause of the poor performance.

Permeable check dams made of other materials, such as gravel, sand bags, straw bales, straw wattles, coir rolls, or rock wrapped in filter fabric are expected to perform better than rock check dams, but few researchers have studied their performance with respect to turbidity reduction. Horner et al. (1990) indicate that straw bales are not as effective at trapping sediment as other controls, presumably because they do not always form a complete barrier and flows can migrate around or between bales. Straw waddles and other fiber check dams are more flexible and can be staked to the ground.

McLaughlin et al. (2009) compared the field performance of standard construction BMPs to fiber check dams (FCDs) installed at two North Carolina DOT road paving projects sites. Standard construction BMPs consisted of small sediment traps followed by rock check dams installed within the roadside conveyance ditch. FCDs consisted of coir logs and straw wattles that were snuggly staked to the bottom and side slopes of the ditch. Site 1 included three test sections: (1) standard BMPs, (2) FCDs, and (3) FCDs with polyacrylamide (PAM). Site 2 included two test sections: (1) standard BMPs and (2) FCDs with PAM. The entire ditch at Site 2 was also lined with an excelsior blanket due to a steeper slope. Flow-weighted composite samples were collected over 20 to 27 storms at Site 1 and over 9 to 19 storms at Site 1. Table 2-1 summarizes the turbidity monitoring results for Sites 1 and 2. As shown in the table, large reductions in turbidity were observed following road paving at each site indicating the ditches were less of a source of suspended sediment than the disturbed soils of the roads. Also, the fiber check dams produced much lower turbidities than the standard BMP installations. However, the FCDs without the addition of PAM were not able to achieve low turbidity consistently. At the FCD section of Site 1, four out of nine storm samples (44%) that were collected prior to road paving exceeded 280 NTU, but only one out of thirteen samples (8%) at the FCD w/PAM section exceeded 280 NTU with the majority of samples being less than 50 NTU. All of the samples collected at the FCD w/PAM section of Site 2 were less than 280 NTU. Cost estimates and additional results from this study are discussed in Section 2.4.6.

Table 2-1. Turbidity Monitoring Results for Standard BMPs and Fiber Check Dams with and without PAM.

	Turbidity at Site 1 (NTU)			**Turbidity at Site 2 (NTU)**	
	Standard BMPs	**Fiber Check Dams**	**Fiber Check Dam w/ PAM**	**Standard BMPs**	**Fiber Check Dam w/ PAM**
Turbidity Range Prior to Road Paving Site 1: 6/26/06 – 10/5/06 Site 2: 7/13/06 – 9/24/06	2,015 to 14,756	24 to 919	9 to 335	877 to 3,419	15 to 90
Turbidity Range After Road Paving Site 1: 10/17/06 – 3/16/07 Site 2: 12/1/06 – 4/24/07	270 to 4,669	20 to 89	3 to 19	24 to 1,351	1 to 261
Average Turbidity for All Storms	3,813	202	34	867	115
Median Turbidity for All Storms	2,488	72	16	308	45

*Data summarized from McLaughlin et al. (2009).

McLaughlin & McCaleb (2010) recently completed a controlled study for NCDOT that utilized simulated stormwater runoff with a constant concentration of 6,000 mg/L to compare the performance of excelsior wattles to rock check dams with and without excelsior blankets wrapped around them. As expected, the excelsior wattles and rock + excelsior blanket outperformed the unwrapped rock check dams. However, the average turbidity was still above 350 NTU for the excelsior wattles and excelsior-wrapped rock check dams for all of the simulated experiments. By adding PAM to the excelsior wattles and blankets significantly improved the performance of the check dams with average turbidity as low as 75 NTU being achieved (see Section 2.4.4 for further discussion).

In May 2011, CDOT conducted roadside BMP performance tests for turbidity in the Mountain Ute Indian Reservation near Cortez, Colorado (McDade, 2011). Different combinations of passive BMPs were evaluated including erosion logs, soil retention blankets, sediment traps, and geotextile gravel bags. The soils at the test sites consisted of silty clay loam and sandy clay loam, so they were highly erosive with high runoff and fine particulate potentials. During the first set of tests, a 2-yr, 24-hr rainfall event (1.5 inch) was simulated and samples were collected at various locations within two separate test ditches containing the BMPs. Ditch 1 was lined with a straw coconut coir blanket followed by lined sediment trap. Ditch 2 was unlined, but contained fiber rolls followed by a lined sediment trap. The results of the first set of tests indicate that these BMPs, even when used in combination, were incapable of reducing turbidity below 280 NTU during a simulated storm event. However, a sample collected from the sediment trap after 90 minutes after the simulated event had a turbidity of 164 NTU. In another test, flocculants were added to the fiber rolls in Ditch 2 and samples were collected during another 2-yr, 24-hr rain event. Results from this test indicate that after passive flocculant treatment of three fiber rolls the turbidity could be reduced from >1000 NTU at the upper part of the ditch to 69 NTU at the settling pond discharge point during a design storm event.

2.3.2 Tackifier Use in Erosion Control and Hydroseeding

Tackifiers are binding agents that can provide temporary erosion control, improve water retention, reduce seed migration, and keep soils open for infiltration. They can be applied as a standalone product over exposed soil or as binder in hydroseed mixes, fiber mulches, and other hydraulically applied materials. When applied with fiber mulch (Figure 2-6), tackifiers increase the effectiveness of the mulch by binding fibers and surface soil particles together. Tackifiers include plant-based products as well as synthetic polymeric emulsions. Example plant-based tackifiers include guar, psyllium, and other plant starches, such as cornstarch and potato starch. Synthetic tackifiers are manufactured polymers and copolymers that include polyacrylamides (PAMs), acrylic polymers and copolymers, methacrylates and acrylates, and hydro-colloid polymers (Caltrans, n.d.).

Figure 2-6. Hydroseeding for Temporary Erosion Control (Caltrans, n.d.).

Besides hydraulic mulch, the primary types of hydraulically applied erosion control materials include stabilized mulch matrices (SMM), bonded fiber matrices (BFM), and fiber reinforced matrices (FRM) (IDT, 2011; Lauro & Theisen, 2006). SMMs consist of defibrated organic fibers bonded by a tackifier (typically PAM). BFMs consist of defibrated organic fibers bonded by cross-linked insoluble hydro-colloidal tackifiers that form an erosion-resistant blanket. Cross-linking is a chemical process that reduces the water solubility and increases the longevity and bonding strength of the tackifier (Lauro & Theisen, 2006). FRMs consist of a mix of defibrated fibers and reinforcing natural and/or synthetic fibers held together with cross-linked hydro-colloidal tackifiers (IDT, 2011).

Table 2-2 compares the various hydraulically applied erosion control products. The Percent Effectiveness is a performance measure based on the cover (C) factor from the Revised Universal Soil Loss Equation and is commonly evaluated using ECTC Test Method #2, ASTM D6459 or from large-scale, rainfall simulation testing (Lauro & Theisen, 2006). Vegetative Establishment is a measure of the amount of germination and growth relative to a control based on ECTC Test Method #4. Values greater than 100% indicate that the erosion control product improved germination and growth relative to a control that did not use the product. Functional longevity refers to the typical length of time that the product can be expected to be effective at reducing erosion.

Table 2-2. Comparison of Hydraulically Applied Erosion Control Products.

	Hydraulic Mulch	**Stabilized Mulch Matrix (SMM)**	**Bonded Fiber Matrix (BFM)**	**Fiber Reinforced Matrix (FRM)**
Recommended Max Slope	3H:1V	2H:1V	1H:1V	0.5H:1V
Recommend Application Rate	1,500 to 4,000 lbs/acre	2,000 to 3,000 lbs/acre	3,000 to 4,000 lbs/acre	> 4,500 lbs/acre
Cover Factor	0.25	0.10	0.05	0.01
Percent Effectiveness	<75% (30 min duration)	>90% (30 min duration)	>95% (60 min duration)	>99% (60 min duration)
Cure Time	12-24 hrs	12-48 hrs	24-48 hrs	0-2 hrs
Shear Stress	0	0	0	1 lb/ft^2
Vegetative Establishment	Not available	>300%	400-600%	500-800%
Functional Longevity	<3 months	3-6 months	6-12 months	>12 months

Adapted from Lauro & Theisen (2006) with specifications added from IDT (2011) and (SCDOT, 2008).

Anionic PAMs are by far the most common type of tackifier used and approved for erosion control by state DOTs and have been used for many years to reduce soil loss from irrigated lands. The Caltrans Erosion Control Toolbox (Caltrans, n.d.) provides detailed guidance on selecting tackifiers for hydroseeding and temporary soil stabilization based on various criteria including availability, ease of clean up, cost, drying time, and mode of application. Many other state DOTs and regulatory agencies also have specific usage approvals and specifications for various tackifiers. Often states have an approved product list, and PAM or products containing PAM must be on that list in order to be used in the state. For example, Wisconsin DOT has erosion control product acceptability lists including one for soil stabilizers (WisDOT, 2010). Manufacturers who wish to be added to this list must request approval by supplying:

1. Acute and chronic toxicity test reports from an accredited testing laboratory and reviewed by the Wisconsin Department of Natural Resources (WDNR);
2. Certified test data showing the products ability to reduce soil loss induced by a rainfall simulator, as detailed in the American Association of State Highway and Transportation Officials National Transportation Evaluation Program (2,4, and 6 inches per hour); and
3. Certified large-scale test data conforming to ASTM D6459.

Other DOTs have similar approval procedures and requirements. Based on the survey of state DOTs, over 70% of the responding DOTs allow application of PAMs as a component of hydraulic slurries, but only 30% of the respondents indicated that they have approval procedures in place and less than 40% indicated that they have specifications. In many cases, the specifications for these PAMs simply state that the manufacturer's directions must be followed. Other common PAM specifications include:

- Must be anionic polymeric blend;
- Must be nontoxic (some require results from specific toxicity tests be provided by the supplier);
- Must be nonflammable;
- Must be functional for at least 180 days;
- The residual acrylamide monomer content must be less than 0.05% by weight;
- Has a high molecular weight (e.g., GA: 16 – 24 mg/mol; VA: 6 – 24 mg/mol, and preferably 12 – 15 mg/mol);
- Has a proven ability to bond soil particles;
- Proven to work in acidic soils down to a pH of 5;
- Contains a low temperature coalescing agent to accelerate curing at near-freezing temperatures;
- Must meet ANSI/NSF Standard 60 for drinking water treatment; and
- Soil tests should be used to determine whether divalent cation additives (e.g., gypsum) are necessary for the anionic PAM to be effective.

Common PAM application requirements include:

- Should be mixed and/or applied in accordance with all Occupational Safety and Health Administration (OSHA) Material Safety Data Sheet requirements and the manufacturer's recommendations for the specified use;
- To provide adequate curing of the product, avoid applications during rain, within 12 to 24 hours of forecasted rain, or on saturated soils;
- Soil temperature must be higher than 40-45^{o} F;
- Minimum and maximum application rate per acre (varies by state, but typically 5.6 to 11 kg/ha with a maximum annual application of 224 kg/ha for pure anionic PAM); and
- Can only be applied to areas that drain to sediment pond or trap prior to discharge.

McLaughlin (2002) evaluated the effectiveness of polyacrylamides (PAM) with and without straw mulch and seeding at various cut and fill slopes at highway construction sites in North Carolina. He found that PAM applied to bare soil on a 2:1 slope did not provide significant erosion control, but some control was demonstrated when applied to bare soil on a 4:1 slope. The high erosive forces on the steeper slope tended to quickly remove the thin layer of structural PAM soil. The erosion rates were 20 times greater on bare soil plots after the first seven events, with or without PAM, compared to those mulched with straw and sown with grass seed. PAM applied at the highest rate (11 kg/ha) on bare soil was effective in reducing erosion and turbidity on the 4:1 cut slope with a clay loam texture, but the effect declined with each storm event. On the sandy 4:1 fill slope there was no evidence of PAM effects, even at an application rate as high as20 kg/ha. Plots with conventional mulch/seed treatment reduced average turbidity levels from approximately 2,300 NTU (bare soil) to approximately 180 NTU. The addition of PAM to the mulch/seed treatments did not appear to provide a discernible benefit. This study indicates that mulch/seed with or without PAM provides more erosion control benefits than PAM alone particularly for steep slopes or fill slopes. This agrees with the research by Horner et al. (1990) who found that rill erosion still occurred when using a chemical agent over bare soil alone.

Nwankwo (2001) evaluated the effectiveness of polyacrylamides at controlling erosion from three highway construction projects around the State of Wisconsin. At each site, test plots were established that included various surface treatments including mulch + seed, PAM + seed, PAM + mulch + seed, and erosion control mat + seed. Slopes ranged from 3:1 to 2:1 and PAM mixtures were applied at approximately 22 kg/ha. The researchers found that PAM performed comparably to erosion mats with seed and better than mulch and seed alone in controlling erosion prior to the establishment of permanent vegetation. The combinations of PAM, seed, and mulch performed the best for both erosion control and vegetative growth. The PAM appeared to increase soil infiltration rates, which resulted in (1) more water for the seeds to germinate, (2) less runoff, and (3) less soil detachment.

2.3.3 Sedimentation Facility Design Enhancements

Various design enhancements are possible to improve the performance of sedimentation tanks and basins. For example, berms or baffles may be installed to decrease flow velocities and turbulence while increasing the flow paths through the facility. Berms may be constructed out of rock, stabilized earthen material, or rock-filled gabion wrapped in filter fabric. Baffles may be constructed out of concrete, untreated wood, reinforced silt fences, or a variety of other materials. Typically, berms and baffles are installed perpendicular to the direction of flow with weirs or slots placed at opposite ends to force the water through a more tortuous flow path. As a general guideline, a 1-foot deep weir should have a width equal to 1/3rd the flow in cubic feet per second (McLaughlin, 2005). If the berm or baffle is porous, then weirs or slots may not be necessary. These types of designs can be more effective than solid baffles because the flow is spread over the entire width of the basin rather than concentrating the flow through a single weir or slot. Porous baffles can be constructed out of coir mesh, woven geotextile, or other highly pervious fabric backed by wire fencing or other structural materials. Figure 2-7 is an example porous baffle installation constructed out of jute netting backed by an erosion blanket within a sedimentation basin.

Figure 2-7. Example Porous Baffles (McLaughlin, 2005).

Based on laboratory modeling of sedimentation basin hydraulics, Horner et al. (1990) found that residence time could be improved by implementing a few simple design enhancements including using a length/width ratio of 5:1, dividing the basin into two chambers rather than a single pond of equivalent size and shape, and using a perforated riser outlet structure. During a second phase of the study, two sedimentation ponds were constructed for treating highway runoff and one was constructed for treating runoff from a fill stockpile area. Two of the ponds (SR-204 Pond and Seattle Stockpile Pond) were designed according to the recommendations from the laboratory findings and the third pond (Mercer Pond) was not. However, the Mercer Pond was designed with a much larger surface area relative to the drainage area. Flow-weighted composite samples during 5-6 storm events were collected from the inlet and outlet of each pond and analyzed for settleable solids, TSS, turbidity, and several other water quality constituents. The monitoring results indicated that all of the ponds were capable of significantly reducing settleable solids and TSS (>85% for most storms). Figure 2-8 includes boxplots the influent and effluent TSS concentrations for the three ponds in the Horner et al. (1990) study. As shown in the figure, all of the ponds provided significant reductions in TSS, but the median effluent concentrations were still quite high for the Seattle Stockpile Pond and SR-204 Pond.

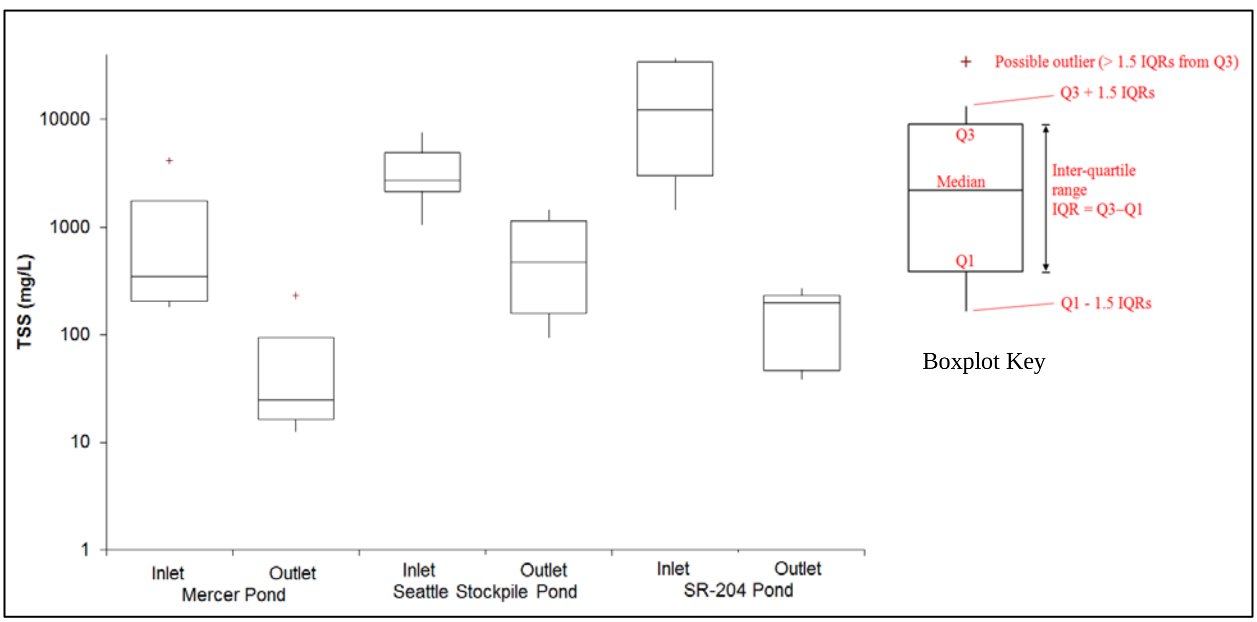

Figure 2-8. Influent and Effluent TSS Concentrations for Horner et al. (1990) Sedimentation Ponds.

While the differences in influent concentrations and site soil characteristics prevents a valid direct comparison of performance between the ponds, it appears the design enhancements at the Seattle Stockpile Pond and SR-204 Pond provided some benefits despite having a 50% smaller pond surface area to drainage area ratio as compared to the Mercer Pond. Turbidity measurements were very high (>1000 NTU) in the first three of the storm event effluent samples for the Seattle Stockpile Pond. However, during two of the storm events for both the Seattle Stockpile and SR-204 Ponds, the turbidity was reduced from >1000 NTU to approximately 200 NTU or less. The results of this study indicate that simple design enhancements to sedimentation facilities may improve solids retention, but to consistently achieve low turbidity effluent additional measures may be necessary (Horner et al., 1990). These additional measures may include additional source controls or additional treatment at the outlet, such as sand filtration.

In addition to berms and baffles, modular settling tubes or inclined plates (Figure 2-9) can be placed within sedimentation facilities to enhance sediment removal and retention. These devices create zones of laminar flow and reduce the depth required for individual sediment particles to settle while also reducing the potential for scour and resuspension. While these devices are most commonly used in wastewater treatment operations, some researchers have used them for stormwater treatment (Daligault et al., 1999; Pitt et al., 1999; Wood et al., 2004). Pitt et al. (1999) found that the settling chamber of the Multi-Chamber Treatment Train (MCTT) device, which includes inclined plates, could reduce TSS concentrations from a median of approximately 26 mg/L to less than 2.5 mg/L. Daligault et al. (1999) observed much higher influent concentrations and found that the settling tubes they installed could not achieve effluent TSS concentrations below about 30 mg/L with mean removal rates of about 30 to 50%. This agrees with Wood et al. (2004) who found mean removal efficiencies for lamella settlers of 26% without the addition of chemical coagulants – with the addition of a polymer coagulant, the researchers observed a mean TSS removal as high as 83%. The differences in performance among the various researchers are likely due to different design surface overflow rates and influent particle size distribution characteristics. Wood et al. (2004) compared the performance of conventional clarification to lamella settling and found that the lamella settlers provided a 5 fold increase in performance for the same size footprint.

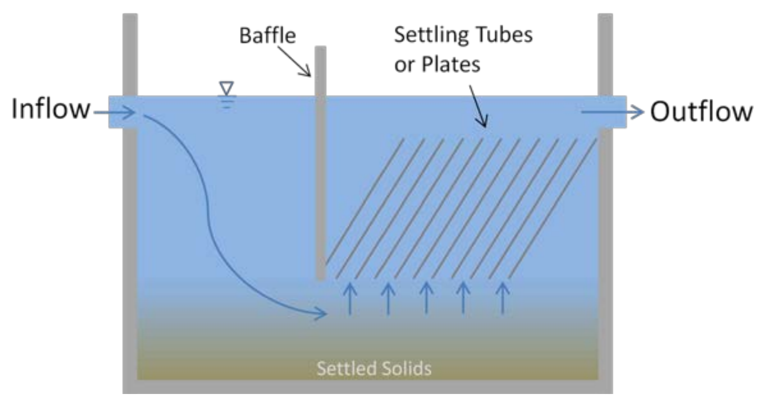

Figure 2-9. Enhanced Sedimentation with Settling Tubes/Plates

Another design enhancement for sedimentation facilities is to use surface outlets instead of the standard perforated riser. In fact, as mentioned in Section 2.1.3, the C&D rule requires the use of surface outlets from basins and impoundments "unless infeasible". While infeasibility criteria were not specifically provided, there are likely few instances where infeasibility could be adequately demonstrated. Surface outlets may simply be an overflow weir from a permanent pool of water. However, if the basin cannot draw down between storms then less capacity is available for 1) detaining subsequent storms, 2) shaving peak flow rates, and 3) maximizing hydraulic residence time. Floating risers (a.k.a. skimmers) are an alternative outlet design that permits near complete draw down between storms while discharging (typically) less turbid water from the surface. Figure 2-10 is an example of a floating riser outlet design (“Faircloth Skimmer,” n.d.)

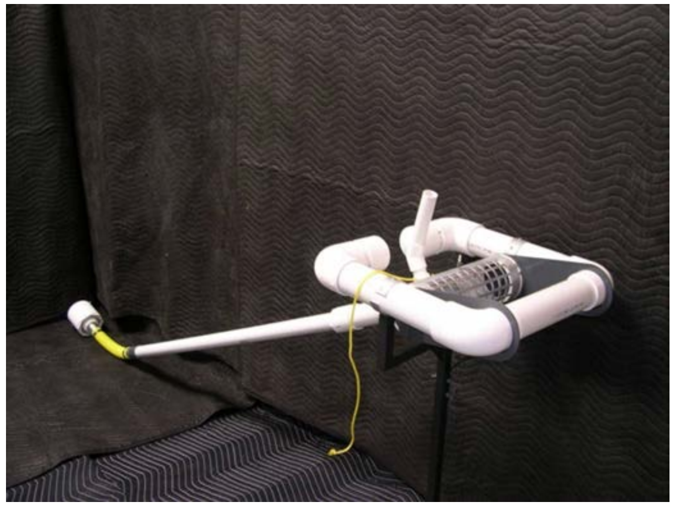

Figure 2-10. Faircloth Skimmer® Floating Riser Outlet.

Millen et al. (1997) compared the performance of a perforated riser and a skimmer outlet structure for two sedimentation basins designed to drain 1.4 inches of runoff in 24 hours. Using 24-hour simulated inflow hydrographs (100 m^3) and simulated sedigraphs (450 kg), these two outlet designs were studied with and without filter fabric baffles installed in the interior of the basins. The monitoring results indicated that the skimmer outlet performed much better than the perforated riser at reducing peak discharges and retaining sediment. The results of the study are summarized Table 2-3. As indicated in the table, the baffles appeared to provide some benefits for the perforated riser outlet, but they did not provide any benefit for the skimmer outlet. The researchers did not elaborate on the potential cause for this difference in performance and the statistical significance of the difference was not reported. The baffles likely improve the retention of larger particles, but may also create more turbulence near the surface of the pond, thereby keeping some of the smaller particles in suspension for longer periods. Since the skimmer outlet is already effective at retaining larger particles, the baffles did not improve the performance. The performance may have been further enhanced if more porous baffles had been used, such as those recommended by McLaughlin (2005), instead of the geotextile-based baffles used in this study.

Table 2-3. Summary of Millen et al. (1997) Study on Perforated Riser Outlet vs. Skimmer Outlet

	Peak Discharge (L/s)	Peak Effluent Concentration (mg/L)	Cumulative Sediment Discharge (kg)	Percent Retention of Particles 6-12 microns
Skimmer w/ Barriers	1.65	800	15.6	86%
Skimmer (No Barriers)	1.65	900	14.3	87%
Perforated Riser w/ Barriers	3.45	800	20.4	82%
Perforated Riser No Barriers	3.50	1,850	26.1	77%

2.4 Coagulation/Flocculation Technologies

Coagulation and flocculation are essential processes in water and wastewater treatment and these technologies have increasingly been considered for reducing turbidity of stormwater. In the sections below, the fundamental physical and chemical processes are described followed by a summary of the various compounds used to facilitate coagulation and flocculation. Active and passive dosing methods are discussed in terms of effectiveness, residual toxicity, pH management, maintenance requirements, and relative costs and reliability.

2.4.1 Treatment Processes

Coagulation and flocculation technologies, as they relate to treatment of stormwater runoff, involve three primary steps:

1. Coagulation;
2. Flocculation; and
3. Filtration and/or sedimentation.

While coagulation and flocculation facilitate removal of particulate matter, they do not actually remove any material from the water column. Therefore, a filtration or sedimentation step is required after flocculation to remove the flocculated material before it is discharged to receiving waters. Background on each of these processes is given below.

Theory of Coagulation and Flocculation

Coagulation and flocculation, while often used interchangeably, are two distinct consecutive physicochemical processes. Coagulation refers to the destabilization of suspended particles by neutralizing their electrostatic charge (typically negative), while flocculation refers to the agglomeration of those destabilized particles into a flocculant mass, or floc. The floc represents a larger aggregate mass that can settle more rapidly that the discrete suspended particles.

During chemical coagulant injection, rapid mixing is typically applied to bring suspended particles quickly into contact with the coagulant to promote destabilization reactions. Coagulation is followed by slow mixing during the flocculation stage to bring destabilized particles into contact with each other, in order to promote floc growth and minimize floc breakup (Strecker et al., 2005). Although flocculation may occur naturally after destabilization (coagulation) has occurred, anionic polymers that are dosed into the solution may act as flocculants even without the addition of coagulants. In this approach, they rely on polyvalent cations in solution to connect the negatively charged clay particles (Rounce et al., 2011).

During flocculation, unstable microflocs are initially formed as individual particles collide. Semi-stable macroflocs are then formed by inter-particle bridging (Tchobanoglaus, Burton, & Stensel, 2003). Anionic polymers act as flocculants and rely on polyvalent cations in solution in order to connect the negatively charged clay particles (Rounce et al., 2011). Floc breakup may then occur as shear forces caused by velocity gradients split flocs until an eventual equilibrium condition exists and stable flocs are formed. The flocs formed from destabilized particles are separated from the stream through sedimentation and/or filtration.

The purpose of the coagulant (generally positively charged) is to neutralize the negative charge on clay particles, but if too much coagulant is added, a positive charge will accumulate on the outside of these particles. Therefore, coagulants typically have an optimum dose, beyond which restabilization of the colloidal structure occurs, preventing sedimentation. Anionic polymers have also been shown to have an optimal dosage, beyond which turbidity is increased (Rounce et al., 2011)

Media Filtration

Media filtration involves the removal of particulates and associated pollutants by passing the water through a filter bed of granular media or a vault of pre-manufactured filtration cartridges under either gravity or pressure. In this process, water is captured and directed through media such as sand, oxide-coated sand (OCS), compost, zeolite, or various combinations of natural and engineered media. Because larger particles have a greater impact on TSS than turbidity, filtration of larger particles tends to reduce TSS more than turbidity (Allhands, 2008).

Media filtration alone may not adequately remove fine sediment; particles as large as 20 micron may pass through a media filter (Tchobanoglaus et al., 2003). Media filtration after flocculation, however, is much more effective, because particles have aggregated into flocs, which are more easily captured by the filter. Finally, high sediment loads can clog media filters, requiring maintenance such as regular backflushing and/or media replacement.

Membrane filtration

Membrane filtration systems separate substances by forcing water under pressure to pass through the pores of a membrane or semi-permeable membrane. Membrane filtration systems are categorized based on the range of pore sizes available. The four general categories of membrane filtration are 1) microfiltration, 2) ultra-filtration, 3) nano-filtration, and 4) reverse osmosis. As the pore size of the membrane decreases, the amount of pressure required to operate the system increases, as does the quantity of water rejected during backflush and the capital and operations costs. Therefore, of the membrane filtration technologies, microfiltration appears to be the most applicable to stormwater treatment from an operations and maintenance perspective, while still being able to remove fine particles and associated pollutants. Microfilters have pore sizes ranging from 0.3-10 microns, allowing the removal of silt- and clay-size particles. Unfortunately, microfiltration systems are prone to fouling, and with the high sediment loading normally seen on construction sites, it is unlikely that microfiltration would apply in all but the most stringent regulatory scenarios, and even then it would require significant pretreatment. Membrane filtration, therefore, is not seen as a viable alternative for use in construction stormwater turbidity reduction systems.

Sedimentation

Sedimentation by itself has been widely implemented in stormwater treatment for many years, and is simply the process of allowing particulate matter to settle to the bottom of a tank or basin due to the influence of gravity. In chemical treatment, the flocculation of particles allows them to settle much faster, and with clay particles, sedimentation that would normally take days or even months can occur in minutes or hours. This accelerated settling occurs because particles have aggregated, increasing the effective particle size, and particle charges are no longer facilitating suspension, because they have been neutralized.

2.4.2 Compounds Used in Coagulation and Flocculation

Coagulants and flocculants are used to enhance settling and removal of suspended sediments and generally include inorganic salts and polymers. Inorganic salts and polymers are discussed in this section along with microcarriers, which are coagulant aids that can be used to enhance settling further.

Polymers are typically flocculants, but can also act as effective coagulants if they acquire a positive charge when dissolved in water. In addition, polymers are non-corrosive, do not add to the total dissolved solids concentration, have lower dosage requirements and do not produce as much residual sludge as inorganic salts (Rath & Singh, 1997; U.S. Army Corps of Engineers, 2001). Though polymers tend to lower pH, they have less effect on the pH than inorganic salts, reducing and sometime eliminating the need for pH adjustment (Bolto, 1995; U.S. Army Corps of Engineers, 2001).

Flocculation requires adsorption of polymer segments onto particle surfaces. This adsorption is made possible through electrostatic and chemical interactions, hydrogen bonding, or hydrophobic bonding (Taylor, 2002). Polymers used for water treatment include both synthetic and natural compounds and are classified as ionic or nonionic. When a polymer is ionic, it is referred to as a polyelectrolyte. Polyelectrolytes may be anionic or cationic. Anionic polyelectrolytes acquire a negative charge when placed in water and are therefore ineffective for coagulating negatively charged particles. Cationic polyelectrolytes acquire a positive charge when placed in water and are therefore effective for coagulating negatively charged particles. Nonionic polymers contain no charge-bearing groups but are usually slightly anionic when placed in water (Tchobanoglaus et al., 2003).

Nonionic and anionic polymers function as a flocculant, rather than as a coagulant, since they do not significantly contribute to the neutralization of the negatively charged particles common in stormwater, but they do bring about agglomeration of the particles by inter-particle bridging. In order for inter-particle bridging to occur, though, divalent cations must be present in the water. Green and Stott (1999) placed samples of an anionic flocculant (PAM) in deionized water with clay and silt loam added and found no improved flocculation with PAM. When they added 0.005 M $CaCl_2$, however, there was significant flocculation.

With coagulants and flocculants, overdosing often results in worse system performance. Because coagulation attempts to neutralize negatively charged clay particles with positively charged particles, the addition of too much results in particle surfaces being positively charged, rather than neutral. The resulting electrostatic repulsion prevents flocculation (Clear Water Compliance Services, 2004). Rounce et al. (2011) showed this for various formulations of PAM. Although none of the formulations was cationic, the inter-particle bridging is still a function of charge, and the authors demonstrated on one of their soils how many of their PAM formulations showed worse performance with doses higher than the optimal dose. Interestingly, the one neutral formulation did not show this trend.

Natural Polymers

Natural polymers include those that are biological in origin or are derived from proteins, tannins, starch, or starch products such as cellulose derivatives and alginates (Tchobanoglaus et al., 2003; U.S. Army Corps of Engineers, 2001). Unlike synthetic polymers, natural polymers are based on renewable organic biomass and are biodegradable, non-toxic and inexpensive (Sharma, Dholdhoya, & Merchant, 2006). While natural polymers may be less expensive than synthetic polymers on a tonnage basis, they require higher dosages than synthetic polymers (U.S. Army Corps of Engineers, 2001). Natural polymers are more susceptible to microbiological attack, so the storage life of natural polymers is less than that of other coagulants and flocculants (Rath & Singh, 1997). Natural polymers discussed in this section include chitosan, Moringa oleifera, and guar.

Chitosan, a biopolymer extracted from shellfish exoskeletons, is the most commonly used natural polymer in stormwater applications. The coagulation efficiency of chitosan is affected by both the pH of the water (see Section 2.4.8), and the properties of clay particles in the raw water (Huang & Chen, 1996; Li & Kegley, 2005).

There are two types of commercial chitosan available for use, chitosan acetate (liquid form) and chitosan lactate (gel form). Chitosan acetate is primarily used in active treatment systems (ATS) for construction stormwater treatment, while chitosan lactate is used in passive treatment, dissolving as flow passes over it (see Section 2.4.5).

Moringa oleifera seeds have been used since time immemorial for water clarification in many third world countries (Lea, 2010). Lea states that the seeds are more effective in higher turbidity applications (greater than 50 NTU) than in lower turbidity applications. They contain water-soluble proteins that carry a positive charge and have been studied for use in water treatment as a coagulant (Folkard, Sutherland, & Shaw, 2000). When alum and soda ash were replaced by a Moringa oleifera derived coagulant at the Thyolo treatment works in southern Malawi, similar treatment performance was observed. With 60 m^3/hr entering the treatment facility, with turbidity ranging between 270 and 380 NTU, the finished water turbidity was consistently below 4 NTU (Sutherland, Folkard, Mtawali, & Grant, 1994). A number of articles have been written in recent years on Moringa oleifera seed use in water and wastewater treatment in tropical regions where this tree is native. While there are no known stormwater treatment applications of Moringa oleifera seeds, the effectiveness of this natural flocculant at reducing turbidity in surface waters indicates that it has potential for this application.

Guar gum (derived from the seeds of the guar plant) and other polysaccharides (i.e., complex carbohydrates) have been chemically modified and grafted with synthetic polymers, to increase their flocculation efficiency. Synthetic polymers were grafted onto the backbones of the natural polymers to combine the positive characteristics of synthetic and natural polymers (Rath & Singh, 1997; Sharma et al., 2006). An extensive review of biopolymer based flocculants (mainly chemically modified and grafted polysaccharides) has shown that they have effectively treated effluents from various industries, flocculating clay suspensions and suspended solids (Sharma et al., 2006). Based on laboratory studies, chemically-modified products of guar gum and grafted copolymers have performed better than polyacrylamide based flocculants (Rath & Singh, 1997) and potentially could replace synthetic flocculants (Sharma et al., 2006). However, additional research and field studies are still needed.

Other natural polymers that have been studied for general water treatment applications include mimosa bark extract (Protech General Contracting Services, 2004) and valonia extract (Ozocar & Sengil, 2002). Neither has been used extensively in the field in stormwater applications.

Synthetic Polymers

Through various synthesis processes, chemists are able to tailor synthetic polymers to achieve desired molecular weights and molecular weight distributions, as well as control the nature, arrangement and percentage of the ionic groups (Sharma et al., 2006). This control allows the creation of polymers that can be targeted to flocculate solids from a specific effluent (e.g., wastewater, stormwater, industrial process water, etc.). Synthetic polymers that have been applied to stormwater treatment generally include polyacrylamide (PAM), diallyldimethyl ammonium chloride (DADMAC), and polyaluminum chloride (PAC).

Polyacrylamide, also known as PAM, has been used in a number of applications for years, including irrigation (as a water additive), paper mills, ore processing, cosmetics, and as a flocculant in water treatment to settle suspended solids. It is commonly used to stabilize soil on construction sites (see Section 2.3.2). The flocculation efficiency of PAM is dependent on the source and properties of the raw water being treated (McLaughlin & Bartholomew, 2007). PAM, a non-ionic polymer by itself, is often copolymerized with different ionic groups, which allow PAM to be anionic or cationic (depending on the ionic group added). The ability to tailor PAM allows it to be effective for various sources and properties of raw water. As a result, there are many different commercially available formulations of PAM.

Diallyldimethyl ammonium chloride (DADMAC) is a monomer that is used in the manufacture of water-soluble cationic polymers (DADMAC HPV Committee, 2004). Polydiallyldimethyl ammonium chloride (polyDADMAC, but often referred to simply as DADMAC) is the polymer created from this monomer that is used for coagulation. Based on a laboratory study of DADMAC in which turbid water taken from an active construction site was dosed at the optimal rate (as determined by dose/response jar testing) it was found that DADMAC could effectively reduce the turbidity from over 1,000 NTU to 2 NTU (Protech General Contracting Services, 2004).

Polyaluminum chloride (PAC) is a coagulant that has been widely used in wastewater treatment. Multiple forms of PAC can be derived; however, it has been shown that the Al_{13} species is the most effective and stable polymeric Al species in water and wastewater treatment. Thus, PAC with a high Al_{13} concentration seems to be main polymer developed and used for water treatment (Gao et al., 2005). Cat-Floc 2953, a PAC polymer, has been successfully field tested at nine construction sites in Redmond, WA ranging in size from 6-65 acres.

Inorganic Salts

Inorganic salts are electrolytic coagulants typically based on iron (ferric), aluminum, calcium, or magnesium (Tchobanoglaus et al., 2003). When these coagulants are dissolved in water, they generate highly charged cations that destabilize (i.e., neutralize) negatively charged particles and allow the particles to come into closer contact. They also require corrosion-resistant storage and feed equipment. Alum has also been shown to contribute toxicity to receiving waters, possibly due to dissolved aluminum or zinc contaminated alum (Pitt et al., 2004).

Large amounts of inorganic salts are typically needed relative to the suspended solids concentration, which results in the production of a large quantity of residual sludge. Metal salts, such as alum and ferric chloride have been shown to remove turbidity and suspended solids to < 5 NTU; unfortunately the amount of sludge produced and pH control required limit their use (Kang et al., 2007).

Microcarriers

The use of microsands as a weighted microcarrier (MC) that assists in the settling of colloids and flocs has also been researched for stormwater applications (Ding, Dresnack, & Chan, 1999; Pitt et al., 2004). The presence of a polymer with the MC increases the bonding of the floc to the MC, which results in higher settling velocities (Ding et al., 1999). While the technology appears to be very promising for improving high-rate sedimentation of stormwater particulates, no field studies could be found in the literature. It has, however, been applied very successfully in many water and wastewater treatment facilities (Veolia Water Solutions and Technologies, 2010). Microsands impart no toxic effects to receiving waters, nor alter the pH of the influent water, as they are essentially inert particles that increase the settling velocity. The sand may be separated from the floc after settling and recycled back through the process (Pitt et al., 2004).

2.4.3 Chemical Active Treatment Systems

In addition to the choice of a coagulant or flocculant, a method of dosing must be chosen. Active treatment systems offer a great amount of process control, as well as high reduction of turbidity. They are more expensive than passive systems.

Chemical active treatment systems employ a powered or liquid method of delivering chemical into the stormwater and often have pH and turbidity sensors, along with the piping and valves to recycle water that requires further treatment. An operator is generally required for these systems. Electrocoagulation, a variant of active treatment, is discussed in Section 2.4.4.

Active treatment systems may be divided into two categories: batch systems and flow-through systems. The primary difference between the two is that batch systems rely on a period for treatment/sedimentation in a tank or pond after chemicals are added before releasing effluent in a batch, while flow-through systems continually discharge effluent (even though there is some storage provided).

A batch treatment system collects stormwater in a storage pond or tank. The pH of the storage pond water is checked and adjusted (see Section 2.4.8 on pH management), and the storage pond is mixed using a recirculating pump. When the proper pH has been reached, the stormwater is moved from the storage pond to one of the two (or more) treatment cells as polymer is added. Clarification may take as much as several hours or as little as half an hour (Killelea & Austin, 2005). When samples from the treatment tank yield appropriate results for pH and turbidity, the effluent is discharged. This type of system requires a storage pond to hold incoming stormwater until a batch treatment cell is available.

A flow-through treatment system also collects stormwater in a storage tank or pond. The water is then pumped toward the filtration system. Chemicals for coagulation/flocculation and pH adjustment are added en route to a filtration system. Effluent from the filtration system is checked for pH and turbidity with real-time sensors and rerouted back to the storage tank if it does not meet required specifications (Killelea & Austin, 2005). Figure 2-11 presents a typical flow-through ATS process schematic and is followed by photos (Figure 2-12 through Figure 2-13) to demonstrate a typical setup of ATS on a construction site. Note that neither the schematic nor the photos represent any of the case studies or projects referenced in this report.

A variation on the active treatment system is the WetSep Water and Wastewater Filtration System, produced by Waste and Environmental Technologies Ltd in Hong Kong. This system appears to have had limited application in the United States to date. The company describes it as chemically enhanced primary treatment. It employs vortices, settling, filtration, PAC, and PAM in one unit (Waste & Environmental Technologies, Ltd., 2011). The unit appears to be effective at turbidity reduction, with a self-described median inflow TSS of 112 mg/L and a median outflow TSS of < 2 mg/L for its applications (Herrera Environmental Consultants, 2011). No quantitative performance information could be found about its application to higher turbidity levels or at construction sites in the United States.

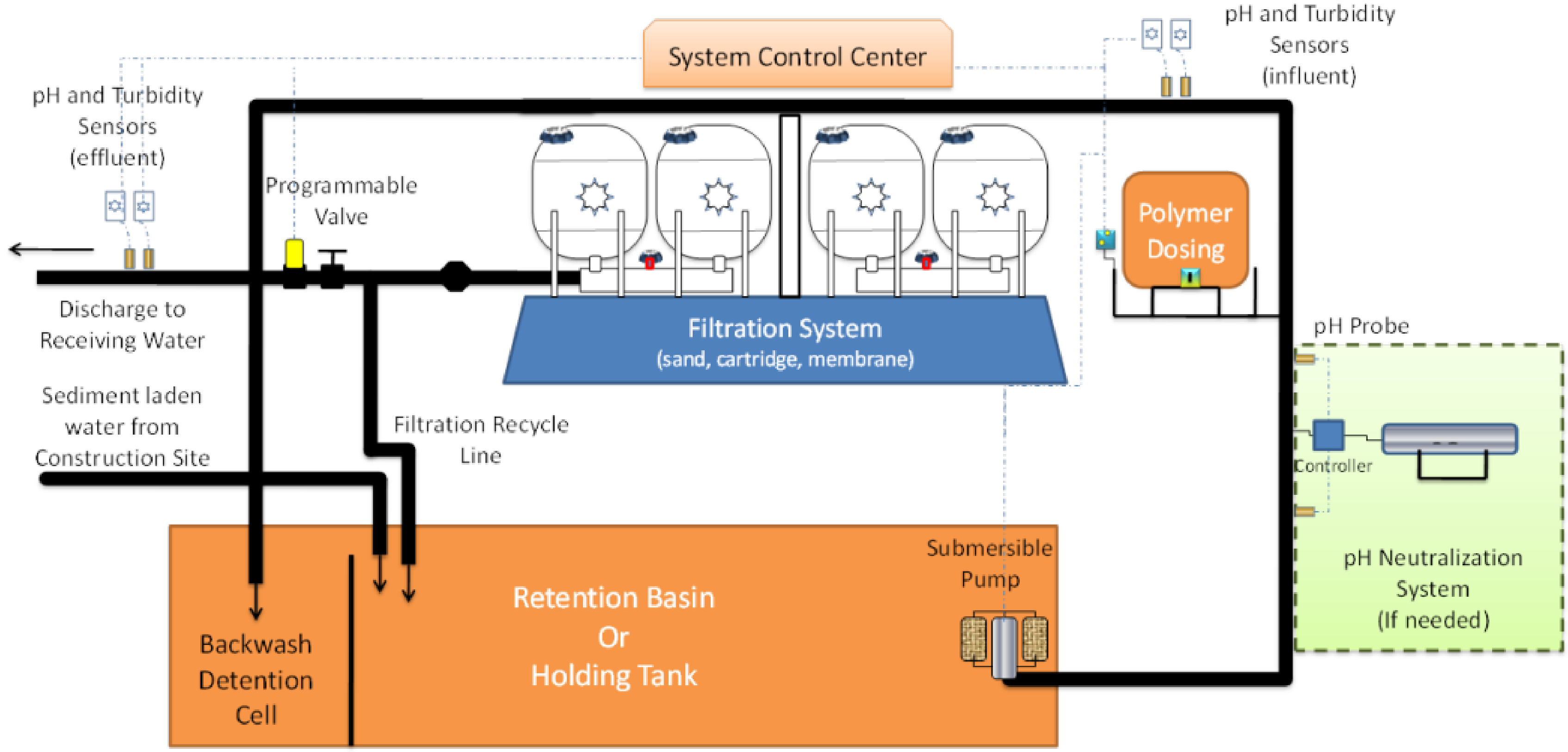

Figure 2-11. Diagram of Typical ATS System.
Figure has been adapted from Port of Seattle response to Washington Dept. of Ecology Action Order 2948

Figure 2-12. Example Water Storage / Settling Tanks. These types of tanks often contain baffles to aid in large sediment removal and can be used as primary detention, settling basins after polymer injection, or holding tanks prior to discharge.

Figure 2-13. Four Chambered Sand Filter. The final step of the ATS process is filtration to remove fine particles and excess chemical residue. Filtration can be media, cartridge or membrane filtration, but is generally sand when used with chitosan.

2.4.4 Electrocoagulation Active Treatment System

Figure 2-14. An Electrocoagulation Trailer with Control Panel (left) and Electrocoagulation Treatment Cells (right) (Mothersbaugh, 2010)

Electrocoagulation is an adaptation of active treatment in which electricity is used to generate charged metal hydroxide species through electrolysis that neutralize the electrostatic charge of suspended particles similar to chemical coagulants. This system automatically adapts to changes in stormwater quality, since higher stormwater conductivity results in more electrical flow and therefore more treatment. Although it requires less operator control than other active systems, it does require more electrical energy.

Electrocoagulation causes removal of fine particles and colloids through the introduction of highly positively charged metal hydroxides (typically iron or aluminum) into the water column under a supplied current. Metal hydroxides are created using a sacrificial anode that supplies positively charged metal ions (Al^{3+} or Fe^{3+}) and a cathode that generates negatively charged hydroxyl ions (OH^-). These metal hydroxides cause the coagulation and flocculation in a manner similar to those chemically applied. However, in electrocoagulation, flocs may either settle or float depending on the supplied current (Holt, Barton, Wark, & Mitchell, 2002). Flocs will tend to float if too much hydrogen gas (H^+) is created.

Holt et al. (2002) compared the turbidity reduction effectiveness of electrocoagulation at various supplied amperages to alum, a chemical flocculant commonly used for drinking water and wastewater treatment, at various dosages and generally concluded that alum outperformed electrocoagulation, particularly under acidic conditions. However, the researchers did observe significant clay concentration reductions with electrocoagulation and admit that the complex and synergistic relationship between thermodynamic equilibrium and reaction kinetics require a deeper understanding to fully investigate the potential of this technology. Electrocoagulation utilizing aluminum ions may not be advised for discharge to water bodies that are impaired by aluminum, as there is limited research on the transport of the excess aluminum in the discharge. The General Use Level Designation (GULD) approval by the state of Washington (Washington State Department of Ecology, 2010) is for iron electrodes, and limits the effluent to 0.300 ppm iron above background.

As might be expected, electrocoagulation systems use a considerable amount of electrical power. This must be accounted for in system setup and plays a role in the O&M costs for this technology. On systems where conductivity is low, a saline solution may be added into the treatment train to facilitate the flow of electrical current (Washington State Department of Ecology, 2010).

Several vendors provide electrocoagulation systems for construction stormwater treatment. One example is Water Tectonics, Inc. Their system, called Wave Ionics™, includes a sedimentation chamber and sand filter following electrocoagulation treatment (MacPherson, 2011). Figure 2-15 shows a diagram of this setup.

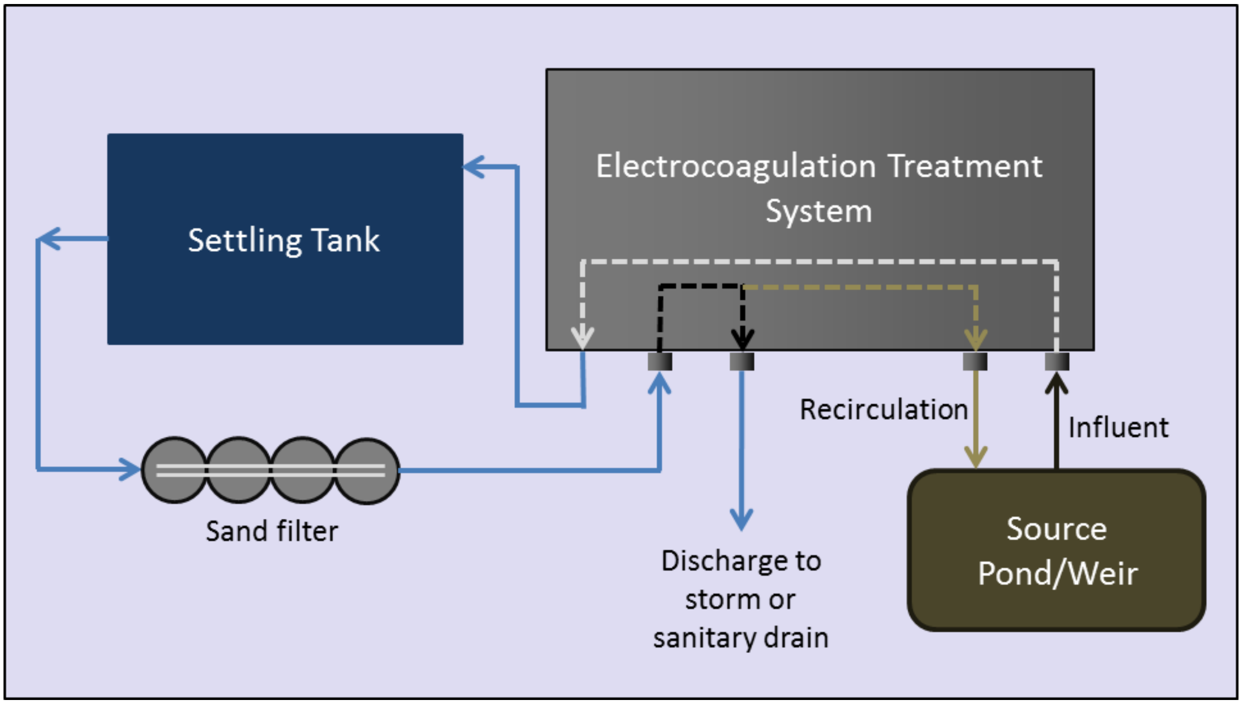

Figure 2-15. System Layout for a Typical Electrocoagulation System (adapted from Water Tectonics, 2012)

One advantage to electrocoagulation is that the applied current varies with the conductivity of the stormwater, which automatically adjusts the quantity of metal hydroxide being added to the system in periods of greater need (Brzozowski, 2007). The Water Tectonics system is approved for use in Washington without an operator present if the system is set to remotely notify the operator and the operator is close enough to respond to system maintenance needs in a reasonable amount of time (Washington State Department of Ecology, 2010).

2.4.5 Passive Dosing

Passive treatment relies on either gravity or dissolution of solid chemicals to work. While an operator may check on the system periodically to add chemicals, there are no real-time changes in doses based on turbidity. There are two broad categories of passive dosing: Liquid dosing regulated by rainfall (referred to in this document as the New Zealand Method), and dissolution of the chemical as stormwater runs over it.

The New Zealand Method

The New Zealand method is clearly the more complex option as compared to passive dosing, but offers greater control over the chemical dosage. This system combines mechanical components together to form an analog computer that determines dosage as a function of rainfall, and then releases the proper amount into the treatment pond.

The New Zealand Method is described in Auckland Regional Council's TP90 Flocculation Guidelines (Beca Carter Hollings & Ferner Ltd, 2003). Figure 2-16 shows the various components of this system. These are generally contained within a small, locked shed located on the construction site. Rain falling on the rainfall catchment tray runs into the header tank, and is collected. The header tank has two outlets, the lower one being smaller, but both leading to the displacement tank. As the displacement tank fills, its increasing weight causes it to displace flocculant from the flocculant reservoir tank. As the flocculant level in this tank rises, it enters a hose that leads to the dosing location.

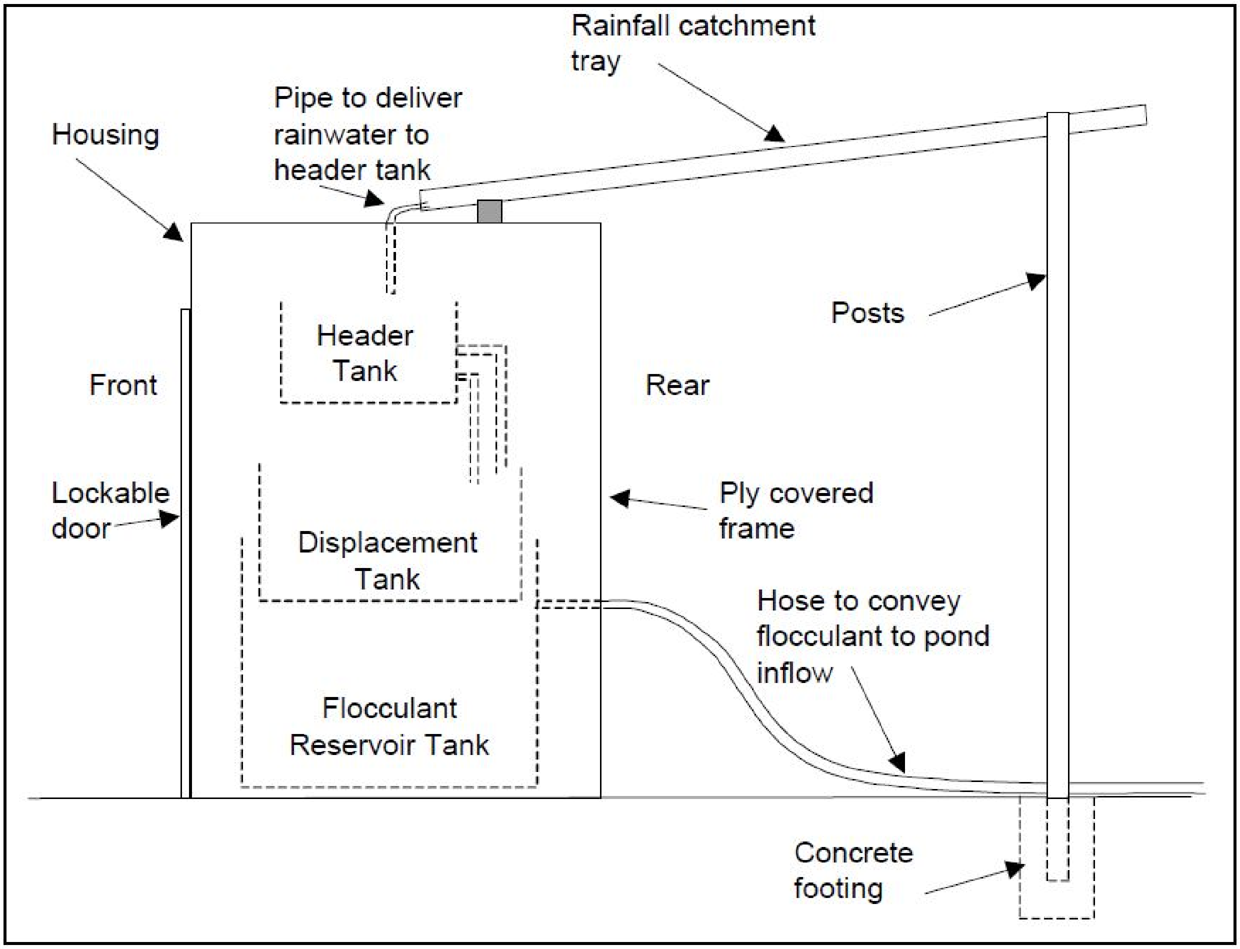

Figure 2-16. Diagram of New Zealand Method Set-up (Beca Carter Hollings & Ferner Ltd, 2003)

By changing the size of the rainfall catchment tray, a larger or smaller quantity of chemical can be added per storm event depth. Likewise, the geometry of the header tank and its outlets allows one to control the dosing profile over the duration of the storm. During the initial phase of the storm, stormwater runoff from the construction site is negligible due to the effects of detention storage and concentration time. The header tank compensates for this by delaying outflow of water into the displacement tank. While the rainfall catchment tray has a small amount of detention storage, it is much smaller than that of the construction site, and concentration time for the catchment tray is negligible. The small lower orifice in the header tank allows for chemical release for a period after the rainfall stops, since site runoff will undoubtedly extend past the end of rainfall.

Clearly, this system requires some attention during set-up and initial operation (calibrating the system to observed rainfall and runoff) and between storm events (refilling flocculant, emptying the header and displacement tank of water, verifying proper function, etc.). However, this can be much less attention than would be required by an active treatment system and there are no power costs, less equipment, etc.

Maintenance needs for the New Zealand method should be assessed after every major rainfall or before leaving the site for the weekend. Typical maintenance activities include:

- pH adjustment to pond that is treated (must be done manually);
- Monitoring during the first few rainfalls to ensure proper operation and results;
- Adjustment of the catchment tray if the construction site runoff area changes in area or character (e.g. paving part of the site);
- Checking the hoses for blockages;
- Checking fittings for leakage;
- Emptying the displacement tank by siphon or by hand baling;
- Filling the flocculant reservoir; and
- Emptying the header tank between storms (if the construction site is dry)

Pitt (2007) states that initially, a proportional dosing (active treatment) system was designed which would have cost approximately $US 9,000, but that this passive system was built instead because the cost was considerably lower at approximately $US 1,800.

Methods of Dissolution

Many passive treatment methods are based on chemicals slowly dissolving into a stream of stormwater in contact with them. McLaughlin and McCaleb (2010) created a lined channel with check dams installed at three points such that the top of lower was level with the bottom of the upper. Treatment of turbid water with a constant influent TSS concentration of 6,000 mg/L was then tested during three consecutive runs. They tested check dams made of 1) rock, 2) rock wrapped in an excelsior blanket, and 3) excelsior wattles. Each of these was tested with and without the hand application of 60 g PAM per check dam. Without PAM, the effluent turbidity ranged from approximately 350 NTU to nearly 1300 NTU with the excelsior wattles performing the best, closely followed by rock wrapped by the excelsior blanket. For all of the check dam types, the application of PAM lowered turbidity an additional 61 to 93% compared to the check dams alone thereby achieving effluent turbidity approximately between 30 and 210 NTU.

A number of proprietary passive methods are regularly incorporated to apply chemicals to construction runoff. One example is Dungeness Environmental's ChitoVan system (Dungeness Environmental, 2010), which employs hoses and filter cartridges containing chitosan lactate to treat turbid water.

Another passive method is PAM-based floc blocks (a.k.a., Floc Logs), which are solid blocks of polymer placed in the stormwater stream. Blocks dissolve in turbid water, and although shown to be effective at sediment removal, it is important to remember that solid PAM can take hours to activate, or fully dissolve and extend its polymer chain (McLaughlin, 2011). Because of the potential variability in both stormwater and polyacrylamide copolymers, these floc logs are often tailored to the characteristics of the soil found on a specific construction site.

The method in which floc blocks are used appears to be an important factor in their effectiveness. Below is a list of tips for optimizing their use (Beca Carter Hollings & Ferner Ltd, 2004; McLaughlin, 2011):

- It is important to have a moderate degree of turbulence to assist in the chemical dissolution of the block;
- It is difficult to achieve proper dosing when stormwater flows vary widely;
- Shading the blocks minimizes their tendency to break down with sunlight;
- Pretreatment is helpful with extremely high sediment loads, since the blocks may become partially covered, or sediment may stick to the floc blocks, preventing dissolution;
- Allow for settling after treatment; and
- Keep the PAM logs moist.

Additional studies showing the effectiveness of various methods of dissolution are included in Section 2.4.6.

2.4.6 Effectiveness of Coagulation/Flocculation Technologies

There is no question that chemical treatment is considerably more effective than traditional turbidity treatment techniques. Stormwater from construction sites usually has far too many clay-sized particles to settle within a practical length of time, even without the effects of particle surface charge exacerbating the problem. A discussion of the effectiveness of both and active passive dosing techniques can be found below.

Passive Treatment – The New Zealand Method

The New Zealand method has been shown to provide reasonably high treatment efficiency, although effluent turbidity can vary considerably. The Auckland Regional Council compiled data on 21 different sediment ponds using this treatment method, and for ponds with good designs, the suspended sediment treatment efficiency was between 90 to 99%.

Figure 2-17 shows the results from the Auckland Regional Council work (Beca Carter Hollings & Ferner Ltd, 2004), in which PAC was passively added to stormwater ponds. Effluent TSS ranges from 14 mg/L to 338 mg/L with a median value of 56.5 mg/L. The combined results from these paired samples are also shown in a box and whisker plot in Figure 2-18. This plot shows the median TSS drop from influent (1450 mg/L) to effluent (57 mg/L), along with horizontal lines showing the first and third quartiles for each. Note that although the effluent TSS has less variability than the influent, these treatment results indicate that the USEPA's proposed (and withdrawn) turbidity limit of 280 NTU would likely be exceeded occasionally (assuming TSS and turbidity are directly correlated). The effluent limits proposed do not allow for occasional exceedances. The only exceptions are for rainfall events larger than the 2-year, 24-hour storm.

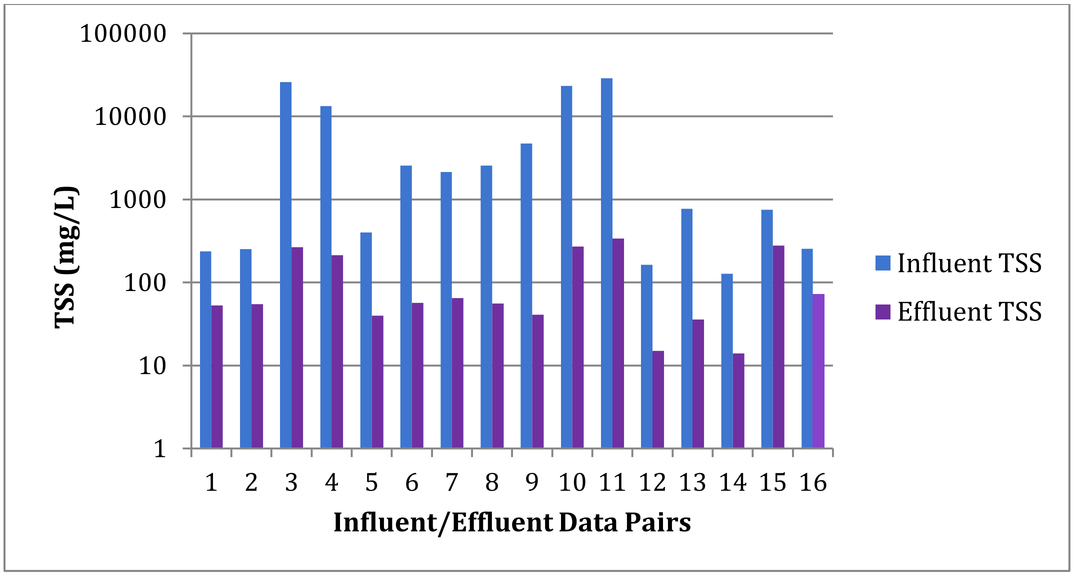

Figure 2-17. Individual Influent/Effluent Sample Results from PAC Treated Ponds (Beca Carter Hollings & Ferner Ltd, 2004)

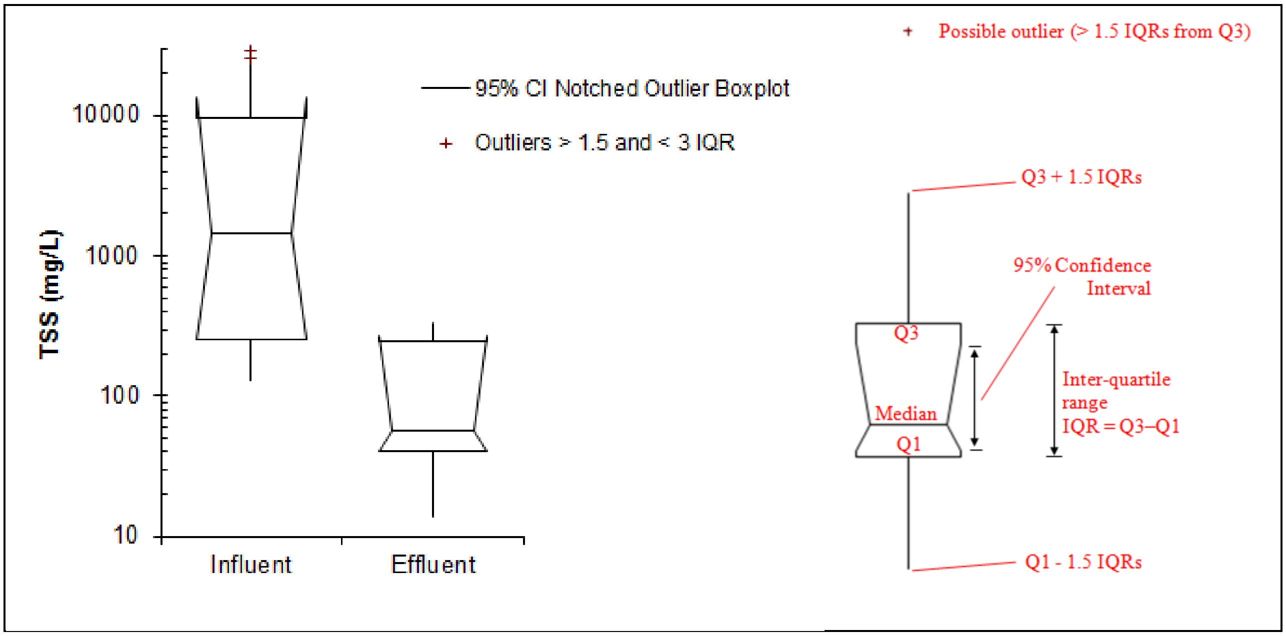

Figure 2-18. Box and Whisker Plot of Individual Influent/Effluent Sample Results from PAC Treated Ponds (Beca Carter Hollings & Ferner Ltd, 2004)

Passive Treatment – Dissolution of Solid Flocculant

McLaughlin, King, and Jennings (2009) studied check dam performance in roadway construction projects on two sites in North Carolina. The three check dam types used were 1) a standard rock check dam with a sediment trap (2.5 m long x 1 m wide x 0.5 m deep) immediately upstream, 2) fiber check dams (incorporating both coir logs and straw wattles), 3) the same type of fiber check dams with 100 g of PAM applied to each check dam after major storm events. The PAM was sprinkled over the lower center portion of the check dam and a small area immediately downstream.

Table 2-4 shows the results from this experiment. Again, the rock check dams performed the worst, and application of PAM significantly improved performance.

Table 2-4. Comparison of Costs and Effectiveness of Check Dams with and without PAM (McLaughlin et al., 2009)

	Site #1 Median Effluent Turbidity (NTU)	Site #2 Median Effluent Turbidity (NTU)	Installation Cost per linear meter (both sites)	PAM Application Cost per Major Rainfall (both sites)
Rock Check Dams with Sediment Trap	2,488	308	\$5.74 – \$6.50	N/A
Fiber Check Dams w/out PAM	72	Not used	\$4.33-\$5.59*	N/A
Fiber Check Dams with PAM	16	45	\$4.33-\$5.59*	\$33 materials \$74-\$79 total cost

*Since assumptions used in cost estimates were the same for fiber check dams with and without PAM, the range of installations costs are assumed to be equivalent for both test section types.

Bhardwaj et al. (2008) tested the performance of passive dissolution of solid PAM at the Sediment and Erosion Control Research and Education Facility at the Lake Wheeler Field Laboratory in Raleigh, North Carolina. The research approach involved creating turbid water from construction site soil, mixing it, and running it through a series of stilling basin configurations. These configurations included various combinations of a bottom inlet level spreader (BILS), coir baffles, Pyramat baffles, and PAM blocks (placed at the inlet to the stilling basin). Results of their study are shown in Figure 2-19. Clearly, the addition of PAM had a significant effect that physical changes in the configuration did not. Note that the use of PAM resulted in turbidities falling roughly in the range of 40 to 60 NTU, depending on the physical configuration. It is not known how these results would change if these tests were run in actual field conditions with widely varying flow rates.

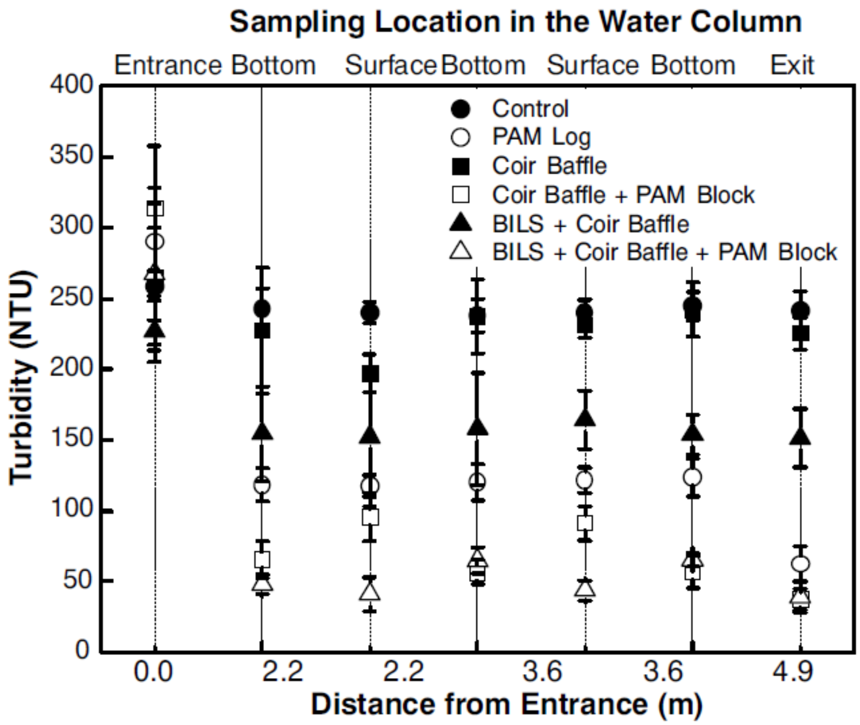

Figure 2-19. Effects of Coir Baffles and PAM, with and without BILS on Turbidity in the Stilling Basin (Bhardwaj et al., 2008)

Earlier, the USEPA (2009a) presented a proposal option requiring compliance with an effluent limit in the 50 to 150 NTU range, and stated this might be an appropriate range in which to place a numeric limit for passive dosing techniques using flocculants. Based on the results presented above, this appears to be an accurate assessment of typical median effluent NTUs from such systems; however, these systems would be variable in performance and therefore if all storms had to meet such limits, compliance would likely not be possible all the time with these systems.

Active Treatment

The studies and literature summarized below show that active treatment systems can consistently deliver median effluent turbidity values below 15 NTU up to their operating storage and treatment rates. A number of studies show values regularly below 5 NTU, especially for chitosan enhanced sand filtration, although pretreatment is generally required for high influent turbidities (e.g., > 600 NTU for the Wave Ionics Chitosan Enhanced Sand Filtration (CESF) system (Herrera Environmental Consultants, 2011)).

The Washington State Department of Ecology (2010) states that when used according to the submitted quality assurance project plan, discharges from the Wave Ionics electrocoagulation system "…are expected to achieve performance goals of a maximum of 10 NTU turbidity, 300 ppb iron above background, and a discharge pH within a range of 6.5-8.5." Electrocoagulation has historically been used for wastewater treatment and is not as commonly used on construction sites as chemical coagulation/flocculation. However, two construction sites in the City of Redmond, Washington have evaluated stormwater turbidity reductions achieved via electrocoagulation (Benedict, Oliver, Franklin, & Devitt, 2004). Results of the study found that influent turbidity values ranging from 2 to 2,500 NTU could be treated to < 1 to 7 NTU.

Herrera Environmental Consultants (2011) surveyed vendors who could potentially provide solutions to industrial and/or municipal stormwater issues causing problems in the Lower Duwamish Waterway in Seattle, WA. Survey results of sediment removal statistics are included in Table 2-5.

Table 2-5. Vendor-reported Sediment Removal Statistics for Chemical Treatment Systems (Herrera Environmental Consultants, 2011; Washington State Department of Ecology, 2010)

Technology	Vendor	Median Influent	Median Effluent	Median % Removal
Chitosan Enhanced Sand Filtration	WaterTectonics	> 25 to > 5000 NTU	< 10 NTU	
Electrocoagulation	OilTrap Environmental Products	600 mg/L	10 mg/L	98.3
Electrocoagulation	Morselt Borne BV			99
Electrocoagulation	Water Tectonics		< 10 NTU	
WetSep	Waste & Environmental Tech. Ltd.	112 mg/L	< 2 mg/L	98

Geosyntec Consultants (2008) collected statistics from six case studies using active treatment. A summary of the performance data gathered is in Table 2-6.

Table 2-6. Comparison of Active Treatment System Case Studies (Geosyntec Consultants, 2008)

Project	Type of ATS	Influent Turbidity (NTU)	Effluent Turbidity (NTU)
City of Redmond (9 sites)	PAC	117 – 14,000 (medians)	4 – 11 (medians)
Confidential Builder	DADMAC	80 – 400	1 - 13
City of Redmond	CESF	168 (median)	2 (median)
Confidential Builder	CESF	165 (median)	1.4 (median)
Lakeside Development (Redmond, WA)	CESF	248 (average)	3.0 (average)
City of Redmond (2 sites)	Electrocoagulation	36 – 143 (medians)	3 – 5 (medians)
West Linn Corporate Park[1]	PAC (batch treatment)	136 (median)	20 (median)

[1] Jurries (2001)

2.4.7 Residual Toxicity

Toxicity tests measure the toxicity of a specific chemical or effluent on exposed test organisms. Both aquatic toxicity and Whole Effluent Toxicity (WET) testing are discussed in this report. In this report, aquatic toxicity tests refer to tests conducted on water samples with known chemical concentrations are added to clean water to identify toxic thresholds for chemicals being used in ATS systems. Aquatic toxicity tests are often reported as a "lethal concentration" (LC50 or LC25) or as an "effects concentration" (EC50). The number following the "LC" value represents the population percentage that has shown the referenced effect. For example, an LC50 indicates that 50% of the test population died when exposed to the listed concentration.

When the toxicity test occurs on an effluent sample using survival of sensitive species as the benchmark for toxicity, it is considered an effluent screening test or a WET bioassay test. USEPA (2011d) has defined WET as "the aggregate toxic effect to aquatic organisms from all pollutants contained in a facility's wastewater (effluent)". A benefit of utilizing WET testing is that overall toxicity of both known and unknown pollutants is assessed in a sample.

Few test results are available on the aquatic toxicity of the polymers used in construction site active treatment systems. The majority of the toxicity tests that are available have been conducted by private companies that manufacture stormwater treatment systems that use polymers for flocculation/coagulation processes. As of November 2011, all Washington state approved technologies for the Construction Treatment category were electrocoagulation or chitosan-based.

The most common polymers used as coagulants in stormwater treatment systems are chitosan, DADMAC (diallyldimethyl ammonium chloride), PAM (polyacrylamide) and PAC (polyaluminum chloride). These are each discussed in a separate section below with a comparison section at the end.

Chitosan

Chitosan appears to be quite safe for use in stormwater treatment. The USEPA (2003) created a fact sheet for chitosan (albeit in regards to its use to help plants fight off fungal infections). That fact sheet states "Risks to the environment are not expected because chitosan has not shown toxicity in mammals, it is abundant in nature, and it is used in tiny amounts."

There are a number of parameters that affect the aquatic toxicity of chitosan; however, the only one discussed in the available studies is turbidity due to its relevancy to the construction industry. In general, the toxicity of chitosan decreases as turbidity increases. Therefore, chitosan is most toxic when contained in clean water (no turbidity), which is indicative of the discharge from a Chitosan Enhanced Sand Filtration (CESF) system. The results indicate that rainbow trout is the most sensitive of the tested species to chitosan. The toxic threshold for rainbow trout has been tested by manufacturers at between 1.1 and 1.2 mg/L for clean water (MacPherson, 2004; Protech General Contracting Services, 2004); however, a study done on cultured rainbow trout showed that significant mortality (6.7% to 40%) was observed at levels between 0.038 and 0.075 mg/L in spring water used for aquaculture (Bullock et al., 2000). No additional peer-reviewed literature was found for comparison and it is unknown as to the cause of the order of magnitude difference in toxicity results between the studies, although the turbidity or composition of the water used in the aquaculture test as compared to stormwater could potentially be determining variables. For turbidities of 50 – 500 NTU, the toxic threshold for rainbow trout ranged from 1.52 mg/L to 3.25 mg/L (MacPherson, 2004). The Washington State Department of Ecology (2008) limits the dosing rate for chitosan acetate (StormKlear LiquiFloc) to 1 mg/L (more used only if in monitored pretreatment) and limits the effluent concentration to 0.2 mg/L.

Aquatic toxicity test results are available from (1) manufacturer laboratory assessments (MacPherson, 2004), (2) a site in Sacramento (Protech General Contracting Services, 2004) and (3) a housing development project in Redmond, WA (Water at Lakeside, 2005). All three sites used chitosan (StormKlear Liqui-Floc: Natural Site Solutions) to treat runoff. Residual chitosan concentrations were at < 0.1 mg/L (MacPherson, 2004) and < 1 mg/L (Water at Lakeside, 2005). WET bioassay results indicate that the levels of residual chitosan in the effluent discharged from the active treatment systems were not high enough to induce toxicity effects on any test species (fathead minnow, rainbow trout, and water flea) within the USEPA required exposure duration (e.g., 24, 48 or 96-hrs). Note that lab studies by Natural Site Solutions on chitosan lactate, the gel form of chitosan, have shown less toxicity than the acetate form of chitosan.

A colorimetric field testing method for residual chitosan has been proposed for use by the Washington State Department of Ecology. The colorimetric determination test is a screening field test, which is used to alert the treatment system operator if chitosan is detected in the treated filtrate at concentrations above 0.10 mg/L (100 µg/L), but does not quantify that presence. If an operator gets a positive test, the system can then be investigated to determine if any of the operating parameters are out of specification. The system can then be corrected and the filtrate retested to confirm the concentration of chitosan is less than 0.10 mg/L in the treated filtrate.

Diallyldimethyl Ammonium Chloride (DADMAC)

Although information on DADMAC is less available than it is for chitosan, information on both the aquatic toxicity of DADMAC and effluent toxicity of discharges from one active treatment system was found in the literature. The available toxicity test results indicate that the water flea species *Ceriodaphnia dubia* is the most sensitive of the tested species to DADMAC. The LC50 of this water flea to DADMAC was found to be 0.32 mg/L, and the EC50 was 0.014 mg/L (De Rosemond & Liber, 2004). The fathead minnow had an LC50 of 0.49 mg/L.

WET test results are available for discharges from a construction site in Sacramento (Protech General Contracting Services, 2004), and indicate that the levels of residual DADMAC in the effluent discharged from the ATS were not high enough to induce toxicity effects on any species (fathead minnow, rainbow trout, water flea) tested within the USEPA required exposure duration (e.g. 24, 48 or 96-hrs).

Field testing methods for residual DADMAC proposed by treatment system manufacturers include flocculation field tests (mixing treated effluent with untreated influent), photometric tests (treating with a reagent causing a color change), and turbidity measurements (overdosing actually increases turbidity). The first two of these have detection limits between 0.5 and 1.0 mg/L.

Polyacrylamide (PAM)

Since PAM has been used in agricultural applications for decades, its toxicity has been heavily studied. Pure PAM is neutral, but cationic or anionic PAM can be created by changing some of the acrylamide monomers to monomers that will dissociate in water to make the polymer negative or positive (copolymerization). Cationic PAM is toxic, since it bonds to the negatively charged gills of fish, causing suffocation (Auckland Water Resources, 2009). Several states require applied PAM formulations to be anionic.

When used properly, anionic PAM is nontoxic to plants, aquatic organisms, or humans (Virginia Department of Conservation and Recreation, 2002). The basic building block (monomer) of PAM, acrylamide, however, is known to be a neurotoxin (Auckland Water Resources, 2009). This is not generally seen as a hazard, since concentrations of acrylamide in PAM are usually very low. The USEPA limits PAM used as a coagulant in drinking water treatment to 0.05% acrylamide (USEPA, 2011e). A 0.05% (or lower) acrylamide content for tackifier/coagulant use is also recommended (Virginia Department of Conservation and Recreation, 2002).

Polyelectrolytes, such as PAM, are too large to pass across biological membranes, so they cannot bioaccumulate (Auckland Water Resources, 2009). Acrylamide is metabolized in water and soil with a half-life of tens of hours (Lande, Bosch, & Howard, 1979), and the degradation of PAM does not result in acrylamide release (Sojka & Lentz, 1996). PAM is degraded mechanically, biologically, and photochemically. Despite its widespread use (potable drinking water treatment, clarification of sugar juice and liquor, cosmetics, agriculture, etc.) over several decades, no significant negative impacts have been noted in soil or water when used as recommended (Sojka & Lentz, 1996).

Aluminum Coagulants: Polyaluminum Chloride (PAC) and Alum

Aluminum coagulants, including both polyaluminum chloride (PAC) and alum (a.k.a. aluminum sulfate), possess high quantities of ionic aluminum. The toxicity of ionic aluminum is strongly related to pH, and waters having low pH show lethal impacts on aquatic life both in the field and in the laboratory at environmental concentrations (Spry & Wiener, 1991). At normal environmental pH of 6.5 – 8.0, there is little threat of toxicity or bioaccumulation (Auckland Water Resources, 2009). However, alum can reduce the pH of waters with low buffering capacity, so aluminum toxicity may still be a concern if the receiving waters are already slightly acidic. Due to this concern, alum is not often used in stormwater treatment applications.

Some water bodies are impaired for aluminum and this should be noted when deciding to use an aluminum-based polymer. Research by the California Department of Transportation (2003a) has shown that the introduction of PACs into neutral pH stormwater actually slightly decreased the amount of soluble aluminum in the water body; therefore if used properly, discharge of soluble aluminum should not be a concern.

Information on both the aquatic toxicity of PAC and the effluent toxicity of discharges from one active treatment system indicate that the rainbow trout is the most sensitive species, with an LC50 of 390 mg/L. The same lethality would likely be observed in fathead minnow and *Daphnia magna* at concentrations of 517 mg/L and >5,000 mg/L respectively (Protech General Contracting Services, 2004).

WET test results are available for discharges from a construction site in Sacramento (Protech General Contracting Services, 2004), and indicate that the levels of residual polyaluminum chloride in the effluent discharged from the active treatment system were not high enough to induce adverse effects in more than 5% of rainbow trout and water flea populations tested within the USEPA required exposure duration (e.g., 24, 48 or 96-hrs). No adverse effects were observed in fathead minnow populations.

Toxicity Comparison

Protech General Contracting Services, Inc. (2004) ran a comparison test of various coagulants/flocculants (PAC, DADMAC, mimosa bark, and 1% chitosan solution) to find toxicity levels. Water was taken from a job in the Sacramento Valley with a turbidity reading > 1000 NTU and high levels of iron oxides and colloidal materials. The runoff sample was treated with each chemical and then tested with representative aquatic species using standard USEPA testing methodology. Dosage was determined by dose/response testing in which a visually clear sample demonstrated that the correct dosage had been reached.

For each of the polymers tested, the optimum dosage was tested for toxicity to *Daphnia magna* (48 hour survival), rainbow trout (96 hour survival), and fathead minnow (96 hour survival). The test was then repeated using a second subsample of the same water and double the optimum dosage. None of the tests showed less than 95 percent survival rate for any species tested, regardless of the chemical used. No chemical showed lower survival rates than the control samples.

In a second test, LC50 values were determined using clean water and a sample of each chemical. The results are presented in Table 2-7. PAC was shown to have the lowest short-term toxicity for these species.

Note that although no chemical in this study demonstrated toxicity even with a 2X overdose, they are likely toxic at some level higher than this and caution should still be used with each to ensure improper amounts are not dosed/released into the environment. All systems should be designed to comply with effluent toxicity standards.

The California Environmental Protection Agency (2009) limits the effluent concentration of chemicals used to 10% of the Maximum Allowable Threshold Concentration (MATC). The MATC is defined as the geometric mean of the No Observed Effect Concentration (NOEC) and the Lowest Observed Effect Concentration (LOEC) Acute and Chronic toxicity results for the most sensitive species tested.

Table 2-7. LC50 Values for Various Coagulants and Flocculants (Protech General Contracting Services, 2004)

Chemical	Daphnia Magna (48 hr) (mg/L)	Rainbow Trout (96 hr) (mg/L)	Fathead Minnow (96 hr) (mg/L)
Polyaluminum Chloride	> 5000	390	517
DADMAC	17.5	0.49	1.65
Mimosa Bark	258	Not available	1.3
Chitosan (pure solution)	13.7	1.1	6.4

Table 2-8 summarizes toxicity information for various chemicals used in active treatment systems.

Table 2-8. Toxicity Summary for Active Treatment Chemicals

Chemical	Toxicity	Factors Affecting Toxicity	Methods of Controlling Toxicity	Overall Toxicity Management Ease
Chitosan	Moderate	Worse with low turbidity	Simple chitosan residual test. Very safe when used in controlled systems.	Easy. Widely regarded as safe when used as directed.
DADMAC	Moderate	Unknown	Test effluent for DADMAC. Monitor effluent turbidity (increases if overdosed)	Moderate
Polyacrylamide (PAM)	Low	Lower toxicity with high molecular anionic PAMs	Ensure acrylamide monomer concentration < 0.05 % in PAM	Easy – Used in agriculture for decades
Polyaluminum chloride (PAC)	Low, although can lower pH	Toxicity strongly increases at low pHs	Avoid low pH	Easy

2.4.8 pH Management

In many systems, pH must be adjusted to maintain desirable levels, and this must be considered when choosing a treatment system. Not only can coagulants and flocculants affect pH, but their ability to treat turbidity can be strongly affected by the pH of resulting stormwater/coagulant mixture. Also, the pH of the effluent must be within water quality standards applicable to that construction site. Generally, this means not changing the pH of the receiving water more than 0.2 standard units (McLaughlin & Zimmerman, 2009).

Chemicals used in stormwater treatment for turbidity vary greatly in their impact on pH. With exception of sodium aluminate ($Na_2Al_2O_4$), the application of aluminum or iron coagulants will consume alkalinity, resulting in a reduction of pH (U.S. Army Corps of Engineers, 2001). For this reason, alum and iron salts generate demand for lime and soda ash for neutralization/pH adjustment. As summarized in Table 2-9, data from Pitt et al. (2007) illustrate the pH impacts of alum and PAC on three sites in New Zealand. PAM has a negligible effect on pH (California Department of Transportation, 2008), but as discussed below chitosan and DADMAC can alter the pH of the water.

Table 2-9. Comparison of the pH Effects of Alum and PAC on Three Sites in New Zealand (Pitt et al., 2007)

Site #	Coagulant	Al Conc. (mg/L)	pH	Alkalinity (mg/L as $CaCO_3$)
1	None (Influent)	0	5.64	1
	Alum	8	4.42	< 1
	PAC	8	4.64	< 1
2	None (Influent)	0	6.68	16
	Alum	8	4.64	< 1
	PAC	8	6.03	7
3	None (Influent)	0	7.15	60
	Alum	8	5.88	13
	PAC	8	6.71	43

ProTech (2004) also did a comparison of treatment chemicals, using PAC, polyDADMAC, mimosa bark, and chitosan. Influent pH was 7.15 and effluents for various chemicals ranged from 7.0 to 7.3, underscoring the fact that not all construction sites are likely to see strong pH drops, even with the more acidic chemicals. Although the pH of PAC and chitosan showed the strongest drops in their study, the fact that chitosan showed a pH increase at low dosage and a pH decrease at higher dosage seems to show that the relative effects on pH of one chemical versus another may be obscured by noise in this study's data.

The City of Seattle, in their Construction Stormwater Control Technical Requirements Manual (2009), discusses the importance of buffering capacity (alkalinity) so that pH does not negatively affect the performance of treatment chemicals or create aquatic toxicity in receiving waters. Based on experience in Redmond, Washington, they recommend raising the alkalinity to 50 mg/L, and prefer using baking soda to do this, since it will not increase the pH as significantly as lime if accidentally overdosed. They have also found that since alkalinity cannot be directly measured in the field, a site-specific correlation between alkalinity and conductivity can be created and used to monitor alkalinity concentrations.

Runoff from freshly poured concrete on construction sites can have a pH as high as 10 or 11 (Clear Water Compliance Services, 2004), and this is commonly lowered with CO_2 injection (HaloSource, 2007), although dry ice pellets, ascorbic acid, muriatic acid, and sulfuric acid have also been used (City of Seattle, 2009). The latter two, although very efficient at lowering pH, are hazardous to handle and if overdosed could potentially cause severe drops in effluent pH.

Chemicals used in construction stormwater treatment generally have a preferred pH operating range and a wider range over which they may be used. For instance, HaloSource (2007) lists their chitosan-based LiquiFloc and GelFloc products with an optimum pH of 6.5 to 8.0 and a useful range of 2 to 10. PAC and alum may be optimally used over a slightly wider range of pHs: 4.5 to 9.5 for PAC and 5.5 to 8.5 for alum (Bolto, 1995; HaloSource, 2007). Although inorganic salts tend to decrease the pH in water, they are also only effective over a particular pH range. Constant pH adjustment is needed to maintain an effective treatment process (Rath & Singh, 1997). The effective pH range and the potential need for constant pH adjustment to maintain an effective treatment process should be considered during flocculent selection.

Electrocoagulation is able to operate from a pH of 5 to 12 (Mothersbaugh, 2011a). This can be an advantage, although in practice, the influent with a pH at either end of that spectrum will likely be treated to neutralize it so that pH does not cause a problem in receiving waters.

Li and Kegley (2005) tested the effectiveness of chitosan at various pH levels and found that for a given dose, effectiveness of chitosan decreased as pH rose from 4.0 to 8.0 for both kaolinite and bentonite. Huang and Chen (1996), however, found maximum turbidity removal for a given dose to occur at a pH 6. Huang and Chen also found the optimal chitosan dosage to increase with an increase in pH from 4 to 7. As they showed, the zeta potential (strength of positive charge) on the chitosan molecules decreases significantly with rising pH. They inferred from this that the contribution of charge neutralization to destabilize bentonite particles is less significant as pH increases, leaving interparticle bridging as the dominant mechanism for flocculation.

2.4.9 Maintenance Requirements

Maintenance of chemical treatment systems is not strongly dependent on choice of chemical used, although there are some effects. For example, polyelectrolytes (such as PAM or chitosan) have been shown to produce significantly less sludge than inorganic coagulants (U.S. Army Corps of Engineers, 2001), and since removal of sludge from sedimentation and treatment tanks/ponds is necessary, this can affect maintenance costs. Sludge removal and disposal is required for all systems. Typical guidance states that sediment should be removed when sediment has filled ⅓ to ½ of the sediment collection area; this is usually at least once every few months (depending on precipitation) and at the decommissioning of the ATS system. It may actually be counterproductive to remove sediment more often than this because sediment left in treatment tanks (batch ATS systems) can increase flocculation/settling. Sediment known to be nontoxic can often be left on site either buried or otherwise stabilized (Killelea & Austin, 2005; McLaughlin & Zimmerman, 2009).

Required expertise and maintenance increases with the complexity of the system, and active treatment systems will require, at a minimum, the following:

- Periodic removal of sediment/sludge from storage pond and treatment tanks;
- Maintenance of flow meters probes, valves, streaming current detectors, controlling computers per QA/QC plan;
- Calibration sensitivity verification of all probes/gauges per QA/QC plan;
- Laboratory duplicate samples;
- Replacement of used treatment chemicals;
- Monitoring and recording operational parameters;
- Monitoring pH and turbidity of influent and effluent for compliance purposes;
- Biomonitoring for toxicity, if required by state regulations; and
- Periodic replacement of filtration media, if used.

Some states specify required maintenance and reporting activities. An excellent example of ATS requirements can be found in the California Construction General Permit – Attachment F (California Environmental Protection Agency, 2009). As part of these requirements, an ATS Plan must be prepared that includes (1) Operations and Maintenance Manual for All Equipment, (2) Monitoring, Sampling, and Reporting Plan (including QA/QC), (3) Health and Safety Plan, and (4) Spill Prevention Plan.

As with any system, electrocoagulation systems also require routine inspections of components such as cells, tanks, valves, and fittings. Inspection and maintenance activities generally require about 4 to 8 hours per month. Routine maintenance for these systems includes (Arcadis, 2008; Mothersbaugh, 2011a):

- Replacement of electrocoagulation cells after treatment of 400,000 to 1,000,000 gallons;
- Replacement of pH adjustment chemicals (if applicable);
- Replacement of media for media filter;
- Calibration of water quality probes; and
- Sludge removal from settling tanks.

2.4.10 Costs of Active Coagulation/Flocculation Technologies

As stated above, the use of active treatment systems is generally higher in cost than other treatment alternatives. Strecker (2011) states that active treatment costs can be 50% or more higher than more passive options such as biotreatment. Anecdotal evidence from New Hampshire (Hemmerlein, 2011) puts the costs of active treatment systems for highway projects at $20,000 - $25,000 per month. To justify these costs for a single system, New Hampshire has found that they would need to collect and treat the runoff from up to two miles of a highway construction project.

The USEPA's Development Document for Final Effluent Guidelines and Standards for the Construction & Development Category (2009a) determined an average cost of $0.02 per gallon treated for active treatment systems, based on cost of case studies and vendor estimates. In their estimate, they included the cost of on-site storage/tanks, chemicals, media filtration, instrumentation, O&M labor, energy, rental equipment, and disposal.

Determining a widely applicable estimate of cost, or even a relative comparison of costs between chemicals used, is difficult for a number of reasons. Variations in soil type, setup, rainfall quantities, disturbed area and duration of a project can strongly affect the cost of implementation. Estimates in literature include different cost components and vary widely.

One factor that can have a significant impact on active treatment systems is the amount of space available for stormwater storage prior to treatment. Larger storage ponds/tanks enable the operator to spread out the time over which treatment systems operate for a given rainfall. This, in turn, lowers the required treatment rate for a site, and smaller capacity treatment systems can be utilized, thereby significantly lowering costs (Mothersbaugh, 2011b). In treatment of stormwater for transportation oriented construction sites, where rights-of-way can be small and space is at a premium, large detention basins or tanks may not be an option.

A summary of active treatment costs found in the literature are shown in Table 2-10. Costs have been adjusted to make them more comparable. Since many of the reports stated one-time and monthly costs, projects were adjusted to a six-month duration where possible, and site preparation costs were eliminated to make these values consistent. The total treatment volume for each study is listed in the table. As expected, there is economy of scale as larger volumes are treated (i.e. higher treatment volumes have lower per gallon costs).

Protech (2004) compared the effectiveness and cost of PAC, DADMAC, Mimosa Bark, and Chitosan. Their comparison showed the chemical costs of $980, $230, $860, and $14,500 per million gallons treated, respectively. These costs were based on optimum dosages determined from dosage/response testing. Although they found chitosan to be significantly more expensive than other alternatives, the chitosan dosage used in the study was 11 mg/L, which is many times higher than typical dosage rates of 0.3 to 3.0 mg/L (MacPherson, 2004). Much lower dosages of chitosan are generally required without a filter (Geosyntec Consultants, 2008), and it is likely that either the lack of a filter or the type of sediment used in the Protech study caused the unusually high dosages required. The wide range of unit costs reported in the literature indicate that that active treatment system costs are site specific and will vary depending on site soils, weather patterns, storage volumes, number and type of system components, etc.

Table 2-10. Costs of Active Treatment Systems

Type of System	Source of information	Total Volume Treated (gallons)	Total Cost	Cost per thousand gallons treated
Chitosan	(MacPherson, 2011)	11,000,000	$148,000	$13
Chitosan	(Geosyntec Consultants, 2008)	3,900,000	$262,000	$67
Chitosan	(Geosyntec Consultants, 2008)	8,100,000	$301,000	$37
Chitosan	(McLaughlin & Zimmerman, 2009)	5,760,000	$166,000	$29
Chitosan	(McLaughlin & Zimmerman, 2009)	28,800,000	$331,000	$11
Chitosan[1]	(Clear Water Compliance Services, 2007)	> 100,000,000		$17
Electrocoagulation[2]	(Arcadis, 2008)	1,900,000	$157,000	$83
Electrocoagulation[3]	(Arcadis, 2008)	9,500,000	$160,000	$17
Electrocoagulation	(USEPA, 2009a) – 2 sites in Redmond, WA	6,200,000		$6 $8
Electrocoagulation[4]	(Mothersbaugh, 2011a)	125,000,000	$498,000	$4
DADMAC[5]	(USEPA, 2009a)	15,000,000	$540,000	$36

[1] Highway project description in which a clear breakdown of costs was not provided. Project lasted over two years.

[2] Project duration of one year. Insufficient breakdown to determine 6 month cost. Value assumed 100 gpm flow rate, which was underutilizing the system's capabilities.

[3] Hypothetical value using cost estimate to determine performance of electrocoagulation unit using maximum flow rate (500 gpm).

[4] Costs were estimated for a purchased electrocoagulation system with a 5 year lifetime of a 300 GPM system with a capital expenditure of $310,000, and O&M costs of $0.0015 per gallon treated. Six month costs per gallon are expected to be higher.

[5] Protech (2004) determined that DADMAC was the least expensive chemical of the four in their study, so it is unlikely that the higher cost noted in this study is caused simply by chemical cost. Since the project was confidential, it is impossible to determine the reason for higher cost.

2.4.11 Reliability

Although there is a definite lack of research in the area of reliability, it seems clear that active treatment systems are more reliable in achieving desired and consistent turbidity levels than passive treatment systems. However, active systems have more mechanical components that are subject to failure (i.e. pump failures, power outages, etc.). Many of these potential problems can be overcome by close monitoring, proper maintenance, and fail-safe modes of operation, but pump failures or power outages can occur on occasion and this must be considered when comparing reliability of treatment systems.

Passive techniques are by definition less subject to intervention. The greater intervention in active systems is a result of increased investment and increased regulations on active treatment systems, and increased toxicity implications of failure. As discussed below, intervention can be broken down into four main categories: personal responsibility, installation and maintenance, and monitoring and control.

Personal Responsibility

In most active treatment systems an operator is onsite full-time and has responsibility for the system. Training is often mandated, sometimes in an approved training program. The operator is much less divided in his responsibilities. Because of this, and the fact that the operator is most likely a contractor, there is greater accountability for poor performance of the system. Finally, active treatment systems are normally employed only when the environmental consequences of sediment release are greatest, so there may be greater oversight of system performance.

Installation and Maintenance

Many of the failures of passive systems occur because of improper installation and maintenance. Water often finds a way around or under improperly installed check dams, resulting in improper sediment control. Silt fences are either improperly installed or ripped in the construction process and not repaired. Sediment accumulates and eventually overtops fences. Conveyance channels or basins are created with walls that are too steep.

In active treatment, the conveyance and holding system tends to have fewer components that are erodible. Accumulation of sediment must be dealt with in both active and passive systems, although it tends to be dealt with much more quickly due to the operator's proximity and greater oversight in active treatment systems.

Monitoring and Control

Monitoring of erosion and sediment controls is usually specified in the SWPPP. This may be expressed as a weekly inspection and after every storm of greater than ½ inch of rain, although requirements expressed in construction general permits vary significantly from state to state. There is simply no substitute for being aware of a problem in the middle of a storm and being able to adjust structures or processes to adapt to problems as they arise. In active treatment systems, it is common to monitor the quality of effluent and to re-treat effluent not meeting effluent limits. This gives active treatment systems a huge advantage in reliability.

2.4.12 Treatment Requirements and Accepted Technologies

Since some states already have effluent limitations and discharge monitoring regulations, it is helpful to look at how these states have implemented monitoring rules, and what guidance/requirements they give in dealing with numeric limitations. A survey was sent out to each state in which each was asked, "Is sampling of construction site discharge turbidity currently required for your DOT projects?" Nine states replied in the affirmative with six of those showing evidence of these sampling requirements in their construction general permits. These six permits were used to supply information on monitoring requirements, treatment requirements, and accepted technologies. A second survey encountered two more states that had discharge monitoring requirements for a minority of locations. Table 2-11 summarizes the findings of this research.

There appears to be no consensus among these 9 states in their approaches to discharge monitoring requirements, treatment requirements, or acceptance of various technologies. Discharge monitoring requirements may be based on rainfall amounts (GA, CA), a result of visible signs of turbidity (AZ, VT), and/or restricted to highly sensitive areas (AK, AZ, CA, NH, SD). California requires suspended sediment concentrations in addition to turbidity monitoring if the numeric effluent limit (NEL) is exceeded in a risk level 3 site, along with bioassessments on sites over 30 acres. Alaska and Arizona DOTs mentioned sampling sensitive receiving waters upstream and downstream of discharge points.

Treatment requirements also vary considerably. Three states (AK, CA, GA) determine limitations based on the ecological risk of the construction site. Four (AK, AZ, NH, SD) have limitations on the turbidity increase in sensitive waters. Two (AK, CA) have exemptions for unusually large storms. Georgia has the effluent limitations that range from 20 to 750 NTU depending on the ecological risk. Vermont and Washington both have flat 25 NTU discharge benchmarks (which in some cases could be below turbidity of natural area runoff).

Specific technologies allowed in meeting effluent benchmarks or limitations are rare. Washington is the only state with a list of acceptable technologies. Their Chemical Technology Assessment Protocol – Ecology (CTAPE) program evaluates proprietary chemical treatment systems for construction sites and gives them one of three designations:

- Pilot Level Use Designation - allows limited use of the technology for field testing;
- Conditional Use Level Designation - allows continued field testing on a broader scale for a limited time; and
- General Use Level Designation - allows unlimited use without further testing.

As shown in Table 2-11, there are five technologies approved for use in Washington. Four of them use chitosan, and the fifth is an electrocoagulation system.

Two other states on this list (AK, CA) do not have specific treatment systems approved, but do have a list of regulations pertaining to active treatment systems in their construction general permits. Alaska requires documentation of approval of particular systems by the USEPA or one of several other states. No other states specifically reference a list of approved technologies.

For comparison to Table 2-11, Table 2-12 shows the monitoring requirements, treatment requirements, and accepted technologies listed in USEPA's 2011 proposed construction general permit. As can be seen, the discharge monitoring requirements are more stringent than those of all states listed in Table 2-11.

Table 2-11. Treatment Requirements and Accepted Technologies of States with Discharge Monitoring Requirements

State	Discharge Monitoring Requirements	Treatment Requirements	Accepted Technologies
AK	Waters with approved TMDL or 303(d) listed for turbidity or sediment Turbidity samples required from all discharge points during storms or snow melt conditions that result in a site discharge. Linear projects may combine substantial identical sampling locations. Either automatic or grab samples allowed. > 20 acres disturbed and 303(d) listed Turbidity samples required upstream and downstream of discharges.	No specific numeric limits stated, except for special case below. > 20 acres disturbed and 303(d) sediment or turbidity listed < 50 NTU upstream: < 5 NTU increase > 50 NTU upstream: < 20% increase, but not more than 25 NTU increase Exemptions are given for storms greater than the 2-year 24-hour storm.	No specific technologies listed, but Section 4.5 of the AK construction general permit has a number of specifications for treatment chemicals, including: • Approval for USEPA potable water use • Approval by USEPA, CA, MN, OR, WA, or WI for use in controlling sediment runoff from agricultural land or construction projects • Manufacturer/supplier test results recognized by USEPA/states above showing non-toxicity when used as directed. • No cationic polymers except chitosan used in ATS. • Proper sedimentation or filtration downstream of chemical dosing
AZ	For projects within ¼ mile of unique or impaired waters, sampling is performed when there is a known or suspected sediment discharge.	Turbidity of receiving water must not increase more than 25% from upstream to downstream in unique or impaired waters.	No specific technologies allowed or disallowed.
CA	Risk Level 2 & 3 sites 3X daily sampling required during storms over 0.5” Risk level 3 sites If NEL exceeded, turbidity and suspended sediment concentration (SSC) must be sampled in effluent and receiving water, along with bioassessment for sites over 30 acres	Risk Level 2 & 3 sites 250 NTU Numeric Action Level Risk level 3 sites 500 NTU Numeric Effluent Limit Exemptions for 5-year, 24-hour storms For ATS systems 10 NTU daily flow-weighted ave. 20 NTU for single sample results Exemption for 10-year, 24-hour storm	No specific technologies allowed or disallowed, but Appendix F of the CA construction general permit has a number of specifications for ATS systems.
GA	Turbidity sampling required for first rain event that reaches 0.5 inches after clearing and grubbing have occurred. Another sample required either 90 days after initial sample or after all mass grading has been completed in the drainage area of the sampling location.	20 – 750 NTU, based on site size, watershed size and warm/cold water designation. (See App. B of GA construction general permit (infrastructure) for more information)	Provides a special list of 20 (mostly erosion control) BMPs, at least four of which will be used for areas draining to Biota Impaired Stream Segments. One of these is passive dosing of anionic PAM (e.g. floc blocks, followed by sedimentation), and another is Dirt 2 Committee recommendations, such as seep berms, floating siphons, and sand filters.

State	Discharge Monitoring Requirements	Treatment Requirements	Accepted Technologies
NH	For I-93 rebuilding, (401 certification regulated project) once per hour for 4 hours if 0.5" of rain have fallen or if 0.5" of rain is predicted and 0.25" of rain have fallen. Sampling required upstream, downstream, and point of discharge (Currier, 2009).	10 NTU above background. Maximum of 50 NTU at end of pipe (Hemmerlein, 2011).	Presently using polyacrylamide Floc Logs.
SD	Turbidity sampling for projects draining to streams in which the Topeka Shiner (endangered species) resides. Must sample 100 feet upstream and 100 feet downstream	No more than 50 NTU increase from upstream to downstream. "Construction methods that produce sediment discharges exceeding this turbidity standard shall cease and may resume only after the Engineer has approved an acceptable plan"(South Dakota Department of Transportation, 2010)	No specific technologies allowed or disallowed.
VT	If visibly discolored water discharging to waters of the state cannot be fixed with BMP maintenance & supplementation, then weekly monitoring begins.	25 NTU benchmark	Nothing specified. Chemical treatment specifically allowed, though.
WA	Turbidity must be measured weekly. Reading over 250 NTU triggers daily sampling. <u>Sites disturbing over 1 acre</u> Transparency tube or turbidity meter sampling <u>Sites disturbing over 5 acres</u> Turbidity meter sampling	Need to meet 25 NTU benchmark. 250 NTU triggers phone reporting and daily sampling.	• CESF with HaloKlear LiquiFloc 1% solution • CESF using FlocClear • CESF using ChitoVan • CESF using StormKlear LiquiFloc 3% solution • Electrocoagulation with WaterTectonic's Wave Ionics system See http://www.ecy.wa.gov/programs/wq/stormwater/newtech/construction.html for a current list

Notes:

1) FL, OR and MN responded to the survey, stating they had discharge turbidity sampling requirements for DOT projects, but these requirements were not found in their general construction permits.

3) Oregon's 2005 1200-C construction general stormwater permit allowed either turbidity monitoring or enhanced use of BMPs when discharging to 303(d) listed sediment or turbidity listed streams or streams with TMDLs for sedimentation or turbidity. Because this only applied to 1% of dischargers, and no registrants chose the monitoring option, discharge monitoring requirements for these streams were removed from the 2010 construction general permit (Brandstetter & Camilleri, 2010). Their 1200-C construction general permit (Oregon DEQ, 2010) specifically lists electrocoagulation and flocculation as two of many options that must be chosen from when discharging to these waters.

4) State construction general permits used in this table are included in the references.

Table 2-12. Treatment Requirements and Accepted Technologies in USEPA's 2011 Proposed Construction General Permit (USEPA, 2011c)

Discharge Monitoring Requirements	Treatment Requirements	Technology Acceptance/Limitations
> 10 acres disturbed (both impaired and non-impaired waters) 3 turbidity samples required at end-of-pipe during each day having discharge. First sample must occur within one hour of beginning of discharge	Effluent limit of 280 NTU is being re-evaluated. Proposed CGP had placeholders for the new effluent limit, but were stricken from the final 2012 CGP. Exemptions are given for storms greater than the 2-year 24-hour storm. 303(d) sediment or turbidity listed waters or those with a TMDL for sedimentation or turbidity Benchmark turbidity levels set on a stream-by-stream basis.	• Chitosan is the only cationic polymer allowed • Stormwater treated with polymers, flocculants, or other treatment chemicals must be routed through sediment trap, filter, or sedimentation basin prior to discharge

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Chapter 3. Construction Effluent Monitoring Methods

To manage turbidity of construction site effluent effectively, sufficient site-specific information must be readily available to state DOTs. Dischargers utilizing adaptive management practices require accurate and frequent monitoring of stormwater discharges to facilitate an assessment of the effectiveness of erosion and sediment control practices. As discussed in Chapter 2, states differ in their regulatory monitoring requirements; however, the *Effluent Limitations Guidelines and Standards for the Construction and Development Point Source Category* (USEPA, 2009b) ("C&D Rule") required that NPDES permitting authorities develop approved methods for turbidity monitoring and reporting:

> *The permitting authority must specify in NPDES permits the requirements concerning the proper use, maintenance, and installation, when appropriate, of monitoring equipment or methods used. 40 CFR 122.48(a). Thus, permittees may elect to use automated samplers and/or turbidity meters with data loggers, if approved by the permitting authority. Each sample must be analyzed for turbidity using methods approved by the permitting authority, but USEPA expects that the use of a properly calibrated field turbidimeter is sufficient. USEPA is also leaving up to the permitting authority the applicable reporting requirements on the permittees sampling of their discharges from C&D sites.*

On November 5, 2010, the numeric limitation and associated monitoring requirements were stayed indefinitely (USEPA, 2010) due to "deficiencies with the dataset that USEPA used to support its decision to adopt the numeric turbidity limitation" (USEPA, 2012b). Since no comments were made against this action, the stay took effect on January 4, 2011.

On April 24, 2011, the USEPA issued a proposed construction general permit (CGP) (USEPA, 2011c) that included monitoring requirements for construction sites and left placeholders for the actual numeric limitations. On January 3, 2012, the USEPA solicited data and information on many aspects of turbidity monitoring (USEPA, 2012b). Although the final USEPA CGP, effective February 16, 2012 (USEPA, 2012a), removed all monitoring requirements, USEPA's solicitation for more information implies that the issue of turbidity monitoring and limitations may resurface in the future.

This chapter discusses construction effluent monitoring methods, starting with lessons that have been learned from states currently requiring monitoring on some or all of their construction sites. Background on sampling and measurement of turbidity in general is then covered. Finally, a comparison of these methods is provided with respect to regulations, safety, cost, accuracy, and reliability.

3.1 Lessons Learned from States with Construction Discharge Monitoring Requirements

3.1.1 Washington

Washington is clearly one of the leaders in the field of construction stormwater monitoring and treatment. As might be expected from a state that has been requiring construction site sampling for many years, Washington has used its experience to develop and publish standard procedures, which are used throughout the state. Washington Department of Ecology has published a booklet entitled *How to Do Stormwater Monitoring: A Guide for Construction Sites* (Washington State Department of Ecology, 2006). Likewise, Section 6.5 of the *WSDOT Highway Runoff Manual* (Washington State Department of Transportation, 2010) lists standard sampling procedures for highway construction site monitoring. Information from these resources has been incorporated throughout this chapter.

3.1.2 California

California is another state on the forefront of construction stormwater monitoring and treatment. As with Washington, institutional knowledge has been incorporated into sampling guidance documents such as *Construction Site Monitoring Program Guidance Manual* (California Department of Transportation, 2012a), *Stormwater Quality Monitoring Protocols* (California Department of Transportation, 2003b), and Appendix D of *Stormwater Best Management Practice Handbook: Construction* (California Stormwater Quality Association, 2011). Key concepts and guidance from these documents are included and referenced throughout this chapter, and the reader is encouraged to seek out these documents as additional technical resources, since they provide a wealth of practical guidance on designing and implementing sampling programs.

3.1.3 Tennessee

Peters (2011) describes a study of five Tennessee Department of Transportation (TDOT) sites designed to better understand sampling and how it might be best used for effluent limit guidelines. In her presentation, she cited several lessons learned in this study:

- Not all rain events produce discharge;
- Grab sampling should be performed by staff on site who can respond more quickly than offsite staff to unpredictable rainfall;
- Have equipment together, clean, and calibrated before the event starts;
- Consider safety in choosing sampling locations;
- Have a plan to handle exceedances of turbidimeter maximum readings;
- Water quality probes must be installed slightly above the bottom of the channel/swale to avoid soil build-up on probe;
- Different meters have different light sources, which affect consistency between different meter types;
- Need to measure discharge to determine when flow occurs, so that turbidity data can be correlated (some probes record air particulate readings when dry); and
- Outfall conditions change over time.

3.1.4 New Hampshire

New Hampshire currently implements effluent limits only on a very small percentage of their projects through their Clean Water Action Section 401 water quality certification process. Their main project incorporating this is the rebuilding of Interstate I-93. Lessons learned on this project include (Hemmerlein, 2011):

- State requirements on stormwater sheet flow runoff combined with small DOT rights-of-way and steeper runoff slopes may preclude use of non-channelized (sheet) flow drainage for DOT projects.
- Five to seven discharge locations per mile is normal, and these locations are pretty much determined by low points in the road. If using an active treatment facility with linear

construction, discharges may have to be conveyed (pumped) a significant distance so that economies of scale make active treatment costs reasonable.

- Autosamplers clog easily. Grab samples are much more reliable.
- Given relatively high permeability soils, it is not practical to sample rain events of less than 0.5-inches because there is little to no runoff generated.
- Each sampling event requires committing field staff (at least two) for a period of at least 4 hours.

3.1.5 Research Currently Being Pursued

The Minnesota Department of Transportation is currently sponsoring a project entitled *Development and Evaluation of Effective Turbidity Monitoring Methods for Construction Projects* (University of Minnesota, 2011). This project will include information on ease of installation, operation, and maintenance of turbidity meters, recommendations on equipment, and will investigate the impact of sampling frequency. Unfortunately, the project's start date was delayed and no results are available at the time of this writing.

Likewise, the Texas Department of Transportation is also sponsoring applicable research. Their project, titled *Synthesis of Hydrologic and Hydraulic Impacts* is focused on developing a set of best practices concerning the interpretation and application of drainage impacts (TxDOT, 2011). Unfortunately, due to a drought in Texas, this study has not been able to make enough progress to be useful at this point.

3.2 Sampling Techniques

There are multiple turbidity sample collection and analysis technique combinations discussed and compared in this report. While most of these involve laboratory analysis or use of a field probe/turbidity meter, one only uses a field probe/turbidity meter. An overview of sample collection techniques, together with sample analysis configurations and analysis methods, is shown in Table 3-1.

State DOTs were surveyed to find out the frequency with which they use each sampling technique (see Appendix A for further information on these surveys). Figure 3-1 summarizes the frequency of various sample collection methods by survey respondents. As might be expected, the two most common methods for sampling were grab samples and use of a water quality probe to take discrete turbidity measurements in the water column or a collected grab sample. Five respondents stated they did not use any of these techniques (i.e. did not sample). It is worth noting that this is also the number of respondents stating they did not use grab sampling, implying that all responding states collecting samples use grab sampling at least occasionally.

Table 3-1. Sample Collection Methods, Analysis Techniques, and Analysis Methods

Sample Collection Method	Potential Sample Analysis Configurations	Potential Sample Analysis Methods
Grab – Manual collection of a sample	Single Samples Multiple Individual Samples Limited Composite (Limited number of aliquots-calculated or composite sample) Time-Weighted Composite (Calculated from multiple individuals, calculated from multiple sub-composites or composite into one sample) Flow-Weighted Composite (Calculated from multiple individuals, calculated from multiple sub-composites or composite into one sample)	Field Turbidity Meter Laboratory Turbidity
Stage – configuring sample bottle intake and exit tubes in a basin or outlet so that they fill as the water level rises	Single Samples Multiple Individual Samples (placed at different stage heights)	Field Turbidity Meter Laboratory Turbidity
Automated – Configuring a device designed to obtain one or more samples after flow or rainfall is detected (simple automatic) or programming a device to obtain samples based on flow or stage and to record flow and rainfall (fully automated)	Single Samples Multiple Individual Samples (4, 8, 16, or 32 bottle configurations) Limited Composite (Limited number of aliquots-Calculated or composite sample) Time-Weighted Composite (Calculated from multiple individuals, calculated from multiple sub-composites or composite into one sample) Flow-Weighted Composite (Calculated from multiple individuals, calculated from multiple sub-composites or composite into one sample)	Field Turbidity Meter Laboratory Turbidity
In-Place Probe – using a device that measures turbidity directly in the water column (no actual sample collected)	Single Samples (not likely approach) Multiple Individual Samples Limited Composite (Calculated from multiple individuals) Time-Weighted Composite (Calculated) Flow-Weighted Composite (Calculated)	In-Situ or Off-line Probe

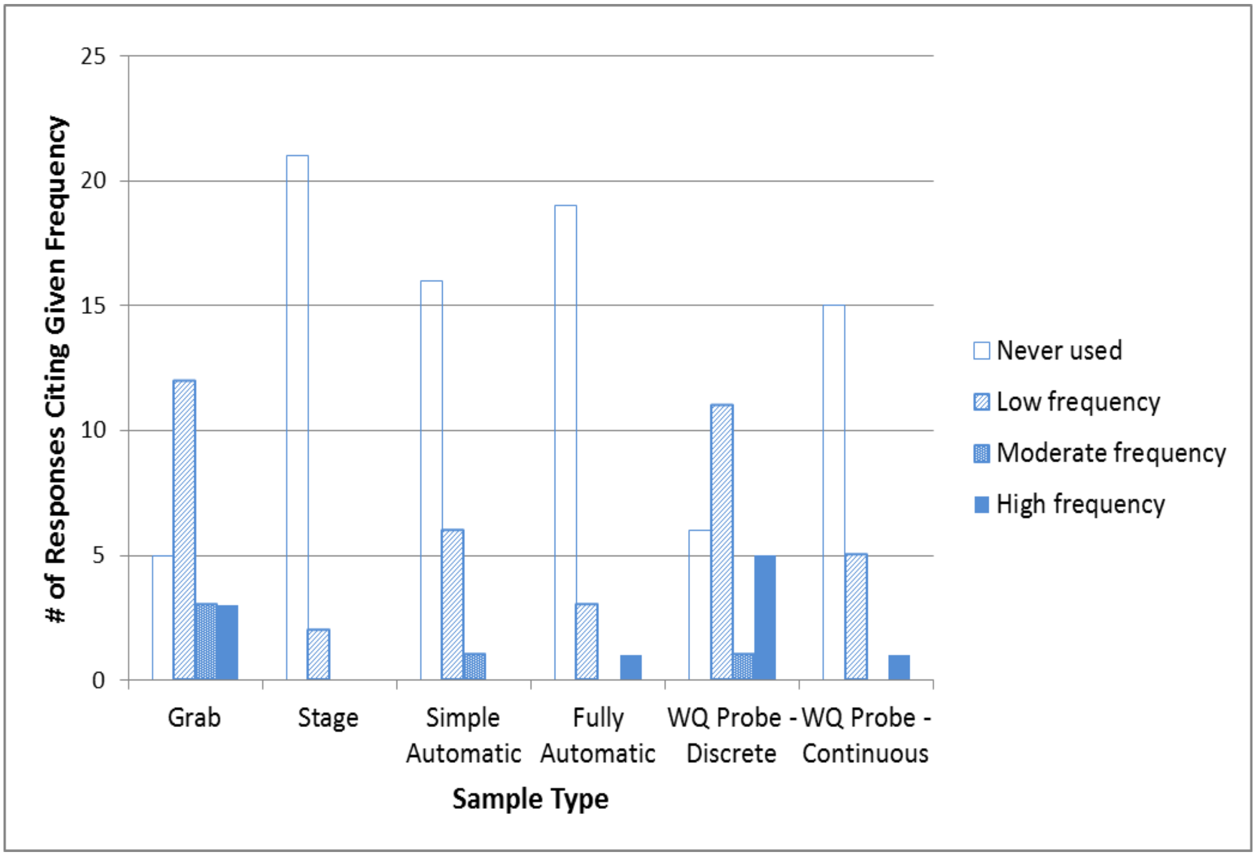

Figure 3-1. Sampling Technique Usage Frequency by DOTs (23 states responding)

Monitoring methods vary significantly in cost, complexity, and ability to capture representative samples. This section provides a review of the various methods that can be used to collect samples and provides some basic guidance on quality assurance. A complete treatment of this topic is beyond the scope of this document, and a number of other sources can be found that provide more depth, such as *Urban Stormwater BMP Performance Monitoring* (Geosyntec and WWE, 2009), *Construction Site Monitoring Program Guidance Manual* (California Department of Transportation, 2012a), or *Stormwater Quality Monitoring Protocols* (California Department of Transportation, 2003b).

USEPA's 2011 proposed construction general permit (USEPA, 2011c) stated that samples will be taken using either manual grab sampling or automated grab sampling techniques. Although the sampling requirements were stricken from the final permit (USEPA, 2012a), USEPA is still pursuing information on monitoring costs and methods (USEPA, 2012b), implying that it may incorporate monitoring in future regulations. It is also likely that not all permitting authorities will implement monitoring guidance in exactly the same way. Because of this, an analysis of five sampling/analysis techniques is provided below.

In order to understand each method, its capabilities, and best application, an understanding of compositing is first necessary. Compositing may be applied to manual grab sampling, stage sampling, or automated sampling.

3.2.1 The Decision to Use Composite Sampling Techniques

When a sample is collected for laboratory analysis, a choice is made to either a) analyze that sample by itself (or analyze multiple individual samples) or b) combine it with other samples before analysis to get some type of composite (combined) sample that is more representative of the entire storm event or at least a majority of the storm event. The use of individual samples collected within a short period at a particular location provides a "snapshot" of stormwater quality at a single point in time. The results from a single sample or even several single samples are generally not sufficient to develop reliable estimates of the event mean concentration (EMC) for the pollutant or pollutant load because turbidity tends to vary dramatically during a storm event.

To estimate turbidity EMCs when utilizing laboratory analysis, a series of samples at shorter time intervals can be collected throughout the course of a storm event. There are several different approaches for obtaining information from a series of grab samples. One approach would be to analyze each grab sample individually and then take a time-weighted, flow-weighted, or arithmetic average of the results to estimate the EMC. If the samples are analyzed individually, a pollutograph can be developed to assess the changes in turbidity during a storm. This approach can be particularly useful if the monitoring objective is to discern peak turbidity and evaluate how turbidities may vary with rainfall intensities or runoff rates. A laboratory analysis of each grab sample separately adds significantly to field effort and laboratory costs; consequently, this approach is rarely used except when program objectives require detailed information about changes in multiple constituent concentrations over the course of a storm. It can be relatively easy to take multiple individual turbidity readings with installed field probes when they function well throughout the course of a storm.

If detecting peak turbidity is not essential, composite sampling can be a more cost-effective approach for estimating EMCs. A composite sample is a combination of several individual sample "aliquots" or subsamples. The aliquots are collected at specific intervals of time or flow during a storm event and combined to form a single sample, which can then be analyzed onsite or transported to a laboratory. Thus, the composite sample integrates the effects of many variations in stormwater quality that occurred during a storm event. Composite samples are suitable for most typical stormwater quality parameters such as turbidity, but are unsuitable for parameters that transform rapidly (e.g., E. coli, residual chlorine, pH, VOCs) or adhere to container surfaces (e.g., oil and grease). Manual compositing is generally impractical if there are more than a few stations to monitor and the monitoring program encompasses more than a few storm events. For these reasons, many monitoring programs doing compositing have found that the use of automated monitoring equipment and methods are more appropriate than manually compositing grab samples.

Compositing of samples may be done with either flow-weighting or time-weighting. Time-weighting refers to the practice of combining sample aliquots whose volume is proportional to the time that has passed since the previous sample was taken. In practice, this means combining equal volume aliquots collected at regular time intervals (e.g., 50 mL every 20 minutes) and then using that combined sample for laboratory analysis. Since time-weighting does not account for variations in flow rate, it is not capable of accurately estimating runoff EMCs, except when flow rates are relatively constant throughout a storm. Urban stormwater research has shown that time-weighted compositing can yield significantly different results than flow-weighted compositing (National Research Council, 2008).

Flow-weighted composite samples are more appropriate for estimating EMCs and can be collected in three primary ways (USEPA, 1992):

- Method 1: <u>Constant Time - Volume Proportional to Flow Rate.</u> Samples are collected at equal increments of time. The volume of runoff added to the composite sample is proportional to the flow rate at the time the sample was collected. This is difficult to perform with automated samplers.
- Method 2: <u>Constant Time - Volume Proportional to Flow Volume Increment</u>. Samples are collected at constant time intervals. The volume of runoff added to the composite sample is proportional the total volume passing the sampler since the last sample was taken. This is also difficult to perform with automated equipment.
- Method 3: <u>Constant Volume - Time Inversely Proportional to Flow Volume Increment</u>. Samples of equal volume are taken at non-regular time intervals. Samples are taken at equal increments of flow volume measured. This results in the time interval being inversely proportional to the volume of flow since the last sample was collected.

The appropriate method for flow-weighting is dependent upon whether manual or automated sampling is being used. Method 1 is clearly less accurate because it does not account for potential flow variability between sample collection times and only provides a rough estimate of incremental volume since the previous sample collection. It is, however, the most practical choice when manual grab samples are being collected. When automated samplers are used, Method 3 is recommended and should be programmed according to the sampler manufacturer's instructions and recommendations.

3.2.2 Manual Sample Collection

Manual sampling is the easiest and most cost-effective method of obtaining a single sample. As shown in Figure 3-2, it is simply placing a sample container in the flow path (or underwater) in the water source of interest. This method requires only a minimal amount of equipment and can be adapted to site conditions. When sampling confined spaces or other locations that are difficult or dangerous to reach, such as rapidly flowing rivers, the sample bottle can be attached to a pole.

When sampling from a bridge, a rope may be attached to the sampling container. Many stainless steel buckets and cookware have handles to which ropes may be tied. This method has the advantage that long distances of rope may be used and compactly stored after use.

The representativeness of a manual sample is strongly affected by the method used to collect the sample. USEPA's 2011 proposed construction general permit (USEPA, 2011c) mandated the following five protocols for ensuring a representative sample:

- Take samples from the horizontal and vertical center of the stormwater outfall channel(s) or other sources of concentrated or channelized flow; and
- Avoid stirring the bottom sediments in the stormwater channel in which samples are taken by not walking through the areas of stormwater flow or disturbing the sediment with the sampling device.

Figure 3-2. Obtaining Grab Samples with a Collection Bottle Attached to a Pole (left) and from a Pipe Discharge (right) (Washington State Department of Ecology, 2006)

- Hold sampling container so that the opening faces the upstream direction of the stormwater channel in which samples are taken;
- Do not overfill the sampling container; and
- Keep the samples free from floating debris.

In addition, the following guidelines will further assist in the avoidance of sample contamination by sampling methods or equipment (California Department of Transportation, 2012a; Washington State Department of Ecology, 2006):

- Sampling containers must be made of chemical resistant materials, such as high density polyethylene (HDPE), glass, or stainless steel. HDPE is usually preferred because it is lightweight and resistant to breakage.
- Make sure to wear gloves;
- If using a field turbidimeter to measure turbidity:
  - Be sure the sample vials have been cleaned, rinsed with distilled water, and dried before going out into the field;
  - Hold the vial only by the top of the vial to keep the outside clean;
- In receiving water, upstream of construction site:
  - Sample in or as close as possible to the main current;
  - Do not sample within 20 feet of the most upstream discharge point or near any visible plume;

- In receiving water, downstream of construction site:
  - Sampling point should be at least 50 feet downstream of the most downstream discharge point in a location where any visible plume is well mixed with stream flow. Because this mixing zone may vary from event to event, the actual downstream sampling location may change as well.

Collecting manual grab samples can be considerably cheaper than automated sampling programs for monitoring programs with few storm events and sampling locations. It also carries the benefit of much greater flexibility. Costs of automated sampler purchase, installation, personnel training, maintenance and operations (e.g. replacing batteries, interrogating data loggers, retrieving and cleaning sample jars) can be substantial (Strecker et al., 2001).

In contrast, manual sampling becomes less attractive for larger sampling programs with many sites that last over a year. In these cases, logistical and labor issues often arise that can outweigh the advantages described above. Similarly, manual sampling is rarely implemented when program objectives required compositing of samples to determine an event mean concentration (in this case turbidity) (Strecker et al., 2001).

Manual Grab Sampling Equipment

Grab samples can be collected by holding a sample bottle under the lip of the outfall or submerging it in the flow. A pole can be attached to the sample bottle to collect samples at locations with steep or slippery banks. *How to Do Stormwater Monitoring: A Guide for Construction Sites* (Washington State Department of Ecology, 2006) should be consulted for more detailed guidance.

Manual Composite Sampling Equipment

If manually compositing with the purpose of determining an event mean concentration, grab samples collected during high flow times will need to be proportionately larger than those during low flow. Large containers for storing each sample prior to compositing will be needed. Polyethylene jugs or polyethylene containers with screw-on caps are recommended for this purpose (Strecker et al., 2001). The samples should be poured into a cone splitter to accurately split stormwater and the sediment and turbidity solids in the water into smaller sample volumes (Gray et al., 2000). These smaller volume subsamples (10, 20, or 50 mL are recommended) can be combined to create any necessary volume required by the flow record. The cone splitter and all splitting containers should be made from high-density polyethylene or Teflon-coated plastic and cleaned before each use (Strecker et al., 2001). This process includes many steps in which mis-measurement, solids loss, sample volume loss or contamination can occur; therefore, care should be taken during the compositing process. References to ensure good sample splitting procedures are provided in Table 3-2.

Table 3-2. Supplemental References on Sample Splitting

Capel et al. 1995. *Precision of a splitting device for water samples.* USGS Open-File Report 95-293, 6 p. http://pubs.er.usgs.gov/usgspubs/ofr/ofr95293
Capel et al.1996. *Evaluation of selected information on splitting devices for water samples.* U.S. Geological Survey Water-Resources Investigations Report 95-4141. 103 p.
Horowitz et al. 2001. *Selected laboratory evaluations of the whole-water sample-splitting capabilities of a prototype fourteen-liter Teflon® churn splitter*. U.S. Geological Survey Open-File Report 01-386. http://pubs.usgs.gov/of/2001/ofr01-386/
Kayhanian et al. 2008. Utility *of suspended solid measurements for storm-water runoff treatment*. Journal of Environmental Engineering, Volume 134, Issue 9. p.712-721.

3.2.3 Stage sampling

The rising stage sampler (Figure 3-3) captures a sample at a predetermined stage as the water level rises in a stream, sedimentation basin, or at a discharge point. It is appropriate for flashy streams and is low cost, easy to install, and easy to maintain (Spotts, 2011).

The stage sampler works by accepting water into the intake nozzle only when the water level outside of the sampler rises above the crest of the intake tube. It should be noted that, depending on the orientation on the intake nozzle, the required water level may be affected by the velocity of the water moving into the intake nozzle. As the water enters, air exits out of the exhaust port. Once the exhaust port is under water, air is trapped in the upper part of the air exhaust tube, which serves as a deterrent to further entry of water into the container as the outside water level rises. Thus, the sampler is filled only during the rising stage of the water, and only at a very specific level of water.

Multiple containers can be placed in one location at different elevations to capture samples at several stages. This can be used to create a composite sample (or analyzed individually) although samples will not be captured on the falling limb of the hydrograph. Since turbidity is generally higher during the rising limb of the hydrograph (Spotts, 2011), this will have the effect of biasing composited results higher than a more representative flow-based composite sample over the entire event. The sample container must be manually emptied after each discharge event and measured for turbidity.

Stage sampling has been used and documented by the U.S. Geological Survey (Edwards & Glysson, 1999; Lane, Flanagan, & Wilde, 2003). There are two versions of the stage sampler. The first has a vertical intake, and is used to sample waters with sediments finer than 0.62 mm. The other has a horizontal intake, which is more appropriate for water with coarser sediment, but is slightly more prone to fouling.

The stage sampler is subject to the following limitations (Edwards & Glysson, 1999):

- Samples are collected near the stream surface at only one point in the stream, usually near the edge of the stream;
- Compositing samples will not result in an accurate event mean turbidity reading;
- Water from condensation may accumulate in the sample container prior to sampling;
- The stage sampler is not adapted to sampling on the falling limb of the hydrograph;
- The time at which a sample is taken is unknown unless a water level instrument with a data logger is installed and used; and
- Very high stream velocities may cause circulation of flow into the intake nozzle and out of the air exhaust. This can increase sediment concentrations dramatically.

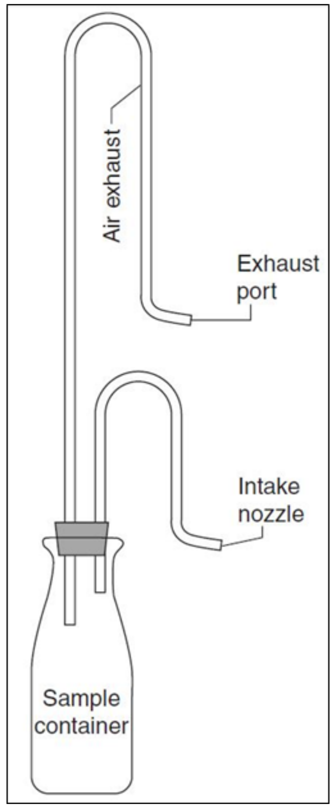

Figure 3-3. US U-59 Sampler Designed to Take Samples as the Stage Rises (Lane, Flanagan, & Wilde, 2003)

The stage sampler was developed by the Federal Inter-Agency Sedimentation Project, and ultimately it is considered a much better tool for evaluation of remote streams than it is for evaluation of construction runoff. The stage sampler does not record the time of sampling and cannot be used to properly composite to estimate an EMC. If used in a stream to gather upstream and downstream samples from a project discharge, it would not be able to distinguish stage increases in the stream from local rainfall and stage increases caused by rainfall higher in the watershed. Although it might be effective at determining turbidity in detention BMPs or slightly upstream/downstream of them, these locations are normally very accessible, making grab samples the better choice during working hours. Regulations for sampling turbidity are usually written to require sampling only during working hours.

Overall, the stage sampler is a good tool for sampling turbidity in remote streams, but is not a good tool for regulatory compliance of construction stormwater turbidity. Manual sampling described above or automated sampling discussed below are generally better alternatives for construction sites. Therefore, the stage sampler will not be included in further discussion of turbidity monitoring techniques in this report.

3.2.4 Automated Sample Collection

Automated sample collection is the collection of stormwater by equipment that is not directly human operated. Flow-weighted composite sampling is often best done with this method. One of the key advantages is that samples can be collected during storms that occur at times when field crews cannot be present (e.g. not during working hours), and might otherwise present hazards to sampling crews from traffic, slipping, or fast-running water. The samplers can be triggered to collect a sample when a preset runoff flow rate or volume is reached. On the other hand, manual sampling (if using offsite crews) relies on accurate weather forecasts and good judgment to make crew mobilization decisions. Crews collecting manual samples may arrive before runoff begins or may arrive after the rising limb of hydrograph has occurred, resulting in missed sampling opportunities or additional labor costs.

Automated samplers are programmable mechanical instruments capable of collecting a single grab sample or a series of grab samples and they can composite samples as they are taken. This on-site compositing is a key advantage, since manual compositing requires measurement of samples and sediment may be lost in the process (see Section 3.2.1 for more information). These samplers are composed of a programming unit to control the sampling process, a sample intake line, a pump to pull samples up through the tube, and a rotating arm for delivery of samples into the appropriate container. They are encased in housing capable of withstanding some shock and moisture.

With proper programming, this equipment can collect samples at specific times, at time intervals, or by use of signals from external equipment such as flow meters, rain gauges, or depth of flow gauges or even via a remote trigger to sample. It can place samples into one central container (compositing), several separate compositing bottles (i.e. more than one aliquot per bottle, with multiple bottles) or into individual sample bottles. Most automated samplers offer multiple bottle configurations that can be tailored to program objectives. Generally, samplers contain 4 to 24 sample bottles. Because compositing can be programmed, the actual number of collection aliquots included in a composite sample can exceed 100.

Figure 3-4. Programming an Automatic Sampler (Geosyntec and WWE, 2009)

Important features of automated samplers include:

- Portability;
- Refrigeration; and
- Alternative power supplies.

Portable samplers can be purchased which are designed for easy installation in confined spaces such as manholes. Alternatively, a sampler can be housed in a secure shelter. Portable samplers can use a 12V DC power supply, solar battery, or AC power.

Many automatic samplers refrigerate samples after collection. These samplers generally require an AC power source, since batteries are not able to provide sufficient power for long-term continuous refrigeration. Non-refrigerated samplers are constructed with space in the housing for the addition of ice, which should be replaced approximately every two days, depending on air temperature.

According to EPA Method 180.1 (USEPA, 1993), turbidity samples should be kept out of the sunlight, refrigerated and analyzed within 48 hours if not analyzed onsite. Refrigeration inhibits any biological or chemical activity that might alter the turbidity after samples are taken. Other literature, however, is more conservative, citing 24 hours as the maximum time between sample collection and sample analysis (American Public Health Association, 2005; Anderson, 2005; Downing, 2005). Current ASTM standards (Anderson cited a standard that was later withdrawn) state that analysis should be completed immediately (ASTM International, 2007). If immediate analysis is not possible, samples should be refrigerated and analyzed as soon as practicable.

Some sampler heads may not function properly at temperatures below freezing without retrofit. Data logger failure may also occur in cold temperatures, resulting in data loss. After-market heaters and thermostats can be purchased for use in colder climates. Heaters can be found as an option on some models (Geosyntec and WWE, 2009).

Sampler intake lines are typically bracketed to the channel bottom, but if high sediment loads cause deposition near the intake, they may be mounted slightly higher up on the side of the channel wall. A strainer is normally attached to the intake to prevent particulate clogging of the tube. The intake tube should face upstream. This configuration minimizes the discrimination against larger sediment particles (> 62 μm) caused by non-isokinetic intake, in which water velocity inside the intake tube is different from water velocity outside the tube. The reader is directed to Edwards & Glysson (1999) for a more complete explanation of the effects of non-isokinetic sample intake.

Two types of pumps are used in automated samplers: peristaltic and vacuum/compressor. Site characteristics may determine which pump is needed, and this, in turn, may affect the choice of manufacturer of the automatic sampler.

Peristaltic Pump

Peristaltic pumps create a vacuum by compressing flexible tubing with a rotating roller, which rolls along the tubing, moving the area of compression down the tubing. Field experience has shown that their ability to draw a consistent sample volume is noticeably inhibited as the static suction head (i.e., vertical rise from the flow stream surface to the sampler) increases. Samplers should not be placed more than 20 feet above the sample intake, unless a remote pump is placed closer to the flow stream to assist in proper sample uptake/delivery (Geosyntec and WWE, 2009). Moving the sampler closer to the sample source is encouraged when possible. Tubing on peristaltic pumps should be replaced regularly, and some sampler models indicate the proper time for tubing replacement as a reminder to field crews.

Vacuum/Compressor Pump

A vacuum/compressor pump can create higher transport velocities in the intake tube than a peristaltic pump. It also provides more uniform discharge velocities, although if not carefully installed, the higher intake velocities can scour channel bottoms, biasing the sediment readings high.

Simple Automatic vs. Fully Automated Samplers

As mentioned above, two types of automated sampling are covered in this document:

1. Simple automatic – configuring a device designed to obtain one or more samples after flow or rainfall is detected or a remote trigger to sample is received.
2. Fully automated – programming a device to obtain samples based on flow or stage and to record flow and rainfall. Initiation of sampling can also be triggered remotely or by rain gage detection of rainfall.

The difference between these two methods of automatic sampling is minimal, depending on accessories that come with the sampler. Many, but not all, automatic samplers come with triggering ports that accept input from flow meters, depth gauges and rain gauges and can use this input, combined with programming, to decide when to collect a sample. These samplers can be programmed to operate in simple automatic mode or fully automated mode. Initiation of sampling can also be triggered remotely if the sampler is equipped to do so.

3.2.5 In-Situ Water Quality Devices

As discussed previously, turbidity in stormwater can vary considerably over the course of a storm. A record of this variability would allow for greater understanding of the dynamics of changing turbidity and therefore provide better resources for understanding causative factors and designing better methods for addressing the runoff from a given site. As in-situ readings can be taken much more frequently than either manual or automated samples, they also provide an advantage of increasing the "coverage" of an event. While automatic samplers can offer the ability to analyze multiple samples (i.e. 24 separate bottles), laboratory analysis of a large number of uncomposited samples can quickly become cost-prohibitive. The ideal solution would provide a continuous or near-continuous record of turbidity without having to analyze each sample at a laboratory. In-situ water quality probes provide such a record. Commonly the term sonde is used to describe an in-situ device that incorporates multiple sensors. By using a sonde, it is possible to simultaneously measure many other descriptors of water quality with turbidity, such as:

- Temperature;
- pH;
- Oxidation-reduction potential (ORP);
- Conductivity;
- Dissolved oxygen;
- Salinity; and
- Ammonium.

Water quality probes do require inspection and maintenance to avoid fouling due to oil and grease, adhesive organics, and bacterial and algal films, which can negatively affect accuracy. To ameliorate problems with fouling of the sensor itself, many sensors come with wipers that periodically wipe any buildup from the sensor window. These instruments should always be cleaned and calibrated before use. While water quality probes with electrochemically active probe surfaces should avoid exposure to air, probes that measure turbidity and temperature do not have to be submersed in water to function and may be placed in an area where no baseflow creates long dry periods.

Water quality probes are usually encased in a protective housing that allows flow to circulate past the sensor. In a pipe, a flow cell is usually purchased to accomplish this. In a stream, it is most common to create a protective case by drilling holes in a small PVC pipe and placing the probe inside. A screen may also be used. Finally, an option is also to pump water from the runoff stream into a chamber with the probe, with flows being routed back to the runoff stream.

Runoff from construction site outfalls can be measured with in-situ water quality probes. Since probes require 3 – 4" of water to give an accurate reading, generally this is done by creation of a permanent pool by use of a V-notch weir or other device. This method does require careful installation and maintenance to ensure that sedimentation does not interfere with probe readings.

3.2.6 Remote Communication

Remote access of memory and programming features can be highly beneficial in large stormwater monitoring networks. Although capital costs are increased, ongoing costs for labor and training of field crews are significantly decreased, since the more technical aspects of equipment management can be remotely conducted by a one system supervisor.

Modem or wireless communication is an option on most automated samplers. This can allow monitoring staff to revise sampling collection programs remotely and to alter the ready status of the sampling unit. For example, if sampling staff are monitoring rainfall totals using Doppler radar and they see an approaching storm of a particular size, they can adjust the programming remotely of the unit in advance of the storm to more evenly time the collection of sample aliquots. Larger storms could be programmed to obtain a 500 mL aliquot after 50,000 liters of water flow past the sample intake strainer while smaller storms could be programmed to obtain 500 mL aliquots after 5,000 liters of water flow past the intake strainer. Another significant advantage is being able to track how many aliquots have been collected and, if needed, alerting field crews for the need to change out bottles if runoff volume is larger than originally anticipated.

Advances in remote communication with samplers and flow meters continue to be made, as these technologies draw from the experience and developments in wastewater and drinking water systems. Some cellular modems allow for Supervisory Control and Data Acquisition (SCADA) of samplers. This has improved remote programming, real-time data inspection, and monitoring of sampler status.

Remote communication equipment can also be connected to in-situ water quality probes as well. This can be a powerful combination, as real-time turbidity information can be sent to a centralized information processing hub for Internet access or be used to notify responsible individuals by e-mail if a reading exceeds a specific limit.

3.3 Measurement of Turbidity

Turbidity measures the scattering of light as it passes through a solution. This scattering can be caused by many constituents in the water, including clay, silt, finely divided inorganic or organic matter, dissolved colored organic compounds (e.g., humic acids), and microscopic organisms (Los Alamos National Laboratory, 2005). Each of these compounds may impact turbidimeters differently, so understanding turbidity measurement is critical to accurate assessment of turbidity, especially in a monitoring program involving more than one turbidimeter or in cases where turbidity is used as a surrogate for total suspended solids. (Note that TSS has been shown to correlate well with turbidity on a site-by site basis, but these correlations do not transfer well from one site to another (Randerson et al., 2005)).

3.3.1 Methods of Turbidity Measurement

Turbidity measurement may be divided into several methods. As mentioned above, turbidimeters use a light source and then measure how a beam of light is scattered as it passes through a sample. Methods compliant with EPA Method 180.1 use a tungsten lamp to generate white light. GLI-2 (Great Lakes Instruments – method 2) uses two source detector pairs situated at right angles to each other. Both of these methods report turbidity in nephelometric turbidity units (NTU). Methods compliant with ISO standard 7027 use a light emitting diode (LED) with a wavelength of 860 nm (near infrared). These measurements are reported in formazin nephelometric units (FNU). FNU and NTU are nominally equivalent units.

Turbidimeters are further subdivided based on the location at which they measure light coming through the samples. Nephelometers (a subset of turbidimeters) measure light scattered at 90° to the light source, although they may also make measurements at other angles as well. Turbidimeters using more than one light sensor to determine the amount of light scattered at various angles to the incident light beam are called ratiometric turbidimeters because they use a ratio of light received at different sensors in their calculation of turbidity. Ratiometric nephelometers incorporate these additional sensors, but rely primarily on the sensor placed at 90° to the incident light beam. The additional sensors make it possible to compensate for effects of color and measurement noise. They also have a significantly extended linear (accurate) response without having to dilute samples (Downing, 2005). The GLI-2 Method uses a ratiometric system.

Backscatter sensors measure radiation that scatters at greater than a 90° angle (back toward the light source). They have a linear response to turbidity up to roughly 4,000 NTU. These instruments consume little power and are compact, although they are strongly affected by particle color. As might be expected for an instrument with an extended range, these sensors are not appropriate for low-level measurements (< 5 NTU) that one might see in effluent from an active treatment system (Downing, 2005). By comparison, a laboratory analysis of turbidity or portable hand-held turbidimeters using EPA Method 180.1 can generally read turbidity well below 1 NTU (often 0.1 NTU or lower). Unless an active treatment system is being used, it is unlikely that detection limits will significantly impact choice of a turbidimeter.

The primary standard for turbidimeters is formazin, a substance with a wide range of particle shapes and sizes. Each meter must be calibrated in a way that is traceable back to this standard. If turbidity in stormwater runoff were to be caused by particles having identical characteristics to formazin, then all turbidimeters would yield identical readings. Unfortunately, this is not the case. Physical characteristics of sediment that cause scattering vary significantly throughout the environment, and these variations cause significant differences in readings. Both particle color and particle size affect measured turbidity, as does particle density (Anderson, 2005).

Small particles, with a diameter about one-tenth of the light wavelength used, will scatter light equally in the forward and backward directions. However, particles greater than one-quarter of the light wavelength used will scatter almost all light in the forward direction. As particles grow even larger, the scattering pattern is concentrated in a 10° cone in the forward direction (Downing, 2005).

The correlation between particle size and scattering pattern has obvious implications for turbidity measurement. For instance, all ISO 7027 turbidimeters use light with a wavelength of 860 ± 60 nm, while EPA 180.1 turbidimeters use white light with a variety of wavelengths generally shorter than

860 nm. Since most suspended sediment is larger than this size, the size distribution may affect one meter differently than another. Likewise, variances in the sensor placement – fairly wide tolerances are allowed, especially in the EPA 180.1 standard – may cause one meter to be impacted differently from another as particle sizes vary.

For these reasons, the same model of turbidimeter should be used whenever turbidity results will be compared. Some states have begun to incorporate this guidance into their regulations. Washington State Department of Transportation (2010) specifies a model of turbidimeter in the Standard Sampling Procedures section of its *Highway Runoff Manual*. South Dakota's DOT (2010) also specifies a model of turbidimeter in its *Special Provision for Construction Practices in Streams Inhabited by the Topeka Shiner* (an endangered minnow), but then allows an equivalent to be used. Caltrans (2012b) provides Standard Operating Procedures for Manual Field Measurement of Turbidity with a commonly used meter, but does not require this model to be used.

Downing (2005) provides guidance on turbidimeter choice, which can be summarized as:

- EPA 180.1 turbidimeters are recommended only for grab samples of non-colored water with turbidities less than 40 NTU;
- ISO 7027 meters and ratiometric meters are less affected by color than non-ratiometric meters with tungsten lamps;
- Submersible ISO 7027 meters are a good choice for applications where turbidities less than 1,500 NTU are expected;
- GLI-2 meters are appropriate in waters with turbidities below 1000 NTU and in waters that are not biologically active, since they are prone to bias due to uneven fouling;
- Backscatter sensors are well suited for submerged applications with turbidities up to 4,000 NTU; and
- Meters being left in biologically active waters for long periods should be equipped with wiper blades.

3.3.2 Field Measurement vs. Lab Measurement

Laboratories normally measure turbidity using EPA Method 180.1. Because this method is limited to low turbidity (< 40 NTU) samples, dilutions are often made to the sample before analysis.

The timing of analysis is important, particularly if a sample must be transported to a laboratory for measurement. Turbidity in a sample may change over time due to biodegradation, settling, or sorption of particulate matter. Precipitation of humic acids and minerals may occur due to pH changes in the sample during transport (Los Alamos National Laboratory, 2005). If samples are to be analyzed by a laboratory, they must be chilled to 4°C to prevent chemical and/or biological transformations. Holding time for these samples should not exceed 24 hours. Although amber bottles are often recommended for these samples, generally the requirement to chill them, and thus requiring storage in coolers, is sufficient to prevent excessive exposure to light.

Field measurement using portable turbidimeters avoids this problem altogether, although measurement errors caused by turbidity exceeding the levels rated for the instrument and less stringent QA/QC procedures may be higher. Errors in the field commonly occur from issues such as (Los Alamos National Laboratory, 2005):

- Inconsistency in sample cell orientation;
- Gas bubbles in the sample that can scatter light;
- Condensation on the sample cell, which is common on hot humid days;
- Scratched or dirty sample cells; and
- Fingerprints.

3.4 Comparison of Monitoring Methods

The following section summarizes some of the regulatory drivers that may influence turbidity monitoring method selection and then compares the accuracy, reliability, and relative costs of the various methods. Monitoring location access and safety considerations for linear construction projects are then discussed.

3.4.1 Regulatory Drivers in the Selection Process

The proper choice of a sampling method is influenced to a large degree by the regulations being enforced. Although there will inevitably be variations in these regulations from state to state, a basic understanding of applicable regulations and potential variations will be useful in this discussion.

As mentioned in the introduction to this chapter, the monitoring requirements were stayed in *Effluent Limitations Guidelines and Standards for the Construction and Development Point Source Category* (C&D Rule) (USEPA, 2009b) and stricken from USEPA's most recent construction general permit, but solicitations for more information on monitoring imply that monitoring requirements could resurface in future permits or national regulations. The C&D Rule prior to the change provides an excellent summary of some potential regulatory drivers if these monitoring requirements are reinstated:

- Permitting authorities must include monitoring requirements in their permits that state the type, interval, and frequency of sampling needed to give representative turbidity readings for the monitored activity;
- USEPA will not specify type, interval or frequency of sampling;
- The numeric effluent limitation applies to the average of samples for each day in which there is discharge;
- Permitting authorities must specify requirements for the proper use, maintenance and installation of monitoring equipment or methods used;
- Analysis of samples must be analyzed for turbidity using methods approved by the permitting authority, but USEPA expects that a calibrated field turbidimeter is sufficiently accurate;
- The number of samples per day should not be arbitrarily changed to assist in reaching effluent limitations;
- USEPA expects that at least three samples per day will be needed at each discharge point; and
- USEPA intends to provide a technical resource guide as additional monitoring guidance to permitting authorities.
- The USEPA's 2011 proposed construction general permit (2011c), however, altered this slightly in that:

- The first sample should be taken within one hour of the start of discharge; and
- Combination of substantially identical discharge locations is limited to linear projects (USEPA has requested comments on this).

As of this writing, state monitoring requirements vary significantly from the USEPA guidelines and from each other. For example, several states currently require in-stream sampling of turbidity in special cases. This sampling is usually driven by the desire to address discharges to waters with existing sediment or turbidity impairments or waters that provide habitat for protected species, or because of potential for a construction site to contribute unusually large volumes of sediment to a stream. In-stream sampling requirements are most commonly written so that sampling is done upstream and downstream of the point of discharge outside of the mixing zone. The difference between these two measurements is then used as a basis for comparison against numeric change criteria. For example, Arizona has a 25% limit for turbidity increases from upstream to downstream for sites close to impaired or unique waters.

In Washington, samples are taken at the point of discharge only once per week when stormwater flows are present, unless a discharge shows ≥ 250 NTU effluent turbidity. At that point, daily samples are required until turbidity is less than or equal to 25 NTU, or the discharge stops or is eliminated. Samples may be analyzed onsite or at a lab using EPA method 180.1 or SM2130. Permittees for construction sites draining to 303(d) listed streams for turbidity may also opt for effluent limits based on background turbidity in the stream (Washington Department of Ecology, 2010).

Another distinction from other permitting authorities is that Washington allows the use of either a turbidimeter or a transparency tube when monitoring discharge from sites with 1-5 acres of disturbed area. A transparency tube is a clear, narrow plastic tube marked in units with a dark pattern painted on the bottom. The tube is filled and water is released from the tube until the pattern at the bottom of the tube is clearly visible. Georgia's construction general permit, while not allowing transparency tubes, does specifically allow use of rising stage samplers alongside manual and automatic sampler use.

Although adoption of numeric turbidity effluent limits at the national level would likely decrease some of the state-to-state variability in monitoring regulations, significant variability may remain in this area. Therefore, sampling methodology choices may need to be adapted to meet the requirements of the applicable permitting authority.

3.4.2 Accuracy Comparison

Any discussion of comparative accuracy must define the term. One definition of turbidity measurement accuracy would be the ability to correctly determine the "true" turbidity of a given sample of water. As discussed in Section 3.3, even this can be complicated, because different meters often provide noticeably different turbidity readings for the same sample, even when properly calibrated and functioning appropriately.

Regulations may set a standard for determination of construction site stormwater turbidity. One such example was the 2011 proposed USEPA CGP (2011c), which set a standard of averaging no fewer than three samples per event with one of those coming in the first hour of runoff. Although the final USEPA CGP (USEPA, 2012a) contains no generally applicable sampling requirement, the proposed USEPA CGP is the best estimate of what future turbidity sampling requirements may be, if included in future versions of the CGP or C&D Rule. The implication of this sample-averaging standard is that, according to

USEPA, this is an acceptable (sufficiently rigorous) definition of construction site stormwater turbidity, given the practical aspects of monitoring programs.

Ultimately, however, this is simply a compromise between true accuracy and reasonable monitoring costs. Therefore, accuracy will be defined herein as the degree to which a numeric turbidity value represents the event mean turbidity of runoff for a given storm, determined from a combination of field techniques, laboratory analyses, and/or computations. This definition of accuracy is important because stormwater turbidity is known to vary significantly (an order of magnitude or more) not only between storms, but within them as well. Spotts (2011) and Harmel & King (2005) state that turbidity values rise with increasing flows in streams and from agricultural fields respectively, and that the rising limb of the hydrograph tends to show more elevated turbidity than the falling limb for any given flow rate. As a result of this variability, flow-weighted composite sampling has been shown to produce a more accurate assessment of event mean turbidity than averaging manual grab samples or time-weighted composite sampling (Harmel, King, & Slade, 2003). See Section 3.2.1 for additional discussion on compositing samples. A key question for any project to consider is the consequences for exceeding some turbidity levels. If consequences are significant, then implementing more rigorous sampling procedures/methods may be prudent, even beyond the minimum requirements.

Since no other sampling method is flow-weighted (except for the use of a turbidity probe with flow measurement), the flow-weighted automatic sampler has an inherent advantage in accurate assessment of event mean turbidity. This is not the only factor in determining accuracy, though. Table 14 shows each sampling technique and a summary of the advantages and disadvantages each has related to accuracy. Sampling frequency is discussed in depth in Chapter 4.

Table 3-3. Summary of Relative Accuracy Comparison for Various Sampling Techniques

Sampling Technique	Potential Advantages for Accuracy	Potential Disadvantages for Accuracy
Manual Grab Samples	• Ability to adapt to problems that arise (e.g. equipment problems) or changing flow conditions.	• Inconsistent sampling technique if sampling crews change. • Single sample may be significantly different than the event mean concentration. • Manual compositing is time consuming and is prone to error.
Simple Automatic	• Consistent sampling technique.	• Sample tubes/intake can clog. • Sampling tubes and pump systems create samples that can exclude larger particles due to their increased settling velocity (Rice, Ziemer, & Lewis, 2004). • Less able to adapt to changing flow conditions
Fully Automatic	• Can easily flow-weight the results to improve accuracy. • Consistent sampling technique.	• Flow metering provides another component that must function properly in an already complex system. • Sampling tubes/intake can clog. • Sampling tubes and pump systems create samples that can exclude larger particles due to their increased settling velocity (Rice et al., 2004). • Less able to adapt to changing flow conditions
Water Quality Probes	• Dynamic/ almost continuous measurement of turbidity (in-situ and in motion) with no settling or temperature change (Anderson, 2005). • No delay in measurement, so properties have no time to change.	• Fouling can occur in biologically active waters (Wagner, Boulger, Oblinger, & Smith, 2006). • May be difficult to place vertically to ensure it is above bedload, but below water surface (Harris, Sullivan, Cafferata, Munn, & Faucher, 2007). • Turbidity may fall outside the range rated for instrument. • Probe can be damaged by debris

Other methods incorporating manual grab samples, simple automatic sampling systems, or even turbidity probes are at a disadvantage in their ability to weight samples according to flow to determine an event mean concentration. The only exception to this would be a turbidity probe used in conjunction with a flow meter, so that flow weighting of the data could be accomplished during data analysis.

Regardless of the monitoring method chosen, accuracy is strongly impacted by proper sampling and measuring techniques. While it may appear that this is more important in manual grab samples, improper setup of automated systems can also create problems. For example, placing a sampling tube or water quality probe too low or too high in the flow may bias results high, since larger sediment particles are not homogeneously distributed throughout the water column (Edwards & Glysson, 1999; Harmel, King, Haggard, Wren, & Sheridan, 2006). No method can be expected to be accurate if proper techniques are not followed. Many permitting authorities, including the USEPA in its 2011 proposed CGP (USEPA, 2011c), have recognized this and explicitly required calibration of field turbidimeters before each use. Extensive guidance in obtaining representative samples and accurate measurements can be found in the following sources:

- *Stormwater Quality Monitoring Protocols* by (California Department of Transportation, 2003b);
- *Construction Site Monitoring Program Guidance Manual* (California Department of Transportation, 2012a);
- *How to Do Stormwater Monitoring: A Guide for Construction Sites* (Washington State Department of Ecology, 2006); and
- Appendix D of *Stormwater Best Management Practice Handbook: Construction* (California Stormwater Quality Association, 2011).

3.4.3 Reliability Comparison

Reliability, for the purposes of this report, will be defined as the ability of a monitoring method to obtain usable data consistently, even if that data is not perfectly accurate (representative of the actual event mean turbidity). While there is a somewhat subjective distinction as to when poor accuracy becomes a reliability issue, this has not been addressed in detail.

For manual grab sampling, the primary factors affecting reliability are gross errors in technique and site accessibility. Proper technique (including sampling equipment preparation ahead of time) can generally be achieved with training. Site accessibility is the more important factor. The Tennessee Department of Transportation (TDOT) found that manual sampling is best performed by personnel who are onsite (i.e. construction staff normally located at site) prior to the initiation of runoff (Peters, 2011), while Caltrans (2003b) states that manual grab samples cannot guarantee that sampling will occur early in an event due to the proximity of staff. Given the 2011 proposed construction general permit put forth by the USEPA (2011c), and its requirement to obtain a sample within one hour of the start of discharge, this could be a significant determining factor in the choice of sampling methodologies. Personnel who are already or normally onsite will have minimal time loss in arriving at discharge sites, and will be more aware of rainfall and discharge conditions at the construction site; meaning that they are less likely to mobilize unnecessarily and less likely to underestimate storm size. These are considerable advantages in reliability. Since most regulations do not require sampling during non-working hours, the remaining limitation to manual grab samples is that of accessibility due to unsafe conditions, especially during severe weather. If unsafe conditions are likely during severe storms, or if onsite monitoring crews cannot be used, automated sampling may be more reliable than manual sampling.

Automated samplers have their own reliability concerns. For example, proper maintenance and equipment setup must occur. Harmel et al. (2006) recommend weekly or biweekly site visits to:

- Inspect power sources, stage recorders, pumps, sample tubes, intakes, and desiccant;
- Calibrate stage recorders for proper flow management; and
- Retrieve collected data so that data loss is minimized in the event of power failures or other malfunctions.

With automated samplers, power outage or battery failure can result in data loss. Sampler intake tube clogging can and does occur. Samplers can become damaged by heavy equipment, stolen, or even washed downstream in some cases if equipment setup and location is not carefully considered. Batteries in submersible turbidimeters expire, sensor optics get dirty, data memory can fill up, and automated cleaning mechanisms can get stuck (Downing, 2005). A good maintenance program will minimize exposure to these problems. Automated samplers still require field crews. Their advantage in staffing is the ability to have fewer staff to operate.

Placement of probes also plays a role. Caltrans (2003b) states that turbidity probes require substantial flow to obtain accurate readings. Harris et al. (2007) stated that reliability problems had arisen in California forestry studies with turbidity probes being placed in small flashy streams. Since these small streams can carry high bedload and low summertime flows, probes may become buried in sediment or may not stay submerged. Both of these situations lead to erroneous measurements. These concerns may be very pertinent since several states now require turbidity monitoring in environmentally compromised streams, and large outfalls on construction sites may approximate flashy streams. Harris et al. also mention that several site visits during dangerous weather may be necessary to troubleshoot these problems.

3.4.4 Cost Comparison

Cost information for turbidity monitoring programs is scarce at this time, as highlighted by the USEPA's (2012b) solicitation for more information on potential costs of sample collection and analysis. Nevertheless, certain aspects of these programs have been estimated as listed in Table 3-4.

Table 3-4. Costs for Turbidity Monitoring Analyses and Equipment (Excludes Labor)

Item	Cost	Comments
Laboratory turbidity analysis	\$10 - \$15 per sample	Done with EPA method 180.1
Automated sampler	\$3,000 - \$10,000	Price range is large due to possible options. \$10,000 system may include optional flow meter, rain gauge, refrigeration, stationary setup and communication. Portable systems are slightly cheaper.
In-situ turbidity probe	\$3500 - \$5,000	Includes internal processor, memory, data logger, turbidity probe
In-situ turbidity probe with communication	~\$10,000	Includes probe listed above plus solar battery recharging and remote cellular communication
Handheld turbidity meter kit	\$800 – \$1,000	Includes solutions for calibration

When planning for the costs of a monitoring program, the components listed below should also be considered. Components may vary depending on location, monitoring methodology and use of onsite vs. offsite personnel.

- Weather Tracking: If offsite personnel are being used in the monitoring program, then a person will need to look at radar and forecasts periodically and make the decision to mobilize. Services are also available to provide subscribers e-mail updates and mobile device notifications of forecasted storm events.
- Station Set-up/Calibration: If an automated station, either auto-sampler or on-line turbidity probe, will be used, the station must be set-up and equipment installed, including any protective housing, intake lines, intake ports, probe installation, etc. If flow monitoring is included, the calibration of that equipment should also be included.
- Mobilization: Field sampling equipment must be calibrated, assembled, and brought to the construction site. Be sure to budget for the involvement of two people for safety. Also important to consider in monitoring budgets is that mobilizations will often exceed valid sample collections by about 25% due to sampling problems or inaccurate weather predictions.
- Sample collection and handling: This might include two staff persons arriving at the site, pulling grab samples or removing composite samples from automatic equipment, restocking autosamplers, completing chain of custody forms, packing the samples in ice, and delivering them to a lab or shipping facility. If turbidity is automatically measured onsite, it will include downloading accumulated data.

Analytical costs of lab, if lab analysis will be used: Per sample analysis. See above.

Data validation, analysis, and reporting, as necessary: This includes processing of any electronic data deliverables with lab results, transcription of manually recorded results, analysis of downloaded data from turbidity probes, and any statistical analysis of the results.

Equipment maintenance, breakage and loss: All equipment requires maintenance. Replacement costs should also be included to account for breakage or loss due to storms or mounting issues.

Turbidity monitoring costs depend on many interrelated factors such as:

- site conditions;
- frequency of storms requiring sampling;
- choice of monitoring methods (automated samplers vs. manual vs. in-situ probe);
- use of remote communication equipment;
- use of contract crews vs. staff;
- use of field turbidimeters vs. laboratory analysis of samples;
- total number of samples taken and analyzed per storm; and
- whether compositing is done.

There is no simple formula for estimating project costs for monitoring turbidity because of a multitude of project, site, and regional variables and their uncertainties. Estimating total cost of a monitoring program may be facilitated by using the costs in Table 3-4, and combining these with anticipated labor and administrative costs resulting from the considerations listed above (e.g., weather tracking, etc.).

The most cost-effective monitoring method will vary, depending on monitoring needs. *Caltrans' Stormwater Quality Monitoring Protocols* (California Department of Transportation, 2003b) state that "[a]utomated sampling generally is the most cost effective method of composite sample collection, and is particularly appropriate for large-scale programs (e.g., where a large number of sampling sites are monitored, or numerous sampling events are conducted over multiple years)." In contrast, construction sites in which monitoring locations change frequently, or which require a limited number of samples because they are completed during drier weather will likely find that manual grab samples are much less expensive.

Again, one overall consideration should be the consequences of inaccurate turbidity measurement could have. For sites that are under higher scrutiny and/or have strict effluent or receiving water limits, more sophisticated and accurate approaches may be more cost-effective overall.

3.4.5 Access and Safety Considerations

Any sampling program should have safety considerations prioritized. As mentioned in the DOT survey results, 90% of responding DOTs stated that safety would have a high or moderate influence on their selection of a monitoring method. In reality, safety should have a high priority in the design and implementation of a monitoring program. That being said, it is possible to sample in difficult situations from a safety perspective, but the proper health and safety equipment and procedures must be employed.

Judicious choice of sampling locations can greatly increase safety of monitoring crews. Sampling locations should be chosen so that sites are not adjacent to travel lanes or, if they must be, that a traffic management plan is implemented. Avoid locations with poor footing, poor visibility, or potential for toxic gas build-up. Safe access should be confirmed during wet weather, as flooding can make access to some locations very difficult during these times.

Even with properly chosen monitoring locations, hazards will exist and be compounded in stormy weather or at night. These safety considerations are explicitly recognized in the USEPA's 2011 proposed construction general permit (2011c):

> *You are only required to take samples during conditions that are safe to sampling personnel. Where your site is experiencing, or will imminently experience, conditions such as high winds, lightning, or intense rainfall, which would cause a reasonable person to believe that the safety of the members of the stormwater team taking samples to be in jeopardy, you are relieved from sampling during those conditions. You must take samples as soon as such unsafe conditions are no longer present or threatening, as long as at that time a discharge continues to occur.*

Clearly, this language does not apply to normal heavy rainfalls. Hazards will remain in these conditions. Choice of a sampling method can reduce the hazards as can a well thought out and implemented health and safety plan. Manual grab samples will require personnel to access monitoring locations during heavy rainfalls, whereas other methods may not normally require access to sample collection locations until after the storm has passed. In cases where rainfall persists for longer periods, however, samples from an automated sampler may need to be retrieved while rain is still falling. Additional in-stream monitoring requirements for environmentally sensitive locations accentuate the hazards of manual monitoring techniques, especially in flashy streams. This should be considered when choosing a monitoring method.

Given how commonly manual grab sampling is used, safety can be a significant factor in method choice. Harris et al. (2007), discussing turbidity monitoring for forest management in California, stated that the primary limitations of manual grab sampling were accessibility during storm events and the safety of field personnel. Depending on the particular site characteristics, this likely is true in the field at construction sites as well.

Chapter 4. Monitoring Strategies and Guidelines

In Chapter 3, a list of sampling methodologies is presented and discussed their benefits, drawbacks, and representative costs. This chapter starts by discussing regulatory drivers in the choice of sampling frequencies, and when risks of exceeding a numeric standard might make increased sampling frequencies and/or techniques more cost-effective in terms of compliance. It then provides recommendations to assist designers and managers in the choice of sampling methods for a given site. Minimization of sampling requirements through the use of representative locations, project phasing, and diffuse (non-channelized) flow are also discussed. The remainder of the document provides recommendations on how to properly implement a monitoring plan to improve the likelihood of sampling program success.

The term "designer" as utilized throughout this document refers to any individual developing the erosion control plan(s) and/or SWPPP(s) for a construction project(s) that has decision making authority on sampling protocols. For some DOTs this may be an in-house engineer or erosion control manager and for others this may refer to a third-party civil engineering or stormwater consultant providing similar services. In addition, the term "monitoring" in the regulatory community can refer to visual inspections and other processes that do not require sample collection; however, for the purposes of this document, the terms "sampling" and "monitoring" both refer to the collection of runoff for purposes of determining turbidity or in-situ measurement of turbidity.

4.1 Sampling Frequency and the Choice of a Sampling Method

There is no single sampling methodology that is applicable to all linear or highway construction projects. The majority of construction sites will likely only require a simple monitoring approach to meet minimum requirements (i.e. monitoring turbidity at outfall locations with a grab sample and field turbidimeter); however, there are many factors that designers and erosion control managers should consider when developing a plan that is appropriate for their specific site and operations. These are summarized below.

4.1.1 Regulatory Drivers

While this document provides recommendations for complying with potential or future regulations (and not just existing regulations), existing federal, state and local regulations have been considered as the starting point for recommendations regarding development of a project monitoring plan. Currently, many erosion control regulations on linear projects allow for the use of a reduced set of "representative" sample locations (which are discussed in detail in Section 4.2) rather than requiring sampling at every discharge location. Although there is a strong precedent for maintaining this practice, future permits may remove or revise this clause and require more extensive monitoring. In addition, it has been the strategy of some state DOTs to apply to the state for a statewide permit (combination of MS4 and construction) that may contain more rigorous monitoring requirements, including flow-weighted compositing, automated sampling and other requirements above and beyond what is currently required in many states' general permits (typically storm grab sampling). Local municipalities may also have regulations that may be more stringent than state or federal standards. Regulatory requirements set a "baseline" of sampling requirements; however, recommendations in this chapter will not solely reflect the minimum legal requirement, but will also provide recommendations to both protect water quality and reduce the risk of unnecessarily triggering a permit violation.

The C&D rule (USEPA, 2009), prior to the staying of effluent limitations and sampling requirements, made three primary statements with regard to sampling frequency:

1) NPDES construction permits issued by states must specify the type, interval, and frequency of sampling "sufficient to yield data which are representative of the monitored activity."
2) Permittees may sample discharge from a location multiple times and average the turbidity readings or composite samples. This average, either arithmetic or flow-weighted, is what should be compared to the effluent limit.
3) While EPA leaves the choice of monitoring frequency to individual states, they expect that the minimum frequency will be three times per day during storms. Both issuing states and permittees may elect to do sampling more frequently than required.

The USEPA also stated that it intended to provide monitoring guidance as a technical resource for their permits, and that it would do this prior to issuing the next USEPA construction general permit. Since the next permit did not include sampling requirements, specific guidance has not been issued. The USEPA's subsequently 2011 proposed construction general permit (USEPA, 2011), however, did provide some clarification on what it believes is an appropriate sampling frequency:

> *You must collect your first sample within the first hour that the discharge begins. After you take your first sample (as required in Part 3.3.1), you must take a minimum of 2 additional samples (a total of 3 samples) during the remaining hours of the work day (for normal working hours) that the discharge continues. The 3 samples must be distributed in such a way that the beginning, middle, and end of the discharge for that day are represented.*

For small drainage areas with short drainage path lengths and low storage capacity, the duration of flow may be very small (i.e. lasting not much longer than the storm itself). Therefore, in regions prone to shorter storms, the sampling interval may need to be decreased substantially in order to collect three samples while runoff is occurring. Also, during periods of scattered showers, the sample collection response time may need to be very short, which may necessitate the use of real-time forecasts and/or active monitoring of radar to ensure runoff samples can be collected. However, it also may be in permittee's interest to collect more than three samples to increase the chances that the resulting either mathematically averaged or composite sample is representative of the average of an event.

As mentioned in Chapter 3, some states have their own requirements on sampling frequency. Table 18 below includes the sampling frequency required by states that have included a sampling frequency requirement in their permits (federal language from draft permit was discussed above).

Table 4-1. Sampling Frequency Requirements by State

State	Sampling frequency	Comments/Applicability
AK	During any storm or snowmelt event resulting in discharge, must have 2 samples per day per storm event.	Only for TMDL or 303(d) listed waters
AZ	Any time a pollutant (including sediment) is known or suspected to discharge from the construction site (no specific frequency listed in construction general permit)	For projects within ¼ mile of unique or impaired waters
CA	Minimum of three samples per day for events producing ≥ 0.5" rainfall. (Risk Level 1 projects are required to sample discharge of accumulated stormwater or groundwater dewatering 3 times/day)	Risk Level 2 and 3 projects only as determined by combining estimates of sediment yield risk and receiving water risk per methods defined in the California Construction General Permit.
GA	Once during first rain event reaching 0.5" accumulation after clearing and grubbing (during business hours) and at first rain event reaching 0.5" accumulation at least 90 days after the first sampling event or after mass grading operations have been completed in the area. Turbidity sampling shall occur for any rainfall event reaching 0.5" accumulation where prior turbidity sampling has shown that BMPs are not sufficient to meet turbidity NALs.	
NH	Once per hour for 4 hours if 0.5" of rain have fallen or if 0.5" of rain is predicted and 0.25" of rain have fallen (Currier, 2009)	Specifically applies to I-93 rebuilding efforts (Sampling only required through 401 certification)
SD	During normal stormwater inspections or at the Engineer's discretion. Normal stormwater inspections occur once every seven days and within 24 hours of a rain event reaching 0.5" accumulation or snowmelt event causing erosion. (South Dakota Department of Transportation, 2010)	Only in streams inhabited by the Topeka Shiner species
VT	No frequency specified in Vermont's construction general permit	Sites where visibly discolored water discharges to waters of the State, and problem is not resolved with BMPs
WA	Turbidity must be measured weekly during periods of runoff. Reading over 250 NTU triggers daily sampling.	

Current guidance and regulations allow dischargers to sample more frequently than required (i.e., no regulatory language was found during review that prohibited additional or more comprehensive sampling) and compare a daily average against the turbidity limit. Therefore, a major decision faced by a designer or erosion control manager in determining an appropriate sampling program is whether to do the minimum required by regulations (and most cost-effective on a per-storm-event basis) or to exceed the regulatory requirement to better characterize site discharge. One option would be the use of an on-line turbidity meter, which in fact may not be that much more expensive than individual grabs (for long-term total costs) and would allow very rich monitoring. The future actions of the USEPA could significantly affect this decision making process if they decide to continue to exclude an effluent limit, and either utilize narrative criteria, or a less stringent action level (which triggers some type of retroactive remedy rather than a permit violation). From a cost perspective, the removal of the effluent limit will remove the threat of permit violation and subsequent potential fines or penalties associated with the violation (although Clean Water Act penalties could still apply). In this case, the design manager would have to review the site's "risk" conditions against the required remedy from exceedance of a numeric action level and determine the cost/benefit to implementing the remedy vs. increased sampling efforts to obtain a more representative sample that may avoid action level exceedances. It should be noted that the C&D Rule (USEPA, 2009) stated that the USEPA would:

> *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. Additionally…EPA's NPDES regulations state that the permit must specify the type, interval, and frequency of sampling sufficient to yield data which are representative of the monitored activity. EPA expects that enforcement authorities would prefer, or even require, monitoring samples at some regular, pre-determined frequency*.

4.1.2 Implementing Increased Sampling Protocol

In 1974, the USEPA performed a comparison study on small sample size (i.e., small number of samples) grab sampling vs. composite sampling for wastewater dischargers. Although sampling equipment at the time was not ideal and often failed, the USEPA concluded that relying on grab sampling to characterize discharge was wholly inadequate and caused a very wide range of performance results (USEPA 1974). Although this study was not related to construction site runoff, construction site discharges are typically much more variable than wastewater discharges, and therefore the differences between grab sampling and composite sampling would likely be even more pronounced.

Even with the inclusion of effluent limits, in most cases the use of manual grab samples and field turbidimeters will be the most cost effective method and will likely provide reasonable results; however, there are many instances where simply performing the minimal sampling per regulations may actually prove to be detrimental from a compliance standpoint. For example, minimal sampling (2 or 3 samples per discharge location) may cause reportable values of turbidity to exceed allowable values due to capturing of the "first flush" or periods of high discharge variability. While many researchers have studied the first flush phenomenon (higher pollutant concentrations at the beginning of a storm due to removal of easily washed off pollutants) for impervious surface, there is a notable dearth of research on this topic for construction sites. No study was found that evaluated the intra-storm variability of turbidity in construction site runoff. Nonetheless, if only a few samples are taken and these samples are not evenly distributed across the range of observed turbidities, the computed average daily turbidity may not be representative of the overall character of the site's daily discharge.

The 2011 proposed USEPA construction general permit called for a sample to be taken in the first hour of a discharge event, which could (depending on many factors) have much higher turbidity than the remainder of the event. In these instances, a more robust composite sampling program, either via multiple sample collection or automated turbidity readings could lead to lower reportable values that are more representative of the overall discharge turbidity, as the reportable values are daily averages. With a small sample population (for instance, 3 samples per day in CA), a data outlier can strongly skew a reportable average. The designer should review the risk factors below and determine if the project site has the potential to be higher than average risk and could benefit from more representative samples obtained from increased sampling frequency.

4.1.3 Risk Factors for Increased Sampling

In this discussion, risk is defined as the increased probability of ecological damage to receiving waters (and exceeding a numeric effluent limitation or numeric action level). The risk factors discussed in this chapter include 1) receiving water type and impairments, 2) climatological region and associated precipitation intensities 3) project location in relation to receiving waters, and 4) project slope, soil type, and drainage path length.

The sections below will provide a discussion of some of the major factors that may put a construction project at greater risk for violation of numeric effluent limitations (NELs) or numeric action levels (NALs). These factors do not include negligent or inadequate erosion and sediment control programs, which could also lead to a site being at risk.

Construction stormwater has a high level of variability in its turbidity over the course of any given storm (Spotts, 2011). A simple statistical analysis will show that a small number of samples (e.g., 2 or 3) of stormwater will tend to yield an average turbidity that varies more than the average of a large number of samples. Since a small sample size will more likely give results either higher or lower than the actual event mean turbidity, it stands to reason that there are two potential scenarios:

a) The actual event mean turbidity (average of all stormwater from the entire storm event's runoff) is below the effluent limit. In this case, the small sample size may trigger a violation even though the "true" mean does not exceed the regulatory turbidity limit. With increased sampling the discharger may be able to compute a sample mean that is closer to the true mean and within permit limits and therefore avoid potential fines and/or expensive treatment options required by permit violations.

b) The actual event mean turbidity is above the effluent limit. In this case, the small sample size may result in a turbidity average below the effluent limit, leading the discharger to conclude that no violation has occurred while potentially still impacting water quality. With increased sampling the sample mean will be closer to the "true" mean and the discharger will become aware that overall controls implemented on-site are inadequate, and that additional measures and/or controls are required to protect water quality.

For either scenario, a more protective (i.e., protective of discharger and water quality) and less uncertain outcome is obtained when a higher number of samples are utilized to determine the average. Obviously, increasing the frequency of sampling has implications for sampling methodology as well, since frequent or flow-weighted sampling will make automatic sampling more attractive. This section is an attempt to assess the value of increased sampling, since there can be more significant capital and operational costs in its implementation. The first step in assessing that value is determining factors that create greater risk of NEL or NAL exceedance.

Receiving water type and impairments

One factor that affects this risk of exceedance is the water quality of the receiving water and the existence of any sediment or sediment-related impairments or existence of Total Maximum Daily Load (TMDL) requirements. Some TMDLs limit turbidity, which may be measured by any of the sampling methods discussed so far, while others limit sediment loads and/or concentrations, which can only be determined by obtaining samples and transporting to a laboratory for analysis. Even in situations where water quality is determined to be impaired by sediment (or sediment related-pollutants), but no TMDL has been developed, many state General Construction Permits contain additional sampling protocols for discharges to these water bodies. TMDLs can also contain an allowable percent increase from background concentrations, and therefore can require background receiving water monitoring. Since receiving water impairments are likely to make turbidity limits stricter, the risk of exceeding those limits is greater. In addition to the water quality status, another factor is the “size” of the receiving water in comparison to the highway runoff that would be discharged. Some states also have limits on the increase in turbidity that is allowed (often included in Clean Water Act Section 401 certifications). A large highway draining to a small stream may receive more scrutiny.

In those sites that are very near or even cross receiving waters, state water quality standards and 401 Water Quality Certification and/or certifications from the Army Corps of Engineers (404 and other Nationwide permits) may be involved. These projects may come under greater scrutiny from regulators, may have more stringent numeric limitations, and may be at greater risk of exceeding applicable numeric limits from utilizing a small number of samples.

Climatological Region

The natural precipitation and resulting stormwater flow characteristics in the climatological region where the construction project is located can have a strong impact on the turbidity of the stormwater discharging from that project, and may change the value placed on controlling turbidity of stormwater runoff. Many locations throughout the United States are deemed as “arid” or “semi-arid” with rainfalls less than 5” and 10” per year, respectively. As such, these locations often have sandy, unstabilized arroyo or wash-like receiving waters that are often dry and, when flowing, have naturally high sediment loads (and subsequent turbidity) as part of the regional sediment cycle. Therefore, sampling requirements and programs in these locations may not need to be as stringent as in other parts of the country, assuming that states in these regions are not required to enforce an effluent limit that does not account for this condition. The opposite may prove to be true if there were to be a federal standard for turbidity that arid regions were required to incorporate. Resultant turbidity in runoff from project soils may be more likely to violate a turbidity effluent limit in these regions during infrequent rain events, due to the natural detachment and transport of sediments; although these sandy sediments are much more likely to be captured by properly implemented sediment control BMPs on a construction project.

Another factor is the rainfall intensities that occur in various regions during the construction period. Regions with generally higher intensities face more difficult erosion control situations that may then lead to decisions to increase the monitoring efforts.

Project Location Relative to Receiving Water

In addition to its climatological location, the project’s location relative to its receiving water(s) may be a significant factor in selecting a sampling protocol. Many linear projects traverse multiple receiving waters that are potentially fish bearing and/or sediment impaired. Other highway projects may be located far from a receiving water, with highly vegetated buffers between construction activities and locations where runoff from the construction activity would enter a receiving water. A large enough vegetated buffer between the site discharge and the receiving water could also provide opportunity to spread flow to the extent that the majority is filtered or infiltrated prior to entering the receiving water. (Section 4.5.2 provides more information on reducing sampling requirements through diffuse flow practices).

Project Slope, Soil Type, and Drainage Path Length

The most important factors affecting soil erosion rates and resulting sediment loads for any given project are (1) the steepness of the designed slopes, (2) whether the slopes are cut or fill slopes, (3) the soil type, (4) drainage path length on the project, and (5) the BMPs applied to the site. Soils high in clay are resistant to detachment from rainfall, and therefore produce less sediment yield than other soil types (although if soils high in clay are detached, they will cause high turbidity readings, as they are difficult to settle out). Coarse textured soils, such as sandy soils, cause low runoff due to high infiltration potential; although these soils are more easily detached (they are also the easiest soils to settle using traditional BMPs). Medium textured soils such as silt loam soils and soils having high silt content are more easily detached and also tend to crust and produce higher rates of runoff. They are therefore the most erodible of all soils.

Project slopes should also be considered when evaluating the risk of high sediment yield. Slope steepness is a bigger contributing factor to sediment yield than slope length; however, increases in both will greatly increase the sediment mobilization to the bottom of the slope. In many DOT projects, with limited rights-of-way and constrained topography, slopes can be both long and steep, and in many cases can directly discharge to a drainage channel along the disturbed area. In most cases, the designer can assume that project areas with the steepest and longest slopes will present the highest risk areas (unless the slopes are comprised mainly of rock). Areas with higher risks should be considered for more intensive monitoring.

4.1.4 Deciding on the Level of Monitoring for Assessing Compliance

As summarized in Chapter 3, three types of equipment may be used to assess turbidity: grab sampling equipment, automated samplers, and water quality probes either in-situ or in combination with grab or composited samples (as stated in Chapter 3, stage samplers are not well suited to construction site use). Deciding when to use each can be complicated, as many factors influence this decision and most of these factors have a continuous range of values. For instance, shorter-term and phased projects tend to favor grab sampling, but this decision is subjective and site specific. The number of rainfall days expected during the construction window, the availability of personnel, and the number of outfalls requiring monitoring may significantly influence the decision of whether to collect manual grab samples or use automated samplers or water quality probes. However, there are no objective thresholds for these factors, and it is the cumulative effect of such factors that should be considered in decision making. Furthermore, due to the dynamic nature of construction, site conditions and project phasing may change significantly from what was expected during the planning and design stage of the project to what actually occurs during construction, which may tip the balance toward one monitoring method instead of another.

Table 4-2 has been developed to illustrate factors and/or situations that may favor one method over another. These factors will need to be weighed to make the proper decision on each project. It is anticipated that the majority of construction sites will favor manual grab sampling because of lower capital and operational costs and greater adaptability to changing site conditions. Continuous, in-situ water quality probes are anticipated to be used less frequently than automated samplers, except for monitoring receiving waters where these probes can be constantly submerged. In-situ probes can be used successfully on construction sites if installed properly and the installation location is monitored to avoid buildup of sediment (see Section 3.2.5).

Table 4-2. Factors for Selecting an Approach to Turbidity Monitoring on Construction Sites

Monitoring Equipment	Factors Favoring Use of This Approach
Manual grab samples	• Narrative discharge criteria or numeric action levels (instead of numeric effluent limitations) • Short-term projects (under 3-6 months, depending on location) • Projects in which sampling locations change frequently • Projects with limited funds for capital expenditures, training, and maintenance • Projects in which on-site personnel are available to access the outfall in a timely manner to collect representative samples • Projects where expected rainfall is minimal or is concentrated in a limited number of events • Projects which drain to water bodies that are not considered sediment-sensitive receiving waters (303(d) listed, etc.)
Automated samplers	• Numeric effluent limitations, rather than numeric action levels • Projects of a long duration with consistent sampling locations • Projects with a large number of expected rainfall days during the construction window • Projects with discharge to or in close proximity to sediment sensitive receiving waters • Projects where sampling locations are difficult or unsafe to access during storm events in a timely manner • Studies in which a turbidity profile over time is required • A desire to obtain flow-weighted compositing of samples to yield an event-mean turbidity due to high risk of exceeding NELs, for example: - Projects with severe slopes or highly erodible soils - Projects in locations with "flashy" weather systems where turbidity may vary significantly within a storm, and sampling can significantly skew average turbidity values • Need for analysis not available in water quality probes, such as particle size analysis of sediment in stormwater[1].
Continuous, in-situ water quality probes	• Receiving waters or discharge locations with continuous flow or where a probe can be maintained in wet condition • Studies in which a turbidity profile over time is required in order to better understand turbidity problems on a site or to be able to demonstrate compliance with numerical criteria. • Areas where sampling crews cannot get on site regularly or safely to retrieve samples • Climates with a high intensity rainfall and a high number of sampling events per month • Situations in which a simultaneous measurement of turbidity is required (e.g. inflow/outflow of best management practices) • Situations in which automated monitoring is desired and automatic samplers have had repeated intake tube clogging issues. • Situations in which remote communication can be used and real-time access to turbidity information is desired.

[1] A particle size analysis may be useful when trying to decide if sediment will settle easily in detention basins or if coagulation/flocculation or filtration-based treatment methods may be needed.

The decision to composite samples is closely linked to the choice of a sampling method. As mentioned in Chapter 3, compositing of manual grab samples includes many steps in which mis-measurement, solids loss, sample loss, and contamination can occur. It also adds to the labor required for sampling. Therefore, it is anticipated that on most projects where manual sampling is used, compositing will not be used or only will include limited compositing (i.e., 3 grabs, including rising limb, max and falling limb of storm for example).

On the other hand, when an automatic sampler is chosen, it can be advantageous to do compositing of samples and can result in a more representative estimate of the event mean turbidity. Compositing reduces the number of samples that require analysis, either by field equipment or by a laboratory, and using more aliquots in the composite requires very little incremental effort compared to two or three samples. Flow-weighted compositing, as noted in Chapter 3, carries inherent advantages for accuracy. However, flow-weighting requires the use of a flow measurement device, such as a flume and pressure transducer, which will add to the monitoring start-up costs and may not be feasible for some outfall locations.

With in-situ water quality probes, the choice is more open. Multiple individual samples (readings) could be used, although a composite sample could also be calculated from numerous readings. Flow-weighted "compositing" is possible if a flow meter is used. Time-weighted compositing can be done without a flow meter. The advantage of the probe is that literally hundreds of readings could be used vs. a practical maximum number of sample aliquots that can be collected by an automated sampler (typically 12-24). In addition, automatic samplers require a set amount of time to collect a sample and prepare for the next one. In flow-weighted compositing, depending on the flow volume interval used to trigger sample collection, intense periods of rainfall may cause samples to be queued more rapidly than the time required to collect the sample. This delay may result samples not being collected at the correct time. For this reason, a large enough flow volume interval must be selected such that the sample collection rate is not exceeded. Consequently, for regions that experience short-duration, high intensity rainfall, the practical number of aliquots is more limited than for regions that experience more uniform rainfall intensities. If thunderstorm activity is expected and flow-weighted composites are desired, continuous water quality probes and a flow meter may be a better option than an automated sampler.

Regardless of the sampling methods utilized on a project, regulatory precedent allows for reduction of sampling requirements by collection of samples from representative locations and by use of judicious project phasing. These topics are discussed below, followed by recommendations on implementing a monitoring program.

4.2 Representative Discharge Sampling Locations

One strategy for decreasing the scope and cost of sampling programs (both manual and automated) is to choose one sampling location out of a group of "substantially identical" outfalls (i.e., those outfalls expected to yield similar quality stormwater based on the characteristics of the areas tributary to each outfall). The concept of sampling with only a representative subset of outfalls for monitoring is not a new one. USEPA's National Pollutant Discharge Elimination System Stormwater Sampling Guidance Document (1992) states that "…when an industrial applicant has two or more outfalls with substantially identical effluents, the permitting authority may allow the applicant to test only one outfall and to report that the quantitative data also apply to the substantially identical outfalls." This guidance document then provides criteria for demonstrating the stormwater outfalls are "substantially identical," which are described later in this section.

USEPA understands that, similar to industrial sites, linear construction sites may include many substantially similar discharge locations, and that cost-effective monitoring that utilizes judicious choice of a subset of these locations may be employed without compromising the compliance monitoring intent of the regulations. The C&D rule (USEPA, 2009) stated:

> *Monitoring from Linear Construction Activities: EPA believes that the permitting authority should exercise discretion when determining the monitoring locations and monitoring frequency for linear construction projects. For instance, the permitting authority might choose, for example, to utilize representative sampling at certain discharge locations that are representative of the discharge characteristics of other locations. EPA views the use of representative sampling points as being acceptable for linear projects due to the potential unique nature of these projects. Because of the size of linear projects, there may be dozens or more discharge points spaced over a large geographic area.*

USEPA further refined its idea of how to determine whether construction stormwater outfalls are “substantially identical” in its proposed construction general permit (USEPA, 2011), where it stated:

> *If you are required to comply with the numeric turbidity limit for a linear project, and you have two or more discharge points that you believe discharge substantially identical effluents, based on the similarities of the exposed soils, slope, and type of stormwater controls used, you may take samples of the discharge from just one of the discharge points and report that the results also apply to the substantially identical discharge point(s). If your project continues for more than one year, you must rotate once per year the location where samples are taken so that a different discharge point is sampled every year. As required in Part 8.2.12.2a, your SWPPP must identify each outfall authorized by this permit and describe the rationale for any substantially identical outfall determinations.*

States that require monitoring at this time for some or all of their construction sites vary considerably in their requirements and guidance on this issue. For instance, New Hampshire does not currently allow permittees to collect one representative sample for all substantially identical discharge points (Hemmerlein, 2011). On the other hand, the Alaska Construction General Permit (Alaska Department of Environmental Conservation, 2011) which only requires turbidity sampling for 303(d) or TMDL listed water bodies, does allow collection from representative sample locations. Justification for this allowance in Alaska simply requires stating in the monitoring plan the following:

- Location of the discharge points;
- Why the discharge points are expected to discharge substantially identical pollutants; and
- Estimates of the drainage area size for each discharge point.

Although the California Construction General Permit does not specifically mention use of representative locations, Caltrans (2012a) has interpreted language in the permit as allowing them. Unlike other states mentioned above, Caltrans has tied turbidity sample results to use of representative locations, specifying that only 20% of discharge locations (or 5 locations, whichever is smaller) must be sampled at a construction site. A sample result above 200 NTU or outside of pH range 6.5 - 8.5 will increase this requirement to 50% of locations. Worse results (>250 NTU or pH outside the range of 6.2 – 8.8) at any location trigger sampling at all discharge locations during the next storm event.

Given the variability in the published regulations and the fact that many states do not provide any guidance on this matter, three general approaches are presented below for determining if outfalls are substantially identical:

1) Use the criteria stated in USEPA's 2011 proposed construction general permit: Evaluate areas tributary to these outfalls based on similarities of slope, exposed soils, and type of stormwater controls used. A comparison of drainage area slopes for evaluating similarity should consider average slope, maximum slope, and distribution of slope categories on an aerial basis. Soil types can be evaluated based on NRCS map units (in locations where exposed soil is not fill) or basic soil types (e.g. high percentage of clays). Stormwater control evaluation should be based on similar source controls (stabilized vs. non-stabilized, etc.) and similar classes of treatment controls (detention-based BMPs vs. swales, etc.).

2) Extrapolate from industrial stormwater criteria in the USEPA's National Pollutant Discharge Elimination System Stormwater Sampling Guidance Document (1992): Although the EPA presented three methods for presenting evidence of similarity of industrial stormwater outfalls, all three used the same criteria. Each required demonstrating that the outfalls to be combined are substantially identical with respect to the following aspects:

   - Industrial activities and processes occurring in the drainage area;
   - Exposure of industrial materials or chemicals to stormwater;
   - Stormwater best management practices and material management practices (including protective coverings or secondary containment; and
   - Stormwater flows, as determined by the estimated runoff coefficient and approximate drainage area at each outfall.

   By analogy, the following list of characteristics might be chosen as a method of determining substantially identical outfalls on linear construction sites:

   - Construction activities and processes occurring in the drainage area – Which stage(s) of construction (clearing and grubbing, excavation, grading, concrete use, etc.) dominate(s) the area tributary area to each outfall?
   - Exposure of materials and equipment to stormwater – Although other chemicals on a construction site may have non-turbidity related stormwater impacts, the primary material of concern with respect to turbidity is exposed soil. Unvegetated areas and stockpiles of exposed soil, sand and structural fill materials are notable examples of these. Other factors with a strong impact are acreage of disturbed vs. undisturbed or stabilized soils, soil type (clay/silt/sand), and imperviousness.
   - Stormwater treatment BMPs and erosion and sediment controls in place, including items such as:
     - Erosion control blankets
     - PAM use as a tackifier
     - Mulches
     - Perimeter controls and vegetated buffers
     - Slope interruption

- Sediment control basins/traps
- Swales/diversions
- Check dams
- Passive/active treatment systems.

- Expected stormwater flow rates - Determined by imperviousness, soil type and level of compaction, slope length and steepness, and drainage area for each outfall.

3) Worst-first approach: The discharger may also consider adopting a "worst-first" approach, in which sampling is targeted to areas pre-determined to be of the highest risk of turbid discharge. Areas with the most disturbed acreage, steepest slopes or most erodible soils should be targeted. The strategy behind this approach is that if the highest-risk area is within acceptable discharge limits, those less-susceptible areas will likely also be within discharge limits and will therefore not require sampling. This approach requires designer-input to assess those areas that are most susceptible to erosion (which may change during project phasing). This approach is not recommended on sites that would be seen as high risk (see Section 4.1.3), and this approach is not presented in any current regulations (i.e., authorization from regulator would be required).

4.3 Project Phasing

One of most effective construction practices a planner can implement to minimize turbid runoff is to phase the project whenever possible so that the area of disturbed soil at any given time is minimized. Regulators encourage this practice by either requiring or incentivizing phasing by tying this practice to monitoring requirements. For example, the proposed USEPA CGP (prior to finalization) and the C&D Rule (prior to staying of effluent limits and monitoring requirements) contained provisions that provided sampling exemptions for projects with disturbed areas of less than 10 acres (USEPA, 2009):

> *The numeric limitation and monitoring requirements only apply when the total disturbed area is 10 or more acres. Therefore, when stabilization of disturbed areas reduces the amount of total disturbances to less than 10 acres, the numeric limitation no longer applies and monitoring of discharges is no longer required. This provision creates an incentive for large sites to stabilize disturbed areas as quickly as possible, thereby reducing the turbidity in stormwater discharges from the site. This is also an incentive to phase construction activities so that less than 10 acres are disturbed at any one time.*

At least one permit (California Construction General Permit) contains provisions that exempt linear construction sites from regulatory requirements regarding turbidity sampling if work areas are covered or stabilized at the end of each work day (more feasible on small transportation projects).

Even if a project cannot get disturbed areas below the limit that regulators explicitly use in incentives (e.g., 10 acres), or even if these limits do not apply to a project, designers or contractors may choose to stage soil disturbing and subsequent stabilization activities to reduce the number of discharge locations that must be sampled. In fact, contractors may choose to do this even if design plans allow larger areas to be disturbed.

The narrow width of many highway construction projects can allow for a significant length of roadway to be constructed within this 10-acre limit. Assuming a 100 ft wide work area, more than ¾ of a mile of highway can be constructed under the 10-acre threshold. A 200 ft wide work area allows for greater than 0.4 miles. A fundamentally different approach in the construction method may be required to maintain the total disturbed area at any one time to 10 acres or less. However, avoidance of sampling requirements can be a significant cost savings in both labor and sample costs, and potential fines and/or penalties for violations.

Another method of phasing that can be utilized to minimize sampling burden is judicious scheduling of construction. In many parts of the country, there are specific “rainy” and “dry” seasons, where very little or no rainfall occurs during the “dry” season. Timing construction projects such that areas identified as high risk due to soil type or slope steepness/length are constructed during dry seasons can lower the cost burden and implementation of a sampling program. On the opposite side of the spectrum, very large infrastructure projects may span multiple rainy seasons, and may pose a very high risk of turbid discharge during the life of the project. In these situations, larger runoff collection systems and storage BMPs (e.g., sedimentation basins, tanks, etc.) should be considered as part of the stormwater management plan as space allows. These structures may also allow for easier installation of automated sampling equipment such as flumes, flow meters, and autosamplers. Some of these facilities may also be converted to post-construction BMPs.

If phasing to minimize disturbance is not practical for a particular project, then a planner may opt to construct the project so that the number of discharge locations is minimized, and so that those locations remain consistent for the longest possible time. Using consistent locations and standardizing collection systems and outfall designs can improve reliability and accuracy in a sampling program.

4.4 Distributed Controls and Diffuse Flow

Another best practice that minimizes or eliminates certain sampling requirements is the use of distributed controls and the elimination of concentrated flow by discharging via diffuse flow. The proposed C&D rule stated (USEPA, 2009):

> *Monitoring Locations: The numeric limitation applies to all discharges from C&D sites. However, diffuse stormwater, such as non-channelized flow through a silt fence or other perimeter control that infiltrates into a vegetated area, and does not then discharge to surface waters, would not generally require sampling. EPA is encouraging (although not requiring) permittees to utilize dispersion of stormwater to vegetated areas and infiltration of stormwater instead of discharging it from the site. EPA encourages increased usage of such techniques, where appropriate.*

While dispersing flow is possible on many sites, the difficulty in this methodology is the regulatory language that requires the infiltration of the diffuse flow into vegetation without discharge to a receiving water. Utilization of this methodology for sampling avoidance requires adequate distance of a project from a receiving water and an undisturbed vegetative buffer with low slopes to ensure no discharge from diffuse flow. Simply relying on silt fences or perimeter controls to discharge non-concentrated flow may result in BMP failure or undermining, as it is difficult to install controls that uniformly distribute flow across a surface. A steep buffer can lead to channelized flows and runoff reaching receiving waters.

Utilization of vegetated areas (also known as buffers or filter strips) located down-gradient from level spreader trenches, perforated pipe, mulch or “seep” berms, or other dispersion controls should be considered as part of hydraulic design prior to construction. Shallow to moderate longitudinal slopes (less than 10%) are generally recommended to promote filtration, to prevent erosion and to make maintenance easier. However, research conducted by Barrett, et al. (1998) showed fairly good pollutant removal efficiency on vegetated slopes in highway medians even on slightly higher slopes (9-12%).

To meet the requirement for infiltrating diffuse flow, the vegetated filter strip must be properly sized to handle runoff from a design storm event. Typically, filter strips should be as wide as the contributing drainage area (same distance in the direction perpendicular to flow). Vegetative filter strips should be sized based on volume of runoff, peak hydraulic loading rate (i.e., flow rate per unit width of flow), and soil infiltration capacity. Construction site controls are normally designed to manage stormwater up to a 2-yr, 24-hour storm event, so it is recommended that this or other regulatory design storm be used for design of vegetated filter strips. Vegetated filter strips should be clearly marked and protected from construction vehicle traffic to avoid disturbance and compaction.

Note that when providing natural buffers between disturbed areas and surface waters, the USEPA (2012a) has established that areas outside operational control of the permittee may be considered areas of undisturbed natural buffer for purposes of complying with that requirement. Therefore, if an undisturbed vegetated area exists along and downgradient from the disturbed construction site, it may be feasible to install dispersion controls along the project limits and utilize the off-site area as a vegetated filter strip.

Application of this technique to linear construction sites may be further limited by local requirements for lower slopes or a greater longitudinal distances for the filter strip. Nevertheless, for some projects it may be effective and should be employed when possible.

4.5 Implementation of a Monitoring Program

Regardless of the sampling techniques selected, the collection of reliable data begins with a carefully planned monitoring program. A key component of any monitoring program is the monitoring plan that clearly describes the sampling objectives, locations, equipment, personnel, and procedures. The following section summarizes the key elements of a monitoring plan.

4.5.1 Writing a Monitoring Plan

Once the designer has established the sampling approach that will be implemented on a project, a monitoring plan should be developed. The monitoring plan should be a stand-alone document (although generally part of an overall SWPPP) prepared prior to construction and should contain the following key elements:

- A summary of permit requirements;
- A method for determining sampling triggers (initiation of a sampling event; weather tracking/onsite precipitation monitoring that trigger a sampling event when certain parameters are reached);
- A description of monitoring personnel and their appropriate training;
- Exemptions from monitoring requirements; and
- A description of the sampling locations, procedures, and reporting requirements.

An example outline of a construction stormwater monitoring plan is shown in Figure 4-1.

I. OVERVIEW
- A. Summary of Permit Monitoring Requirements
- B. Site Characteristics
- C. Monitoring Plan Organization

II. MONITORING LOCATIONS AND EQUIPMENT
- A. Discharge Points and Representative Sampling Locations
- B. Sampling Equipment

II. WEATHER TRACKING
- A. Weather Forecasting/Precipitation Monitoring
- B. Sampling Event Triggers
- C. Rain Gauges

III. MONITORING PERSONNEL

IV. MONITORING EXEMPTIONS

V. VISUAL MONITORING (INSPECTIONS)

VI. WATER QUALITY SAMPLING AND ANALYSIS
- A. Sampling Procedures
- B. Sampling Frequency
- C. Field Documentation
- D. QA/QC
- E. Data Verification

VII. REPORTING REQUIREMENTS AND RECORDS RETENTION
- A. Standard Reporting
- B. Exceedance Reporting

ATTACHMENT 1: Sampling Log

ATTACHMENT 2: Rain Gauge Log

ATTACHMENT 3: Additional Documentation

ATTACHMENT 4: Health and Safety Plan

Figure 4-1. Example Stormwater Monitoring Plan Outline

The guidance documents listed in Table 4-3 can be used to find more specific details on preparing and implementing a monitoring plan.

4.5.2 Sampling Personnel and Training

A critical aspect of a sampling program is proper sampling technique. Without proper sampling technique, results are often unreliable and/or invalid. For this reason, it is of critical importance to have well trained personnel, and to minimize sampling personnel changes during a project, if practical. Maintaining consistency in sampling personnel reduces the variability resultant from differing sampling techniques and employment of sampling equipment.

Many states (WA and GA for example) have state-sponsored training programs that are required for individuals who oversee construction stormwater compliance (including sampling) for construction permittees. In CA, SWPPPs must be developed and amended by a Qualified SWPPP Developer (QSD) and implemented by a Qualified SWPPP Practitioner (QSP). QSD and QSP certification requires completion of a multi-day class (3 days QSD; 2 days QSP), passing a corresponding exam, and having an applicable professional credential (e.g., CA Civil PE, CA Professional Geologist, CPESC for QSDs; CESSWI or CISEC for QSPs). There are also national certification programs, including the Certified Professional in Erosion and Sediment Control (CPESC), Certified Erosion and Sediment Control Lead (CESCL) and Certified Professional in Stormwater Quality (CPSWQ) certifications provided by Envirocert International that are generally accepted by regulatory agencies as sufficient training to provide sampling/monitoring as part of a construction permit. A discharger should consider a third-party subcontractor that specializes in stormwater sampling if they do not have appropriately trained personnel on their staff for a project. Most DOTs have trained sampling personnel for MS4 or other industrial permit purposes; therefore internal training for construction personnel may provide adequate training (if acceptable by state regulations).

Table 4-3. Construction Stormwater Monitoring Guidance Documents

Title	Author and Date	Link
Stormwater Monitoring Guidance Manual for Construction Activities	Arizona Department of Transportation. (2009)	www.azdot.gov/inside_adot/OES/Water_Quality/Stormwater/PDF/storm_water_guidance_for_construction.pdf
Stormwater Quality Monitoring Protocols	California Department of Transportation (2003b)	www.dot.ca.gov/hq/env/stormwater/special/newsetup/_pdfs/monitoring/CTSW-RT-03-105/CTSW-RT-03-105.pdf
Construction Site Monitoring Program Guidance Manual	California Department of Transportation. (2012a)	www.dot.ca.gov/hq/construc/stormwater/SamplingGuidanceManual.pdf
Standard Operating Procedures for Manual Field Measurement of Turbidity	California Department of Transportation. (2012b)	www.dot.ca.gov/hq/construc/stormwater/Caltrans_SOPs_CD.pdf
Construction Storm Water Sampling and Analysis Guidance Document	California Stormwater Quality Task Force. (2001)	www.cabmphandbooks.com/Documents/Construction/Appendix_C.pdf
Monitoring of Turbidity in Stormwater Runoff from Construction Activities	Vermont Department of Environmental Conservation. (2008)	www.vtwaterquality.org/stormwater/docs/construction/sw_turbidity_monitoring_guidance.pdf
How to do Stormwater Monitoring: A Guide for Construction Sites	Washington State Department of Ecology. (2006)	www.eco-3.com/manuals/DOE_Guide_to_SW_Monitoring.pdf

Chapter 5. Conclusions and Recommendations

USEPA's recent actions imply that it is considering a potential revision and reinstatement (in some form or another) of turbidity monitoring with associated numeric effluent limitations (NELs) or numeric action levels (NALs). This report has sought to prepare DOTs and others planning and implementing transportation-related construction projects for this potentiality by providing them with information on traditional and state-of-the-art turbidity reduction and monitoring practices.

5.1 Turbidity Reduction

The turbidity of stormwater runoff from active construction sites is a function of many factors such as soil type, slope, extent of disturbed soils, precipitation patterns, and the BMPs implemented. Construction stormwater BMPs include erosion prevention practices that are used to minimize the initial mobilization and entrainment of sediment particles as well as sediment control practices that capture and treat sediment-laden runoff. Preventative measures, such as covering and diverting flows around exposed soils, scheduling site activities to minimize the duration and area of exposed soils during rainfall, and using temporary mulch and erosion control blankets, are typically more cost-effective than removal of particles already entrained in stormwater runoff.

Research on turbidity reduction practices and technologies indicates that conventional erosion and sediment control BMPs, such as fiber mulch, silt fences and sediment traps, can be effective at reducing the initial mobilization and transport of sediment particles, but generally will not reliably meet low turbidity effluent limits for construction sites. More rigorous and seemingly redundant application of conventional BMPs may be effective for some sites, but even these "enhanced" controls in combination may not consistently achieve turbidities below 280 NTU, especially for sites with steep slopes, highly erodible soils, and high intensity precipitation (or rapid snowmelt) events. For some sites with challenging circumstances, the use of chemical coagulants or electrocoagulation would likely be necessary to meet turbidity limits consistently.

The most common chemicals used as coagulants and flocculants in stormwater treatment systems are natural and synthetic polymers. While a variety of polymeric blends have been considered for stormwater treatment, the most popular include:

- Chitosan – very popular and widely accepted natural polymer for stormwater treatment derived from shellfish exoskeletons;
- DADMAC (diallyldimethyl ammonium chloride) a.k.a. polyDADMAC – is less expensive, but may have some toxicity concerns. Not as widely used as others;
- PAC (polyaluminum chloride) – Less impacts to pH than alum when alkalinity is low; and
- PAM (polyacrylamide) – often copolymerized to vary the electrostatic charge. There are many formulations of PAM, and small molecular sizes and cationic formulations should be avoided. Extensively used in agriculture for decades. Generally used in erosion control and passive chemical treatment scenarios rather than active treatment.

The cost and reliability of implementing turbidity reduction practices at construction sites depends on a number of factors including, but certainly not limited to: soil type, precipitation and drainage characteristics, vegetation establishment/extent of disturbed area, duration of project, treatment system type and configuration, and level of monitoring and maintenance. In general, the active treatment systems are much more expensive to install and operate than passive dosing methods, but they can be expected to be significantly more consistent at achieving low effluent turbidity (usually below 10 NTU) at a variety of flow rates whereas the performance of passive systems is much less certain, particularly when flow rates are highly variable. The costs and effectiveness of electrocoagulation appear to be similar to those of other active treatment methods employing chemical coagulants.

Besides site specific factors, treatment costs for active treatment depend on availability of materials, energy costs, and whether the system is rented or purchased. Costs per gallon of stormwater treated are also highly dependent on the utilization of the equipment, which in turn, is dependent on 1) amount of storage available for equalization, 2) size and effective imperviousness of the drainage area, and 3) the precipitation patterns during the construction period. The O&M costs will be higher for a system that runs for long durations; however, more stormwater will be treated, so the capital expense relative to the volume treated is less than for a system that sits idle for long periods of time. Due to these many considerations it is not surprising that 6-month treatment costs for these systems appear to range from as low as $4 to as high as $83 per thousand gallons treated (Table 2-10). Passive treatment systems are expected to be considerably lower in cost because there are no energy costs, limited (if any) mechanical equipment, and lower operation and maintenance requirements. Based on estimates produced by the USEPA (2009a), the total monthly costs for a 17-acre model site treated using the New Zealand treatment method would range from approximately $1.80 to $13 per thousand gallons treated..

Very few studies have conducted side-by-side comparisons of the various technologies, so direct comparisons of costs and performance of available data are tenuous, at best. Nonetheless, based on the available information gathered during the course of this study, some general comparisons of the four major classes of turbidity reduction technologies are possible, as indicated in Table 5-1. The turbidity ranges are approximate and are roughly based on the performance studies and data reviewed. They are intended to provide order-of-magnitude comparisons of what may be expected from these sediment control technologies.

Table 5-1. Summary Comparison of Major Classes of Turbidity Reduction Technologies.

Sediment Control Method	Expected Achievable Turbidity Range	Reliability	Monitoring & Maintenance	Relative Cost
Conventional BMPs	500-2,000 NTU	Low	Low	Low
Enhanced Conventional BMPs	100-500 NTU	Low	Low	Moderate
Passive Coagulation	20-500 NTU	Moderate	Moderate	Moderate
Active Treatment	1-20 NTU	High	High	High

5.2 Turbidity Monitoring

Obtaining an accurate turbidity measurement for construction site runoff can be difficult and is complicated by the challenges associated with collecting representative samples and differences in turbidity measurement equipment. If turbidity results are to be compared or are used for strict enforcement, measurement equipment should be standardized in that program, since different turbidimeters can give significantly different readings for the same sample.

Flow-weighted compositing requires continuous flow measurements, but delivers the most representative turbidity for a given storm. Choosing to composite samples in part depends on the desired level of confidence in obtaining a representative measurement and the potential consequences of exceeding a numeric threshold (e.g., NEL or NAL).

Each of the sampling methods discussed in this report (manual grab sampling, stage sampling, simple and fully automatic sampling, and sampling by in-situ water quality probe) have strengths and weaknesses, which will, in turn, influence how it is best used. See Table 4-2 for a listing of preferred applications for each method. Each method's strengths, weaknesses, and most preferred application is summarized as follows:

- Manual grab samples benefit from low capital, training, and maintenance costs, but complicate compositing and require crews to be at each sampling location with short notice. Manual sampling is the preferred method for most construction projects, but especially for low budget projects of shorter duration, those with fewer or changing discharge locations, and those not discharging to sensitive receiving waters.
- Stage sampling was originally designed for remote stream sampling, and has significant limitations, such as poor control over (and no record of) when a sample is taken and inability to sample during the falling leg of the hydrograph. Although it is specifically allowed in one state (Georgia), it was only discussed briefly in this report and not compared to other methods due to the inherent limitations.
- Automatic samplers can take and composite samples without crews onsite at sampling time, and can be controlled remotely with additional equipment, but have large capital, training, and O & M costs. These criteria make them a good fit for projects of long duration with consistent sampling locations, those requiring compositing to determine the most accurate assessment of a rainfall event's average discharge turbidity, and those for which it is difficult for crews to reach all locations in a timely and safe manner.
- In-situ water quality probes can record turbidity in near-continuous fashion and send this information electronically to e-mail or websites for wider accessibility in real-time if interfaced with communication equipment. They avoid sample transportation and analysis costs, but have high capital costs and require careful installation and maintenance (e.g., routine calibration and cleaning) to ensure that readings are not biased by fouling, excessive sedimentation, partially submerged sensors, or calibration drift. This makes them best suited to receiving water monitoring and projects in which there are strong needs for real-time or near-continuous feedback on erosion control and treatment practices.

Regardless of the technique chosen, accuracy is strongly affected by proper sample collection, handling, and analysis methods. Guidance manuals from states with significant experience in turbidity monitoring should be used in developing new monitoring programs. See Section 3.2 for guidance and additional resources on these topics.

Due to the inherent and extensive variability from site to site in construction projects, there is no simple prescriptive formula for developing an appropriate sampling program for a linear construction project. Several subjective decisions must be made when selecting sampling methods and equipment.

The first choice is to determine the sampling frequency and method to be used. The majority of linear construction projects will likely implement the regulatory minimum (if the site requires sampling), which is anticipated to be manual grab sampling at discharge locations three times per storm event during normal business hours, and will likely implement reactive measures, as stipulated by permits, if discharge turbidity exceeds numeric limitations. In the event that a site has chosen to implement a minimal sampling program in accordance with regulations, it is recommended to incorporate provisions for modifying the program with the inclusion of additional grab samples, or transitioning to an automated program if violations of turbidity standards are noted.

While automated sampling with flow-weighted averaging of turbidity is more costly than grab sampling, this approach decreases the likelihood of "false positive" violations of effluent limitations and reduces the chances of "false negatives" that hinder proper response to inadequate source or treatment controls on the site. Automated sampling programs are well suited for large and long-term construction projects that span multiple rainy seasons. Projects that discharge to sensitive receiving waters or cross multiple receiving waters should consider in-situ water quality probes. Remote communication equipment with these probes can enable a much faster response to turbidity problems in streams than can be accomplished with any other method. This combination should be applied in situations where repercussions for high turbidity in receiving waters are especially serious.

It is expected that regulators will continue to incentivize construction phasing that minimizes exposure of disturbed soils, as well as non-channelized discharge of stormwater through vegetated buffers. DOTs may be able to reduce or eliminate monitoring locations by using distributed sediment controls that prevent concentrated flow conditions. These distributed controls, when properly installed and combined with source controls, are typically more effective than "end of pipe" controls because flow depths, velocities, and erosive forces are reduced and the ability to infiltrate and filter surface flows is increased. Linear DOT construction sites, particularly in lower slope/grade areas may be conducive to using controls that produce diffuse discharges when the majority of down-gradient site boundaries are oriented along somewhat level ground and when sufficient right-of-way space exists.

Finally, it is also likely that regulations will continue to allow sampling of a subset of outfalls that are representative of the whole site, particularly for linear construction sites. While the regulatory criteria for accepting representative sites is limited, the key similarities between drainage areas that should be considered include the percent of exposed soils, type of construction activities, type and extent of erosion and sediment controls, and the expected stormwater flow rates. The ability of a DOT to utilize representative sites to reduce monitoring requirements may depend largely on how well this site information is presented to the permitting authority.

In summary, judicious planning can and does make a difference with regard to the performance of erosion and turbidity control and costs associated with implementation and monitoring. The fundamental concepts that should be considered with any construction stormwater management planning effort include:

- Prevent sediment from becoming entrained in stormwater by stabilizing or using temporary covering;
- Stage construction projects to minimize exposed soils;
- Disperse stormwater in non-channelized paths when possible;
- Choose representative sampling locations as allowed; and

- Select a sampling technique based on the site conditions, expected number of rainfall events during construction, duration of construction, availability of personnel, and monitoring goals.

Planners should consider all of these fundamental factors in the development of stormwater management and monitoring plans. Treatment and monitoring goals can be reached by implementing a variety of methods, but avoiding the discharge of turbid runoff and minimizing monitoring requirements in the first place can reduce stormwater management costs and potential permit violations.

5.3 Data Gaps and Research Needs

Turbidity effluent limits are non-existent in most states and are relatively new in the few states that have adopted standards. Because of this, research is needed on turbidity reduction technologies, particularly in regards to practices and costs for applications to construction site runoff. Certain aspects of turbidity reduction are very well understood because of the overlap with wastewater treatment and agricultural erosion control practices. This knowledge base provides a basic understanding of processes, which have been applied to the development and testing of treatment technologies for stormwater treatment. However, many of the existing technologies involved are proprietary, and sharing of research results and best practices is not always possible. Specific areas in need of research are listed below.

Field studies of rigorous conventional BMP implementation

- Fiber mulch effectiveness studies that evaluate turbidity. Many manuals recommend 2 tons per acre for wood and straw fiber mulches, which results in a half-inch thick covering for a bulk density of 60 lbs./cy. However, for some soils, slopes, and climates a thicker mulch layer (4 tons/acre or more) and/or the addition of a tackifier may be required to achieve high performance erosion control and resulting low turbidity discharges.
- Additional studies evaluating a combination of conveyance controls to reduce turbidity. For example, lined conveyances with fiber roll check dams appear to be much more effective at preventing high turbidity discharges than unlined conveyances with rock check dams. However, few studies have thoroughly tested a wide range of rainfall intensities and soil types.
- Enhanced sedimentation basin design performance studies. The use of baffles, settling tubes, and floating outlets has the potential to significantly improve sediment capture in temporary sedimentation basins. However, few studies have investigated the performance of these design enhancements for the treatment of construction site runoff.
- Additional studies on the effectiveness of controls (both sediment and erosion) on turbidity reduction.

Flocculant research

- Studies comparing the effectiveness of different synthetic and natural flocculants, especially those with limited use in this country (e.g., Moringa oleifera).
- Studies on flocculant effectiveness as a function of different soil characteristics.
- Further studies on how soil properties may affect the optimal pH range for specific flocculants.
- Additional third-party research on secondary effects of flocculants (i.e., toxicity) to develop reliable data for regulators to feel comfortable allowing the use of flocculants.

Cost Research on Chemical Treatment Systems

- Compilation of capital and O&M cost data from states/cities for different active treatment systems.
- Analysis of the cost factors for active treatment systems, particularly site parameters such as slope, soil type, layout/linearity of project, remoteness of site, mobilization/demobilization, duration of project and rainfall amount intensity, etc.
- Comparison of electrocoagulation with other active treatment system costs, especially as a function of runoff volume.
- Compilation of cost data in projects using non-chemical treatment techniques.
- Compilation of cost information on non-traditional flocculants, such as guar-derived products, Moringa oleifera seeds, mimosa bark extract, and valonia extract.
- In addition, sustainability factors could also be quantified (greenhouse gas emissions, life-cycle costs, etc.) for the various approaches to provide additional decision-making information.
- Evaluation of sludge generation quantities and disposal costs.

Flocculant Toxicity

- Studies testing the toxicity of construction site treated effluent in receiving waters.
- Compilation of data related to frequency of spills/overdosing of flocculant in chemical treatment systems.
- Toxicity of non-traditional flocculants such as guar-derived products, Moringa oleifera seeds, mimosa bark extract, and valonia extract.

Reliability of Various Treatment Systems

- Collection of data showing the number of discharges exceeding desired effluent quality of various systems, especially passive systems.
- Collection of data showing the corrective actions when effluent benchmarks were exceeded and their efficacy in lowering turbidity to effluent limitations.
- Collection of data on the mechanical reliability of active treatment systems.

Passive Treatment Dosing

- Assessment of the potential for overdosing with the New Zealand method, the toxicity implications of overdosing, and willingness of regulators to accept any risks involved.
- Pilot-scale testing of various passive dosing methods to determine how accurately they are providing the design dose, especially in widely fluctuating precipitation and runoff conditions.
- Investigation of causes of poor treatment performance for passive dosing compared with active treatment (dosing/mixing/other causes).
- Investigation of potential design modifications of the New Zealand method to compensate for factors other than rainfall intensity (e.g., using influent density to determine sediment loading).
- More side-by-side cost and performance comparisons of passive and active treatment technologies.

Turbidity Monitoring

- Additional accuracy and reliability evaluations of turbidity probes and stage samplers.
- Field comparison of discharge turbidity from nearly identical drainage areas to evaluate the magnitude of differences associated with random processes. This type of study could provide guidance on how different turbidity measurements may be, while still being representative of each other.
- Collection of data from transportation projects regarding costs of using each monitoring method. These costs should include expenses from management of projects, as well as training, equipment, and O&M costs.
- Research into stage sampler use in Georgia, where this technique is specifically allowed in regulations, specifically determining the prevalence of its use there, and experiences with it.
- Research into dispersion of stormwater on DOT projects to determine how commonly this is feasible, given limited rights-of-way and other restrictions imposed by local jurisdictions.
- Collection of field data showing the variation of stormwater turbidity as a function of time (first flush effect) vs. turbidity as a function of rainfall intensity on construction sites.
- Collection of field data on failure of samplers to obtain a valid sample given each of the sampling methods discussed in this document due to safety concerns, mechanical failures, electrical failures, coordination issues, etc.
- Field studies on automatic samplers to quantitatively assess the effects of sample tube intake velocity on turbidity for various classes of soils. This is especially important given the different types of pumps available for automatic samplers.
- Field studies assessing the impact of refrigeration & immediacy of analysis on turbidity changes in construction stormwater samples. Biological activity may be significantly different in stormwater than is collected in other environments. If so, are the requirements for refrigeration and analysis within 48 hours from EPA Method 180.1 still needed to prevent turbidity changes? Relaxation of these limits may improve cost effectiveness.
- Field studies quantifying the discrepancies of readings among various brands and models of turbidimeters for construction site runoff. Tests should represent a variety of soil types.
- Determination of the repeatability and reliability of the various sampling methods.

Arid Climate Issues

- Evaluate the economic, policy and natural environment consequences of setting turbidity limits for construction storm water run-off that is cleaner than what occurs naturally in stormwater runoff from undisturbed ground or in naturally turbid receiving waters.
- Produce guidance for selecting appropriate BMPs for arid climates where turbidity is naturally high and biota are adapted to turbid waters.

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References

Alaska Department of Environmental Conservation (2011). General Permit for Discharges from Large and Small Construction Activities. Retrieved from http://www.dec.state.ak.us/water/wnpspc/stormwater/docs/Final_2011_ACGP_%2820110519%29_w_app.pdf

Allhands, M. (2008). A Treatise on Turbidity and TSS. Water Online. Retrieved from http://www.orival.com/casestudies/Turbidity%20and%20TSS.pdf

American Public Health Association (2005). *Standard Methods for the Examination of Water and Wastewater, 21st Edition*. New York: Clesceri, L.S., Greenberg, A.E., and Eaton, A.D. (eds.). Published in conjunction with the American Water Works Association and the Water Environment Federation.

Anderson, C. W. (2005). Turbidity. *National Field Manual for the Collection of Water-Quality Data (TWRI Book 9)*. U.S. Geological Survey. Retrieved from http://water.usgs.gov/owq/FieldManual/Chapter6/Section6.7_v2.1.pdf

Arcadis (2008). *Boatyard Stormwater Treatment Technology Cost Analysis*. Retrieved from http://pugetsoundkeeper.org/files/Final_BoatyardCostAnalysis_062708.pdf

Arizona Department of Transportation (2009). *Stormwater Monitoring Guidance Manual for Construction Activities*. Retrieved from http://www.azdot.gov/inside_adot/OES/Water_Quality/Stormwater/PDF/storm_water_guidance_for_construction.pdf

ASTM International (2007). Standard Test Method for Determination of Turbidity above 1 Turbidity Unit (TU) in Static Mode (D7315-07a). Retrieved from http://www.astm.org/Standards/D7315.htm

Auckland Water Resources (2009). *Overview of the Effects of Residual Flocculants on Aquatic Receiving Environments* (Technical Publication 226). Auckland Regional Council. Retrieved from http://www.arc.govt.nz/albany/fms/main/Documents/Plans/Technical%20publications/201-250/TP226%20Overview%20of%20the%20effects%20of%20residual%20flocculants%20on%20aquatic%20receiving%20environments.pdf

Barrett, M. E., Kearney, J. E., McCoy, T. G., & Malina, J. F. (1995). *An Evaluation of the Use and Effectiveness of Temporary Sediment Controls* (CRWR Online Report No. 95-6). Center for Research in Water Resources. Retrieved from http://www.crwr.utexas.edu/reports/pdf/1995/rpt95-6.pdf

Barrett, M. E., Walsh, P. M., Malina, J. F., & Charbeneau, R. J. (1998). Performance of Vegetative Controls for Treating Highway Runoff. *Journal of Environmental Engineering, 124*(11).

Beca Carter Hollings & Ferner Ltd. (2003). TP90 Flocculation Guidelines (draft). Prepared for Auckland Regional Council.

Beca Carter Hollings & Ferner Ltd. (2004). *The Use of Flocculants and Coagulants to Aid Suspended Sediment Settlement in Earthworks Runoff - Trials, Methodology and Design* (Technical Publication 227). Prepared for Auckland Regional Council.

Benedict, A. H., Oliver, G., Franklin, R., & Devitt, R. (2004). Raising the Bar on Construction Stormwater Treatment. *Stormwater*. May-June. Retrieved from http://www.stormh2o.com/may-june-2004/construction-stormwater-treatment.aspx

Bhardwaj, A. K., McLaughlin, R. A., & Babcock, D. (2008). Energy Dissipation and Chemical Treatment Improve Stilling Basin Performance. *Transactions of the ASABE, 51*(5), 1645–1652.

Bolto, B. (1995). Soluble Polymers in Water Purification. *Prog. Polm. Science, 20*, 987–1041.

Brandstetter, E., & Camilleri, J. (2010, November 30). National Pollutant Discharge Elimination System (NPDES) General Permit 1200-C Renewal Evaluation Report. Oregon Department of Environmental Quality. Retrieved from http://www.deq.state.or.us/wq/wqpermit/docs/general/npdes1200c/1200CandCNEvalReport.pdf

Brzozowski, C. (2007, September). Nontraditional Stormwater Treatment: Innovative Methods. *Stormwater*. Retrieved from http://www.stormh2o.com/september-2007/runoff-uv-electrocoagulation.aspx

Bullock, G., Blazer, V., Tsukuda, S., & Summerfelt, S. (2000). Toxicity of Acidified Chitosan for Cultured Rainbow Trout (Oncorhynchus Mykiss). *Aquaculture, 185*, 273–280.

California Department of Transportation (2003a). *Caltrans Lake Tahoe Storm Water Treatment Pilot Project Jar Test Results and Summary Report Volume 1 of 3* (CTSW-RT-03-063.33.41) (p. 81). Retrieved from http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/_pdfs/tahoe/CTSW-RT-03-063/CTSW-RT-03-063.pdf

California Department of Transportation (2003b). *Stormwater Quality Monitoring Protocols* (CTSW-RT-03-109.51.42). Retrieved from http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/_pdfs/monitoring/CTSW-RT-03-105/CTSW-RT-03-105.pdf

California Department of Transportation (2008). *Treatment BMP Technology Report* (CTSW-RT-08-167.02.02). Retrieved from http://www.dot.ca.gov/hq/env/stormwater/annual_report/2008/annual_report_06-07/attachments/Treatment_BMP_Technology_Rprt.pdf

California Department of Transportation (2012a). *Construction Site Monitoring Program Guidance Manual* (No. CTSW-RT-11-255.11.01-F). Retrieved from http://www.dot.ca.gov/hq/construc/stormwater/Caltrans_Guidance_Manual_CD.pdf

California Department of Transportation (2012b). *Standard Operating Procedures for Manual Field Measurement of Turbidity* (CTSW-RT-11-255.11.02-F). Retrieved from http://www.dot.ca.gov/hq/construc/stormwater/Caltrans_SOPs_CD.pdf

California Environmental Protection Agency (2009). California Construction General Permit - Attachment F: Active Treatment System (ATS) Requirements. Retrieved from http://www.waterboards.ca.gov/water_issues/programs/stormwater/docs/constpermits/wqo_2009_0009_att_f.pdf

California Stormwater Quality Association (2011). Stormwater Best Management Practice Handbook: Construction. Retrieved from http://www.cabmphandbooks.com/

California Stormwater Quality Task Force (2001). *Construction Storm Water Sampling and Analysis Guidance Document*. Appendix C of the Construction BMP Handbook. Retrieved from http://www.cabmphandbooks.com/Documents/Construction/Appendix_C.pdf

Caltrans (n.d.). Erosion Control Toolbox - Caltrans EC Toolbox. Retrieved September 29, 2011, from http://www.dot.ca.gov/hq/LandArch/ec/index.htm

Carpenter, T. (2006). Proper Silt Fence Installation. *Land and Water*, *50*(2), 52–56.

City of Seattle. (2009). Stormwater Manual - Volume 2: Construction Control Technical Requirements Manual. Retrieved from http://www.seattle.gov/dpd/codes/dr/DR2009-16.pdf

Clear Water Compliance Services (2004). *Advanced Treatment Systems Overview*. Presented at the Conference on Advanced Treatment for Construction Sites. Retrieved from http://www.swrcb.ca.gov/water_issues/programs/stormwater/docs/advtreat/clearwatercompliance.pdf

Clear Water Compliance Services (2007). Comment Letter - Draft Construction Permit. Retrieved from http://www.swrcb.ca.gov/water_issues/programs/stormwater/docs/constpermits/comments/matt_hromatka.pdf

Currier, P. (2009). Amendment of the February 2, 2009 Guidance for BMP Inspection and Maintenance, and Turbidity Sampling and Analysis Plan for I-93 Expansion Project Water Quality Certification. State of New Hampshire Inter-Department Communication.

DADMAC HPV Committee (2004). Test Plan for Diallyldimethyl Ammonium Chloride (DADMAC). U.S. EPA. Retrieved from http://www.epa.gov/hpv/pubs/summaries/dialdime/c15208tp.pdf

Daligault, A., Meaudre, D., Arnault, D., Duc, V., Bardin, N., Aires, N., Biau, D., et al. (1999). Stormwater and Lamella Settlers: Efficiency and Reality. *Water Science and Technology*, *39*(2), 93–101.

De Rosemond, S. J., & Liber, K. (2004). Wastewater Treatment Polymers Identified as the Toxic Component of a Diamond Mine Effluent. *Environmental Toxicology and Chemistry*, *23*(9), 2234–42.

Ding, Y., Dresnack, R., & Chan, P. C. (1999). *Assessment of High-Rate Sedimentation Processes: Microcarrier Weighted Coagulation Jar Tests.* (EPA Internal Report No. EPA-600-X-99-033). Retrieved from http://www.epa.gov/nrmrl/pubs/600x99033/epa-600-x-99-033.pdf

Downing, J. (2005). Turbidity Monitoring. *Environmental Instrumentation and Analysis Handbook*.

Dungeness Environmental. (2010). ChitoVan Chitosan Lactate Cartridge. Retrieved from http://www.dungenessenviro.com/chitosancartridge.html

Edwards, T. K., & Glysson, G. D. (1999). Field Methods for Measurement of Fluvial Sediment. *Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 3, Applications of Hydraulics, Chapter C2*. U.S. Geological Survey. Retrieved from http://pubs.usgs.gov/twri/twri3-c2/pdf/TWRI_3-C2.pdf

Faircloth Skimmer (n.d.).*Faircloth Skimmer*. Retrieved April 24, 2012, from http://www.fairclothskimmer.com/index.html

Folkard, G., Sutherland, J., & Shaw, R. (2000). Water Clarification Using Moringa Oleifera Seed Coagulant. Water and Environmental Health at London and Loughborough. Retrieved from http://www.lboro.ac.uk/well/resources/technical-briefs/60-water-clarification-using-moringa-oleifera-seeds.pdf

Gao, B., Chu, Y., Yue, Q., Wang, B., & Wang, S. (2005). Characterization and Coagulation of a Polyaluminum Chloride (PAC) Coagulant with High Al13 Content. *Journal of Environmental Management*, *76*(2), 143–147.

Geosyntec Consultants (2008). *Evaluation of Active Treatment Systems (ATS) for Construction Site Runoff*. Prepared for California Building Industry Association.

Geosyntec Consultants and Wright Water Engineers (WWE) (2009). *Urban Stormwater BMP Performance Monitoring*. Prepared for the Water Environment Research Foundation (WERF) Retrieved from http://www.bmpdatabase.org/Docs/2009%20Stormwater%20BMP%20Monitoring%20Manual.pdf

Gray, J. R., Glysson, G. D., Turcios, L. M., & Schwarz, G. E. (2000). *Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data* (Water-Resources Investigations Report 00-4191). U.S. Geological Survey. Retrieved from http://www.jlakes.org/web/wrir00-4191.pdf

Green, V. S., & Stott, D. E. (1999). Polyacrylamide: A Review of the Use, Effectiveness, and Cost of a Soil Erosion Control Amendment. Presented at the 10th International Soil Conservation Organization Meeting, Purdue University. Retrieved from http://www.tucson.ars.ag.gov/isco/isco10/SustainingTheGlobalFarm/P046-Green.pdf

HaloSource. (2007). Water Treatment Professional’s Natural Treatment Solutions Manual. Retrieved from http://www.stormklear.com/sites/default/files/literature_48[2].pdf

Harmel, R. D., & King, K. W. (2005). Uncertainty in Measured Sediment and Nutrient Flux in Runoff from Small Agricultural Watersheds. *Transactions of the ASAE*, *48*(5). Retrieved from http://www.ars.usda.gov/SP2UserFiles/person/3013/King22.pdf

Harmel, R. D., King, K. W., Haggard, B. E., Wren, D. G., & Sheridan, J. M. (2006). Practical Guidance for Discharge and Water Quality Data Collection on Small Watersheds. *Transactions of the ASABE*, *49*(4). Retrieved from http://ddr.nal.usda.gov/bitstream/10113/222/1/IND43838985.pdf

Harmel, R. D., King, K. W., & Slade, R. M. (2003). Automated Storm Water Sampling on Small Watersheds. *Applied Engineering in Agriculture*, *19*(6), 667–674.

Harris, R. R., Sullivan, K., Cafferata, P. H., Munn, J. R., & Faucher, K. M. (2007). Applications of Turbidity Monitoring to Forest Management in California. *Environmental Management*, *40*, 531–543.

Hemmerlein, M. (2011, October 25). Personal conversation with Mark Hemmerlein, NHDOT Water Quality Program Manager.

Herrera Environmental Consultants. (2011). *Literature Review of Existing Treatment Technologies for Industrial Stormwater*. Retrieved from www.wastormwatercenter.org/file_viewer.php?id=448

Holt, P. K., Barton, G., Wark, M., & Mitchell, C. A. (2002). A Quantitative Comparison between Chemical Dosing and Electrocoagulation. *Colloids and Surfaces A: Physiochemical and Engineering Aspects*, *211*(2-3), 233–248.

Horner, R. R., Guedry, J., & Kortenhof, M. H. (1990). *Improving the Cost Effectiveness of Highway Construction Site Erosion and Pollution Control* (Washington State Department of Transportation Technical Report No. WA-RD 200.1) (p. 64). Washington State Transportation Center (TRAC). Retrieved from http://www.wsdot.wa.gov/research/reports/fullreports/200.1.pdf

Huang, C., & Chen, Y. (1996). Coagulation of Colloidal Particles in Water by Chitosan. *J. Chem. Tech. Biotechnology*, *66*, 227–232.

IDT. (2011). *Stormwater Management Plan (SWMP)*. Idaho Transportation Department. Retrieved from http://itd.idaho.gov/enviro/storm%20water/SW_Mgmt_Plan/

Jurries, D. (2001). Flocculation of Construction Site Runoff in Oregon. Retrieved from http://www.deq.state.or.us/wq/stormwater/docs/nwr/flocculation.pdf

Kang, J. H., Li, Y., Lau, S. L., Kayhanian, M., & Stenstrom, M. K. (2007). Particle Destabilization in Highway Runoff to Optimize Pollutant Removal. *Journal of Environmental Engineering*, *133*(4), 426–434.

Killelea, J., & Austin, L. (2005). *Stormwater Management Manual for Western Washington, Volume II*. Retrieved from http://www.ecy.wa.gov/pubs/0510030.pdf

Lande, S. S., Bosch, S. J., & Howard, P. H. (1979). Degradation and Leaching of Acrylamide in Soil. *Journal of Environmental Quality*, *8*(1), 133–137.

Lane, S. L., Flanagan, S., & Wilde, F. D. (2003). Selection of Equipment for Water Sampling. *National Field Manual for the Collection of Water-Quality Data (TWRI Book 9)*. U.S. Geological Survey. Retrieved from http://water.usgs.gov/owq/FieldManual/Chapter2/Chapter2_V2uncompressed.pdf

Lauro, F. J., & Theisen. (2006). Spray Solutions: Performance-based Classification System Simplifies Selection of Hydraulically Applied Erosion Control Materials. *CE News*, *August*. Retrieved from http://www.cenews.com/magazine-article----spray_solutions-4531.html

Lea, M. (2010). Bioremediation of Turbid Surface Water Using Seed Extract from Moringa oleifera Lam. (Drumstick) Tree. *Current Protocols in Microbiology*. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/9780471729259.mc01g02s16/pdf

Li, Q., & Kegley, L. (2005). Assessing the Effectiveness and Environmental Impacts of Using Natural Flocculants to Manage Turbidity. Retrieved from http://www.oregon.gov/ODOT/TD/TP_RES/docs/Reports/AssessingTheEffectAndEnvir.pdf

Los Alamos National Laboratory. (2005). *Field Water Quality Analyses* (ENV-DO-203, R0). Retrieved from http://permalink.lanl.gov/object/tr?what=info:lanl-repo/eprr/ERID-205434

MacPherson, J. (2004). StormKlear (Chitosan) Toxicity and Applications: Construction Stormwater Treatment. Sacramento, CA. Retrieved from http://www.swrcb.ca.gov/water_issues/programs/stormwater/docs/advtreat/naturalsitesolutions.pdf

MacPherson, J. (2011). *Managing Construction Stormwater in the Northwest*. Presented at the NEBC Stormwater Conference, Seattle, WA. Retrieved from http://www.nebc.org/Documents/Stormwater11/3B-Macpherson.pdf

McDade, R. (2011). *ELG Field Demonstration Report - Draft*. Colorado Department of Transportation.

McLaughlin, R. A. (2002). *Measures to Reduce Erosion and Turbidity in Construction Site Runoff* (Research Project Report No. FHWA/NC/2002-023) (p. 131). North Carolina Department of Transportation.

McLaughlin, R. A. (2005). Soil Facts: Using Baffles to Improve Sediment Basins. North Carolina Cooperative Extension. Retrieved from http://www.soil.ncsu.edu/publications/Soilfacts/AGW-439-59/AGW_439_59.pdf

McLaughlin, R. A. (2011). *Turbidity Control*. Presented at the Clear Water Alabama Field Day and IECA Roadshow. Retrieved from http://swcc.alabama.gov/pdf/Presentations%20for%20ICEA/12%20Turbidity%20Control,%20Richard%20A.%20%20McLaughlin,%20Ph.D..pdf

McLaughlin, R. A., & Bartholomew, N. (2007). Soil Factors Influencing Suspended Sediment Flocculation by Polyacrylamide. *Soil Sci. Soc. Am. Journal*, *71*, 537–544.

McLaughlin, R. A., King, S. E., & Jennings, G. D. (2009). Improving Construction Site Runoff Quality with Fiber Check Dams and Polyacrylamide. *Journal of Soil and Water Conservation*, *64*(2), 144–154. doi:10.2489/jswc.64.2.144

McLaughlin, R. A., & McCaleb, M. M. (2010). Passive Treatment to Meet the EPA Turbidity Limit. Presented at the TMDL 2010: Watershed Management to Improve Water Quality, Baltimore, MD: ASABE.

McLaughlin, R. A., & Zimmerman, A. (2009). *Best Management Practices for Chemical Treatment Systems for Construction Stormwater and Dewatering* (FHWA-WFL/TD-09-001) (p. 12). Retrieved from http://www.wfl.fhwa.dot.gov/programs/td/publications/documents/cts-booklet.pdf

MDE. (2009). *2010 Maryland Standards and Specifications for Soil Erosion and Sediment Control*. Maryland Department of the Environment, Water Management Administration. Retrieved from http://www.mde.state.md.us/assets/document/sedimentstormwater/MD_ESC_Standards_10-15-09_DRAFT_III.pdf

Millen, J. A., Jarrett, A. R., & Faircloth, J. W. (1997). Experimental Evaluation of Sedimentation Basin Performance for Alternative Dewatering Systems. *American Society of Agricultural Engineers*, *40*(4), 1087–1095.

Mothersbaugh, T. J. (2011a, November 29). Technology Profile for WaveIonics System from Water Tectonics.

Mothersbaugh, T. J. (2011b, November 30). Personal communication.

National Research Council. (2008). *Urban Stormwater Management in the United States*. Retrieved from http://www.epa.gov/npdes/pubs/nrc_stormwaterreport.pdf

NRCS. (2011). Silt Fence Fact Sheet | Wyoming NRCS. Retrieved October 4, 2011, from http://www.wy.nrcs.usda.gov/technical/ewpfactsheets/siltfence.html

Nwankwo, K. N. (2001). *Polyacrylamide as a Soil Stabilizer for Erosion Control* (WI 06-98). Wisconsin Department of Transportation. Retrieved from http://wisdotresearch.wi.gov/wp-content/uploads/wi-06-98polyacryl1.pdf

Oregon DEQ. (2005). *Erosion and Sediment Control Manual*. Retrieved from http://www.deq.state.or.us/wq/stormwater/docs/escmanual/manual.pdf

Oregon DEQ. (2010). General Permit National Pollutant Discharge Elimination System Stormwater Discharge Permit (1200-C). Retrieved from http://www.deq.state.or.us/wq/wqpermit/docs/general/npdes1200c/permit.pdf

Ozocar, M., & Sengil, I. A. (2002). The Use of Tannins from Turkish Acorns (Valonia) in Water Treatment as a Coagulant and Coagulant Aid. *Turkish J. Eng. Env. Sci.*, *26*, 255–263.

Peters, J. (2011). *Stormwater Turbidity Sampling on TDOT Projects*. Presented at the Clear Water Alabama/IECA Roadshow. Retrieved from http://swcc.alabama.gov/pdf/Presentations%20for%20ICEA/8%20TDOT%20Turbidity%20Sampling%20on%20TDOT%20Projects,%20Janette%20Peters,%20PE,%20CPESC,%20CPSWQ.pdf

Pitt, R., Clark, S., Johnson, P. D., Morquecho, R., Gill, S., & Pratap, M. (2004). High Level Treatment of Stormwater Heavy Metals. *World Water and Environmental Resources Conference 2004*. Salt Lake City, UT.

Pitt, R., Clark, S., & Lake, D. (2007). *Construction Site Erosion and Sediment Controls: Planning, Design, and Performance*. Lancaster, PA: DEStech Publications.

Pitt, R., Robertson, B., Barron, P., Ayyoubi, A., & Clark, S. (1999). *Stormwater Treatment at Critical Areas: The Multi-Chambered Treatment Train (MCTT)* (EPA/600/R-99/017). U.S. EPA. Retrieved from http://www.epa.gov/nrmrl/pubs/600r99017/600r99017.htm

Protech General Contracting Services. (2004, July). Polymer Coagulants and Flocculants for Stormwater Applications. Retrieved from http://www.protechgcs.com/Library/TR01.1-electronic.pdf

Randerson, T. J., Fink, J. C., Fermanich, K. J., Baumgart, P., & Ehlinger, T. (2005). *Total Suspended Solids-Turbidity Correlation in Northeastern Wisconsin Streams*. Presented at the AWRA - Wisconsin Section Meeting, Delavan, WI. Retrieved from https://www.uwgb.edu/watershed/student/activities/Presentations/AWRA_Randerson.pdf

Rath, S., & Singh, R. (1997). Flocculation Characteristics of Grafted and Ungrafted Starch, Amylose, and Amylopectin. *Journal of Applied Polymer Science*, *66*, 1721–1729.

Rice, R. M., Ziemer, R. R., & Lewis, J. (2004). Evaluating Forest Management Effects on Erosion, Sediment, and Runoff: Caspar Creek and Northwestern California. *A Century of Forest and Wildland Watershed Lessons.* Bethesda, MD: Society of American Foresters. Retrieved from http://www.fs.fed.us/psw/publications/rice/riceSAF.pdf

Rounce, D. R., Eck, B. J., Lawler, D., & Barrett, M. E. (2011). Reducing Turbidity of Construction Site Runoff: Coagulation with Polyacrylamide. Transportation Research Board Annual Meeting 2012 Paper #12-1250.

SCDOT. (2008). *Supplemental Technical Specifications*. South Carolina Department of Transportation. Retrieved from http://www.scdot.org/doing/sup_tech_specs.shtml

Sharma, B. R., Dholdhoya, N. C., & Merchant, U. (2006). Flocculants - An Ecofriendly Approach. *J. Polym. Environ.*, *14*, 195–202.

Sojka, R. E., & Lentz, R. D. (1996). A PAM primer: A brief history of PAM and PAM-related issues. *Managing Irrigation-Induced Erosion and Infiltration with Polyacrylamide.* (pp. 11–20). University of Idaho. Miscellaneous Publication No. 101-96. Retrieved from http://eprints.nwisrl.ars.usda.gov/1194/1/914.pdf

South Dakota Department of Transportation. (2010). Special Provision for Construction Practices in Streams Inhabited by the Topeka Shiner. Retrieved from http://sddot.com/transportation/highways/environmental/endangered/docs/topekashiner.pdf

Spotts, J. W. (2011). *Turbidity Sampling of Runoff from Construction Sites*. Presented at the Clear Water Alabama/IECA Roadshow. Retrieved from http://swcc.alabama.gov/pdf/Presentations%20for%20ICEA/Turbidity%20Sampling,%20James%20Spotts.pdf

Spry, D. J., & Wiener, J. G. (1991). Metal Bioavailability and Toxicity to Fish in Low-Alkalinity Lakes: A Critical Review. *Environmental Pollution*, *71*(2-4), 243–304.

Stevens, E., Barfield, B. J., Britton, S. L., & Hayes, J. S. (2004). *Filter Fence Design Aid for Sediment Control at Construction Sites* (EPA/600/R-04/185). U.S. EPA, Office of Research and Development. Retrieved from http://www.epa.gov/nrmrl/pubs/600r04185/600r04185.pdf

Strecker, E. (2011). *Minimizing the Potential for Sediment Recontamination and Associated Liability from Stormwater System Sources*. Presented at the Managing Stormwater in the Northwest, Seattle, WA. Retrieved from http://www.nebc.org/Documents/Stormwater11/2A-Strecker.pdf

Strecker, E., Huber, W., Heaney, J., Bodine, D., Sansalone, J., Quigley, M., Leisenring, M., et al. (2005). *Critical Assessment of Stormwater Treatment and Control Selection Issues* (WERF 02-SW-1). Water Environment Research Foundation.

Strecker, E., Mayo, L., Quigley, M., & Howell, J. (2001). *Guidance Manual for Monitoring Highway Runoff Water Quality* (FHWA-EP-01-021) (p. 206). Federal Highway Administration. Retrieved from http://www.environment.fhwa.dot.gov/ecosystems/h2o_runoff/h2oroff.pdf

Sutherland, J., Folkard, G., Mtawali, M., & Grant, W. D. (1994). Moringa Oleifera as a Natural Coagulant (pp. 297–299). Presented at the Affordable Water Supply and Sanitation, Colombo, Sri Lanka. Retrieved from http://www.miracletrees.org/Moringa%20Documenten/sutherla.pdf

Taylor, M. (2002). *Mechanisms of Flocculant Action on Kaolinite Clay* (DocPhDApSc). University of South Australia.

Tchobanoglaus, G., Burton, F. L., & Stensel, H. D. (2003). *Wastewater Engineering - Treatment and Reuse*. Boston, MA: Metcalf & Eddy, McGraw-Hill Companies, Inc.

TxDOT. (2011). Research Program Addendum FY 2011. Research and Technology Implementation Office, Texas Department of Transportation. Retrieved from ftp://ftp.dot.state.tx.us/pub/txdot-info/rti/2011_addendum.pdf

U.S. Army Corps of Engineers. (2001). *Engineering and Design - Precipitation/Coagulation/Flocculation*. Retrieved from http://140.194.76.129/publications/eng-manuals/em1110-1-4012/toc.htm

University of Minnesota. (2011). CTS - Research Projects: Development and Evaluation of Effective Turbidity Monitoring Methods for Construction Projects. Retrieved from http://www.cts.umn.edu/Research/ProjectDetail.html?id=2011108

USEPA. (1992). *National Pollutant Discharge Elimination System Stormwater Sampling Guidance Document* (EPA 833-B-92-001). Retrieved from http://www.epa.gov/npdes/pubs/owm0093.pdf

USEPA. (1993). Determination of Turbidity by Nephelometry. Retrieved from http://water.epa.gov/scitech/methods/cwa/bioindicators/upload/2007_07_10_methods_method_180_1.pdf

USEPA. (2003). Chitosan; Poly-D-glucosamine (128930) Fact Sheet. Retrieved from http://www.epa.gov/oppbppd1/biopesticides/ingredients/factsheets/factsheet_128930.htm

USEPA. (2007). *Developing Your Stormwater Pollution Prevention Plan - A Guide for Construction Sites* (EPA-833-R-06-004). U.S. EPA. Retrieved from http://www.epa.gov/npdes/pubs/sw_swppp_guide.pdf

USEPA. (2009a). *Development Document for Final Effluent Guidelines and Standards for the Construction and Development Category* (p. 266). Retrieved from http://water.epa.gov/scitech/wastetech/guide/construction/upload/2009_12_8_guide_construction_files_chapters.pdf

USEPA. (2009b). Effluent Limitations Guidelines and Standards for the Construction and Development Point Source Category; Final Rule, Docket ID # EPA–HQ–OW–2008–0465. Retrieved from http://edocket.access.gpo.gov/2009/pdf/E9-28446.pdf

USEPA. (2010). Effluent Limitations Guidelines and Standards for the Construction and Development Point Source Category Docket ID # EPA-HQ-OW-2010_0884. Retrieved from http://edocket.access.gpo.gov/2010/pdf/2010-28033.pdf

USEPA. (2011a). Construction and Development. Retrieved from http://water.epa.gov/scitech/wastetech/guide/construction/index.cfm

USEPA. (2011b). Regulatory Development and Retrospective Review Tracker: Effluent Guidelines and Standards for the Construction and Development Industry - Revision. Retrieved from http://yosemite.epa.gov/opei/rulegate.nsf/byRIN/2040-AF27#1

USEPA. (2011c). National Pollutant Discharge Elimination System General Permit for Discharges from Construction Activities (Proposed Construction General Permit). Retrieved from http://www.epa.gov/npdes/pubs/cgp_proposed.pdf

USEPA. (2011d). Whole Effluent Toxicity. Retrieved from http://water.epa.gov/scitech/methods/cwa/wet/index.cfm

USEPA. (2011e). Basic Information about Acrylamide in Drinking Water. Retrieved from http://water.epa.gov/drink/contaminants/basicinformation/acrylamide.cfm

USEPA. (2012a). National Pollutant Discharge Elimination System General Permit for Discharges from Construction Activities. Retrieved from http://www.epa.gov/npdes/pubs/cgp2012_finalpermit.pdf

USEPA. (2012b). Effluent Limitations Guidelines and Standards for the Construction and Development Point Source Category. Retrieved from http://www.gpo.gov/fdsys/pkg/FR-2012-01-03/pdf/2011-33661.pdf

Veolia Water Solutions and Technologies. (2010). Actiflo. Retrieved from http://www.krugerusa.com/en/files/5113.htm

Virginia Department of Conservation and Recreation. (2002). *Application of Anionic Polyacrylamide for Soil Stabilization and Stormwater Management* (Erosion & Sediment Control Technical Bulletin #2). Retrieved from http://www.dcr.virginia.gov/stormwater_management/documents/anoinic.pdf

Wagner, R. J., Boulger, R. W., Oblinger, C. J., & Smith, B. A. (2006). *Guidelines and Standard Procedures for Continuous Water-Quality Monitors - Station Operation, Record Computation, and Data Reporting* (U.S. Geological Survey Techniques and Methods 1-D3). Retrieved from http://pubs.usgs.gov/tm/2006/tm1D3/pdf/TM1D3.pdf

Wanielista, M. P., Yousef, Y. A., Van DeGroaff, L. M., & Rehmann-Koo, S. H. (1986). *Best Management Practices - Enhanced Erosion and Sediment Control Using Swale Blocks* (Florida Dept. of Transportation in cooperation with the Federal Highway Administration No. FL/DOT/BMR-85-293) (p. 49). University of Central Florida.

Washington Department of Ecology. (2010). Construction General Permit. Retrieved from http://www.ecy.wa.gov/programs/wq/stormwater/construction/permitdocs/cswgppermit120110.pdf

Washington State Department of Ecology. (2006). *How to do Stormwater Monitoring: A Guide for Construction Sites* (06-10-020). Retrieved from http://www.eco-3.com/manuals/DOE_Guide_to_SW_Monitoring.pdf

Washington State Department of Ecology. (2008, January). Use Designations for Erosion and Sediment Control for Chitosan-Enhanced Sand Filtration using StormKlear™ LiquiFloc™. Retrieved from http://www.ecy.wa.gov/programs/wq/stormwater/newtech/use_designations/LiquiFlocGUD012208.pdf

Washington State Department of Ecology. (2010, March). General Use Level Designation for Erosion and Sediment Control for Water Tectonics’ Wave Ionics Electrocoagulation Subtractive Technology. Retrieved from http://www.ecy.wa.gov/programs/wq/stormwater/newtech/use_designations/WTECCUD31008.pdf

Washington State Department of Transportation. (2010). *Highway Runoff Manual* (M 31-16.02). Retrieved from http://www.wsdot.wa.gov/publications/manuals/fulltext/M31-16/HighwayRunoff.pdf

Waste & Environmental Technologies, Ltd. (2011). WetSep Water and Wastewater Filtration. Retrieved from http://wetsep.com/WetSep_overview.php

Water at Lakeside. (2005, September). Cleaning the Water at Lakeside. Forester. Retrieved from http://www.stormh2o.com/SW/Articles/84.aspx

WisDOT. (2010). *Erosion Control Product Acceptability Lists (PAL)*. Wisconsin Department of Transportation. Retrieved from http://www.dot.wisconsin.gov/business/engrserv/docs/pal.pdf

Wood, J., Dhanvantari, S., Yang, M., Rochfort, Q., Chessie, P., Marsalek, J., Kok, S., et al. (2004). Feasibility of Stormwater Treatment by Conventional and Lamellar Settling with and without Polymeric Flocculant Addition. *Water Quality Resources Journal of Canada*, *39*(4), 406–416.

Appendix A. NCHRP 25-25(74) DOT Survey Results

A-1. Methodology

First draft surveys were produced in July 2011 and distributed to the NCHRP project officer and panel for review and comment. Subsequently, the survey was reduced in size and split in two (see Attachments A-1 and A-2). Both surveys were distributed to AASHTO Water Quality Community of Practice Members, who had a month to complete the survey. The first, shorter survey, conducted in August, garnered responses by two-thirds of DOTs. The second survey conducted in September solicited more detailed information from the DOTs, expecting participation by a smaller set. Twenty-three DOTs participated in the second survey. In three states, more than one person completed the survey; the responses here control for these duplications and sometimes conflicting answers. A map showing states responding is shown in Figure A-1. The survey responses frequently represent the efforts of teams of people on the state level, in the one response typically provided by each state. The effort involved in this survey was large and reflects the commitment and desire of all those serving in the water quality arena at DOTs to improve processes and share insights and lessons learned.

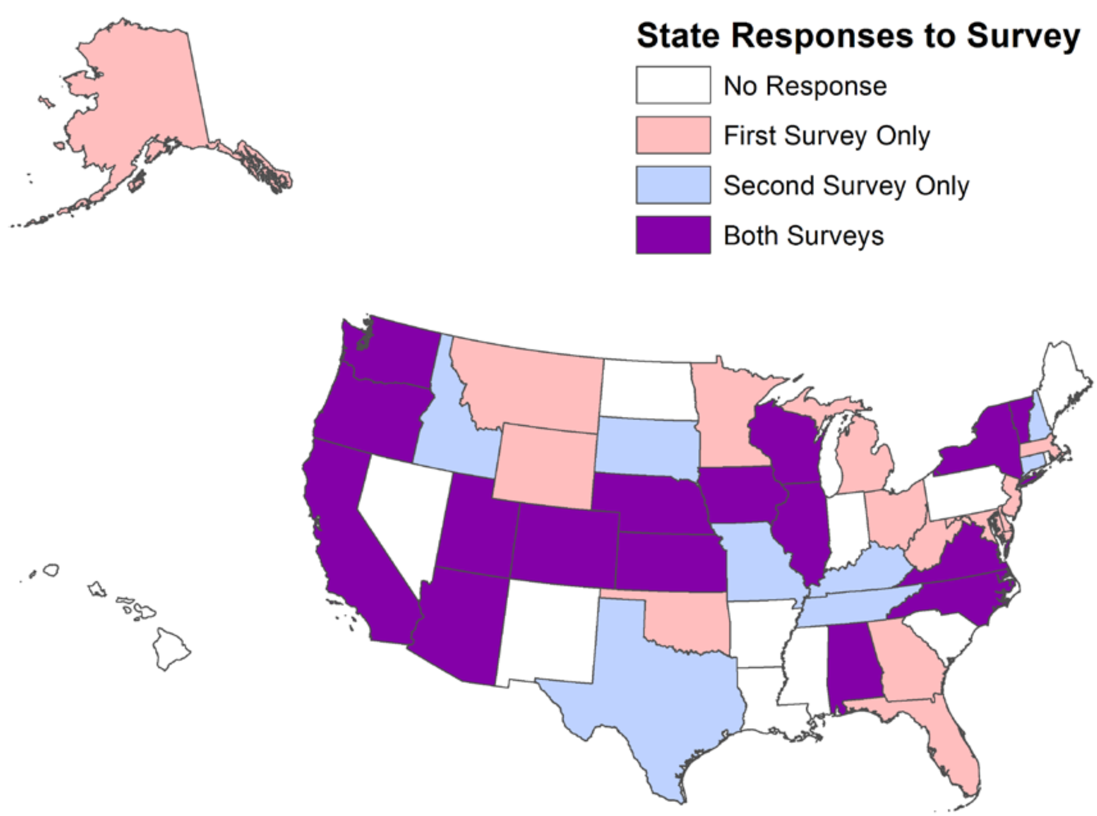

Figure A-1. States Responding to First and Second NCHRP Surveys

A-2. What Turbidity Reduction Technologies Have Been Reported to Work

In the first survey (Attachment A-1), with responses by two-thirds of state DOTs, respondents noted what they considered to be the primary factors in successful erosion and sediment control and turbidity prevention at their agencies; such programs may be models for others. As summarized in Figure A-2, respondents were able to check all program areas that applied, and 97% of respondents identified BMP implementation and 90% noted BMP maintenance. This was followed by enforcement of BMP implementation and maintenance (77% of respondents: AK, AL, CA, CO, DE, FL, GA, IA, IL, KS, MD, MI, MT, NE, OH, OK, VA, UT, WA, WV). The following states (38%) said they regularly implement measures for noncompliance (AL, CO, GA, IL, KS, MD, NE, VA, WA, WV).

Around 50% identified agency priority (53%) and agency leadership (47% - AK, AL, CA, GA, IL, KS, MD, MI, NE, OK, OR, VA, VT, WV) as primary factors in successful erosion and sediment control (ESC) and turbidity prevention. In some cases, upper level managers have performance metrics related to construction site ESC performance and monitoring. Smaller numbers identified phasing rules (30% - AK, AL, DE, IA, KS, NE NY, OK, VT), incentives for agency staff to enforce or use the penalties at hand (10% - AK, OK, VT), and use of flocculants (10% - only KS, NC, OK).

Four percent had other responses:

- Training inspectors to enforce contract provisions regarding erosion control (WA)
- Training and internal tools for WSDOT design staff to develop contractually enforceable SWPPPs (WA)
- Training targeted at direct and practical solutions for erosion and sediment control (CA)
- Modeling software: RUSLE2 (CA)
- Good plans for contractors to implement and proper money to do the work (MN)
- Incentives or damages based upon surprise inspections at least every 2 weeks (MD)

Over half of respondents indicated elements they thought had made their construction stormwater compliance (and turbidity prevention) program particularly effective. These elements are summarized below. Again, states are listed so that their model programs can serve as resources to others.

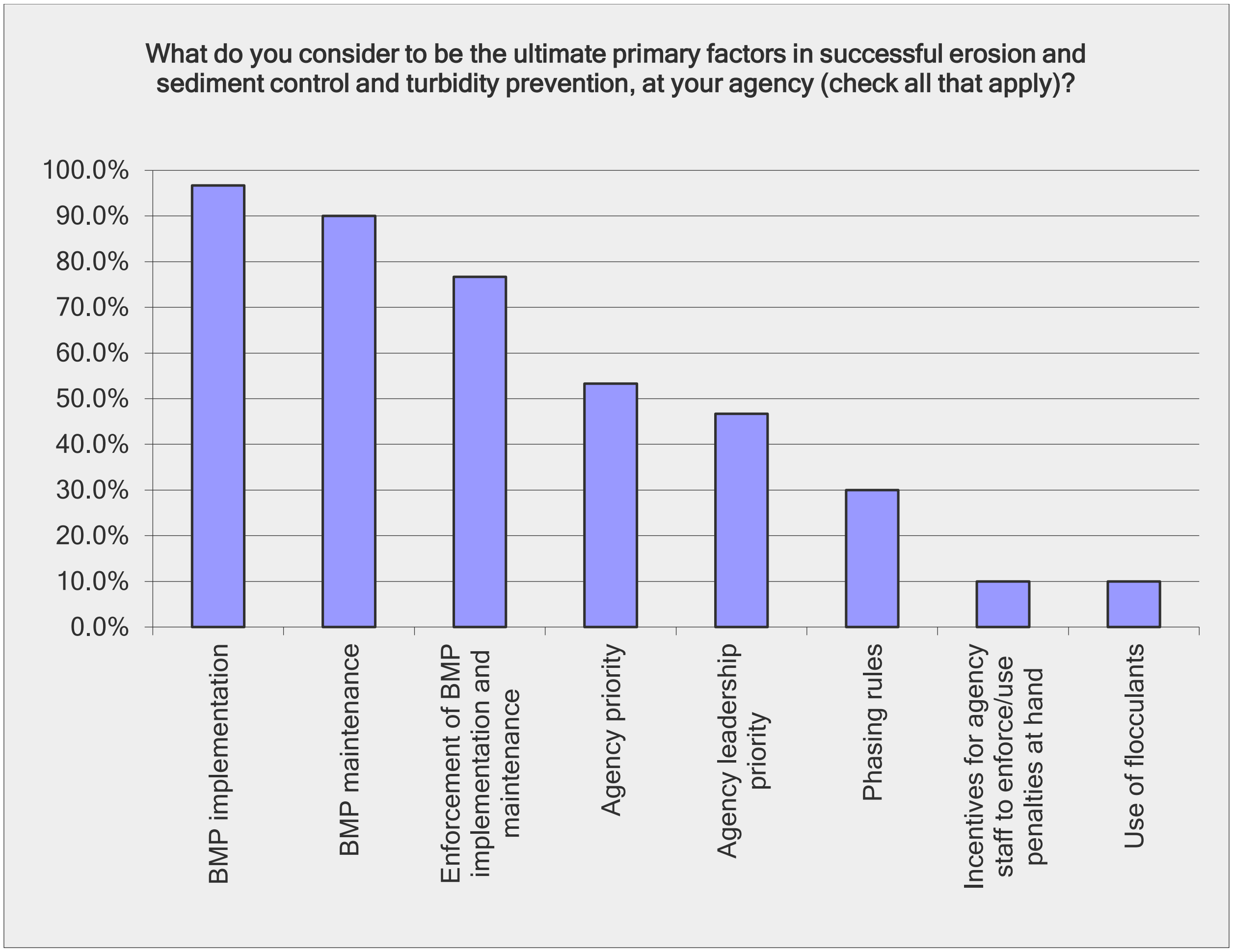

Figure A-2. Factors shown to be successful in DOT erosion and sediment control prevention

Quality Inspections, Tracking, & Consequences/Enforcement

Inspection (Including Inspector Training) and Tracking Results

- Training of the DOT's environmental field inspectors (WA)
- Certified Erosion and Sediment Control Owner and Contractor Inspectors, and specific ESC inspection schedules (VA)
- Daily inspections by the contractor, bi-weekly inspections by the Project ECS, and monthly inspections by the DOT Water Pollution Control Manager (CO)
- Multiple levels of review for compliance, by both the State and Contractors (AK)
- Quality Assurance Programs for independent inspection of construction sites (MD)
- Internal databases for discharge monitoring and reporting (WA)

Consequences and Enforcement for Non-Compliance

- Penalties for non-compliance (CO)
- Projects are subject to incentives for high ratings and liquidated damages for poor ratings (MD). CA also uses liquidated damages.
- Enforcement by EPA and consent decree requirements (AK)
- Improved methods of contract enforcement (WA)
- The regulator is the determining factor (GA)

Permitting & Contracting Arrangements

- DOT and contractor are co-permittees (OH)
- Contractor develops SWPPP after contract is sold (OH)
- State DOT pays for needed ESC remediation work (WA)

Cultural Change/Organizational Priority

- Change in culture & management techniques, leadership buy-in and promotion (AL)
- Proactive engineer in charge (VT)
- Chief Engineer's Performance Measure (CO)

Site-based practices

- Minimizing disturbed area and stabilizing as you go, which has been difficult for contractors to accept (NE)
- Use of compost (OR) – shared at Oregon Environmental meeting

DOT Regulations, Guidance & Training

- DOT's plans, standard specifications, and compliance with state laws and regulations (DE)
- DOT erosion/sediment control training program that serves staff, contractors, and consultants (CA, OR, UT)
- Yearly training for state personnel and consultants (AK)
- State regulations for erosion and sediment control and water quality (NC)
- 72-hour stockpile requirement (CA)
- NPDES Construction General Permit, Section 401 WQ Certifications (CA)

With regard to training, on the follow-up survey, 78% of responding DOTs indicated that they (or their state permits) require formal training and certification related to permit compliance. In some cases, training is internal only, with no professional certification. Over 90% of DOTs provide construction stormwater training internally to staff. In addition to training their own inspectors and engineers, 70% of responding DOTs train contractors as well; states offering such training include: CA, CO, IA, ID, KS,

MO, NC, NE, NH, NY, SD, TX, UT, VA, VT, and WI. NCDOT offers a two-day certification course, with one day in class and one day in the field. In other states, contractors and construction inspectors are required to take a 4-hour training session created by the state DEQ. In another state, statutes identify that annual erosion control training is provided, but no specifics or attendance requirements are identified. In other cases, the DOT requires Erosion Control Supervisors to receive training, which the DOT may certify. Iowa, Maryland, North Carolina, and Virginia are among those requiring certification.

Seventy percent (70%) of responding state DOTs certify contractors or others to do the training. Iowa offers web-based training developed by the DOT. In Illinois, training is conducted by the University of Illinois and the Corps of Engineers Construction Engineering Research Laboratory; new training is currently under development. Oregon DOT indicated that contractor certification was not at the same level as internal staff certification. Some state DOTs avoid such discrepancies by providing the training themselves (e.g., NY, UT, WI) or having the DNR or DEQ do so.

A-3. PAM/Flocculant Use & Guidance

No state mentioned flocculant use as a factor that had made their construction stormwater compliance and turbidity prevention particularly effective on an overall basis; however, over half of responding states (54%) have used enhanced coagulation or flocculation technologies (e.g., chitosan, polyacrylamides (PAMs), alum, or electrocoagulation) at construction sites.

Flocculant use is still in the experimental stages in many states; less than a third of respondents (30%) to the initial survey had approved or developed any specifications for usage or conducted research related to use of flocculants or PAMs at construction sites (including hydraulic application of PAM as a component in hydraulic slurries applied for erosion control and revegetation). In that initial survey, those indicating they have specifications or research on flocculant/PAM use (30%) included the following states: AL, CA, GA, MD, MN, NC, NY, VT, WA, and WI.

Approvals for PAMs

The more in-depth follow-up survey provided greater detail on approvals for PAMs, which are in process at many state DOTs. Arizona DOT, Illinois DOT, and TxDOT said PAM was allowed by their state but not used by the DOT. MoDOT said it is “frowned upon” by their Department of Natural Resources, but not forbidden.

- A small number of states said that PAM was disallowed as a component in hydraulic slurries (or in other form) for erosion and sediment control (CO, IA, ID, NE, UT, VA).
- 30% of states had approval procedures for these PAM-based products. 43% did not. The rest of the respondents left this question blank indicating many of the respondents may not know.

Two states provided links to specs:

Wisconsin provided a link to their process for approving PAMs:

- http://roadwaystandards.dot.wi.gov/standards/stndspec/Sect628.pdf (Standard Specifications, Section 628 Erosion Control)

- 10-10-47 in http://roadwaystandards.dot.wi.gov/standards/fdm/10-10.pdf Wisconsin DOT Facilities Development Manual – See section 10-10-47, Soil Stabilizer, Type B

Specifications for PAM-Based Products

Nearly 40% of responding states have specifications for PAM-based products; these include: AL, CA, MO, NC, NH, TN, TX, WA, and WI. TxDOT has a process to test, approve, and specify erosion control products, but those procedures don't distinguish between products that contain PAM and those that don't.

Two states provided links to specs:

- Oregon: www.oregon.gov/ODOT/HWY/SPECS/docs/08book/08_00200.pdf (2008 Construction Standard Specifications – very limited detail)
- Wisconsin: http://www.dot.wisconsin.gov/business/engrserv/docs/pal.pdf (Wisconsin DOT Erosion Control Product Acceptability Lists for Multi-Modal Applications – Good detail in Soil Stabilizers section – Type B stabilizer). Wisconsin DNR also provides significant guidance on approval, application criteria, and other PAM use guidelines at: http://dnr.wi.gov/runoff/pdf/stormwater/techstds/erosion/dnr1050-polyacrylimide.pdf.

PAM-based Products Being Used by DOTs

The following PAM-based products are being used by the nearly half of 23 state DOTs that responded to the in-depth survey.

- 39% are using PAM in tackifiers in combination with other measures; (e.g., mulch, etc.) (CA, MO, NH, NY, OR, SD, TN, WA, and WI).
- 35% are using PAM in hydroseeding/revegetation mixes (CA, KS, KY, MO, NH, OR, TN, VT, and WI).
- 26% are using PAM in tackifier without other measures (MO, NH, SD, TN, WA, and WI).
- 13% are using PAM in dust suppression (CA, OR, and SD).
- NC said they are applying PAM to wattles for introduction into stormwater runoff.
- NY said they are using PAM in active treatment systems, for effluent from sediment basins.
- TX said some of the approved erosion control products contain PAM, but they are not typically specified as having PAM.

A-4. Phasing & Source Control Methods

A majority of DOT respondents have design practices, standard specifications and/or contractual requirements to address the timing and size of disturbance, as an erosion and sedimentation control and turbidity prevention measure. In particular, most (50%+) of respondents in the initial survey (2/3 of DOTs participating) indicated their agencies are:

- Requiring stabilization if work is not continuously active from grubbing through placement of seed and final slope protection (AL, DE, GA, IL, KS, MD, MN, NC, OK, VA, VT, WA, WI, and WV)
- Limiting area that can be disturbed (unstabilized) at one time (AL, AK, AZ, CO, DE, FL, GA, KS, MD, MN, MT, NE, NJ, WA, and WV)
- Designating general sequence of construction activities in SWPPP and designating BMPs associated with each phase of construction
- Identifying measures (e.g., penalties, fines, reporting to permitting agencies, etc.) for non-compliance
- Considering work as being started with grubbing and completed when the specified cover material is applied, or final stabilization is otherwise in place.

Others state DOTs indicated they are:

Scheduling Projects to Minimize Runoff

- Scheduling projects so that major soil disturbance and mass grading activities occur during periods with lower expected runoff or precipitation (15% - ID, NH, OR, TN, WA), usually in the summer or April – September.
  - In Tennessee, select projects may not allow disturbance January – March.
  - California, New Hampshire, Oregon, and Washington State (13%) perform risk assessments ahead of seasons with pronounced heavy runoff to identify projects that may need extra attention or effort to maintain compliance.
  - Caltrans indicated that they assign risk based on sediment yield and receiving water sensitivity and implement Rain Event Action Plan in appropriate areas.
- Limiting the size of the work area by the grading, seeding, and final slope protection the contractor can complete within a defined timeframe (AK, KS, MA, MD, MN, NC, NE, NJ, and VA). This may also be considered in the following category.

Regulating the Limits of Disturbance (LOD)

- Establishing a goal of limiting disturbances to 5 acres at any one time (NY). In contrast, Tennessee allows “only 25 acres on some projects” and Kansas reports “phasing of disturbance and limiting disturbance when necessary.” Missouri reports that “in general our approach to project phasing is to encourage contractors to finish as they go, moving methodically through the corridor, avoiding disturbance where practical and covering up disturbance behind you.”
- Requiring General Contractor to certify that no earth disturbance or construction related activities will occur outside the limits of disturbance (15% - CA, KS, KY, NH, and TX).
- Defining separate limits of disturbance for each phase of the project (AL, AK, DE, FL, MD, MI, NJ, NY, and VT).

- Identifying measures (e.g., penalties, fines, reporting to permitting agencies, etc.) for non-compliance (AK, AL, CO, DE, IL, KS, MA, MD, MN, MT, NC, NE, NJ, OH, OK, UT, VA, and WA).
- Specifying disturbed acreage limitations (AL) or using special provisions to limit disturbed areas, or restrict to specific phases allowed open (WI).

Marking LOD on Plans and in the Field

- Including plan notes requiring selective clearing (IA) or only as needed for active work areas (NH).
- Designating limits of disturbance on project drawings (67% - AL, AZ, CA, CO, ID, IL, KS, KY, MO, NE, NH, NY, OR, SD, TN, TX, VA, VT, WA, and WI).
- Requiring installation and maintenance of stakes, tape, high visibility fencing, or other visual reference points to delineate the LOD (30% - AZ, CA, ID, IL, MO, TN, VA, VT, and WA).
- Using high visibility fence to delineate sensitive areas (TN and TX).

MnDOT also indicated that it requires the contractor to a develop sequence of operations before they start the work and provides a construction amendment process in the field.

Particularly Effective and Cost-Efficient Practices Mentioned by DOTs

Almost two-thirds (65.6%) of respondents said their agency had developed or employed innovative construction phase erosion or sediment control best management practices or combination of practices that they had found to be particularly effective or cost-efficient for the purpose of reducing construction site discharge turbidity (AK, AL, CA, DE, FL, GA, IA, IL, MN, NC, NE, NJ, NY, OR, VA, VT, WA, WI, and WV). As shown in Figure A-3, the most common innovative practices mentioned were:

- Sedimentation basins with physical enhancements such as silt curtains, baffles, skimmers and/or settling tubes (86% of respondents), followed by
- Grassed/vegetated swales or buffer areas (82% of respondents).

Over 72% of respondents employed erosion control compost/mulch and 50% use passive treatment systems with flocculating agents. Between 27% and 37% of respondents use sand filters, infiltration basins/trenches, active treatment systems with flocculating agents, or level spreaders. Only two respondents (9%) indicated they used distributed or low impact development measures for the purposes of reducing turbidity. Other approaches mentioned were designating an erosion control supervisor with the prime contractor (MN), and implementing “Five Pillars of Construction Stormwater Management - a holistic management approach to addressing construction stormwater issues” (AL).

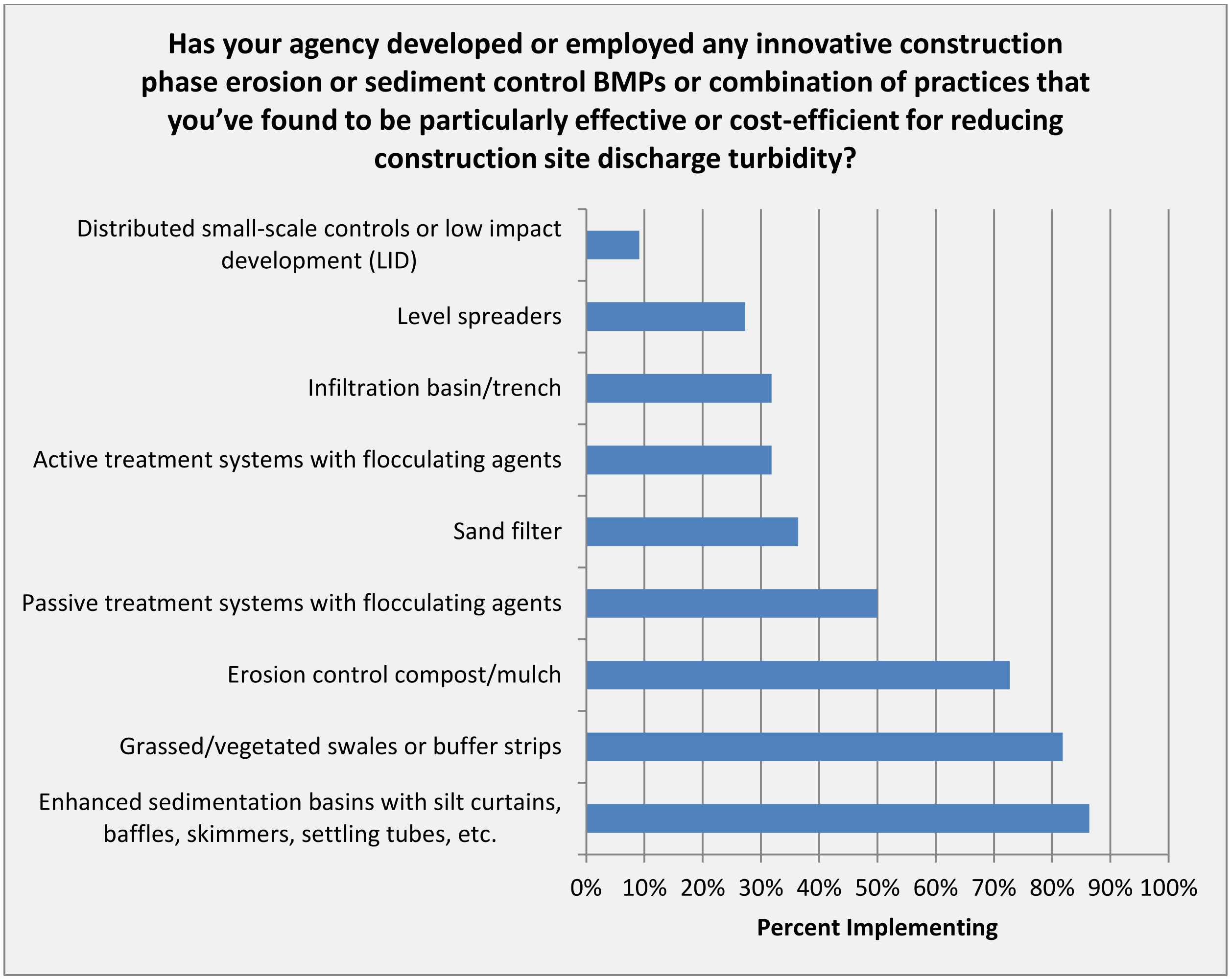

Figure A-3. Innovative erosion or sediment control BMPs found to be effective or cost-efficient

Interestingly, in the follow-up survey where more detailed information was requested, only 14% of the 23 states participating said their DOT had been involved with any projects that used innovative or unique project phasing or approaches to successfully limit disturbed areas.

Stabilization Practices - Overview

DOTs were surveyed about stabilization practices. Four questions were used to differentiate between sloped (embankment or cut slopes) vs. flat (< 10% grade) areas and permanent vs. temporary stabilization. Overall, seed mixtures were the most popular method, followed by hydraulic application of mulch. Summary graphs of the data are shown in Figures A-4 and A-5. Details of these results are given in the four sections that follow.

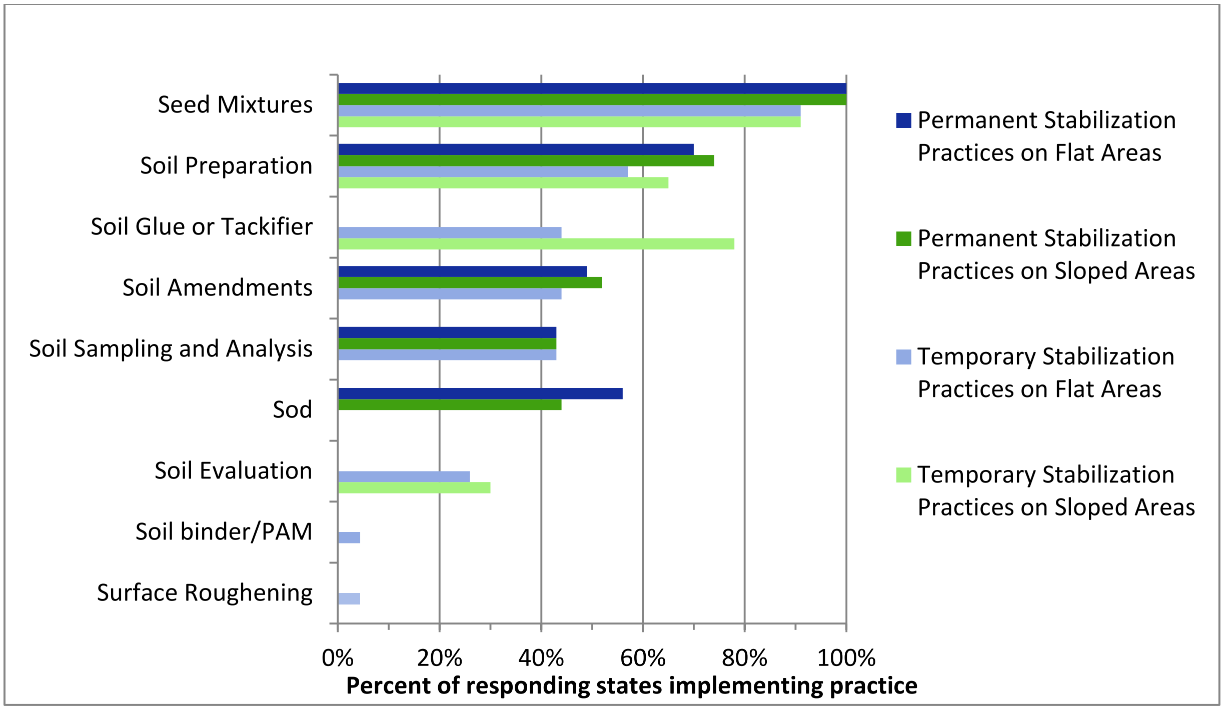

Figure A-4. Stabilization Practices - Soil and Seeding

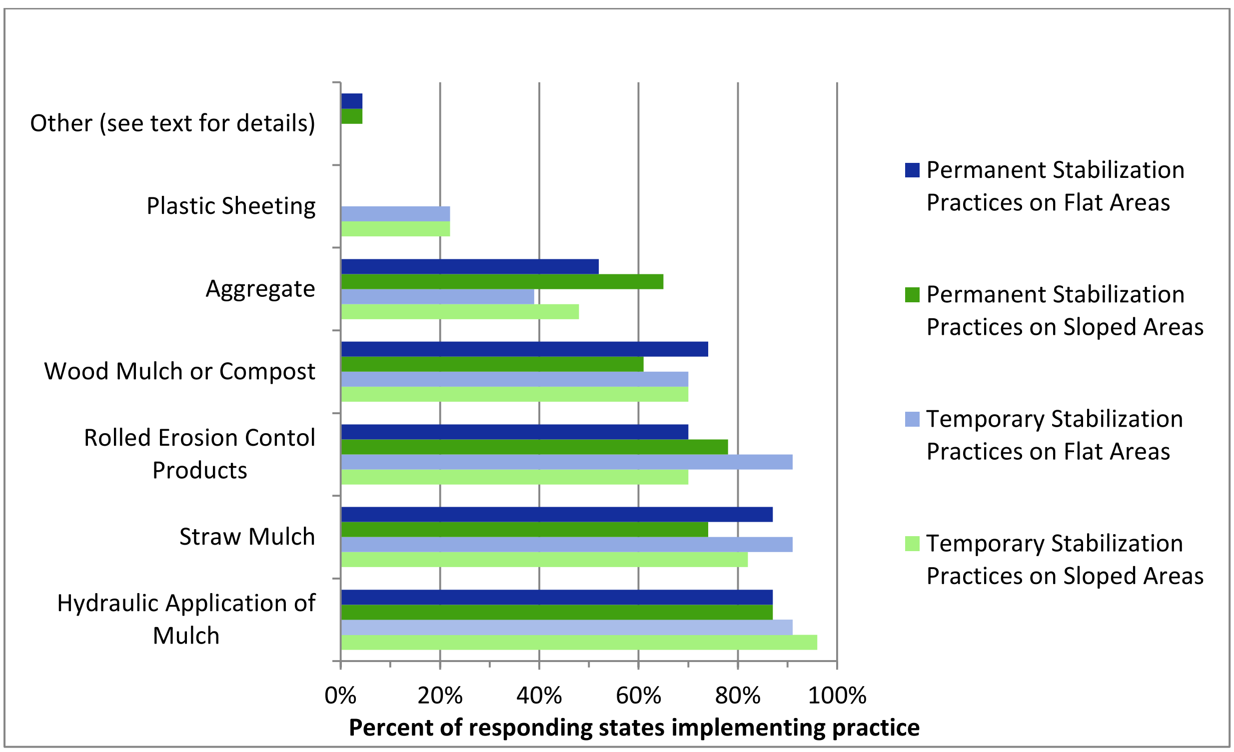

Figure A-5. Stabilization Practices - Mulches and Other Practices

Temporary Stabilization Practices or Combinations Thereof on SLOPED Areas

In the follow-up survey, DOTs were asked what temporary stabilization practice or combination of practices is typically used on embankment or cut slopes on DOT projects. Of those responding,

Soil and Seeding

- 30% use soil evaluation - CA, KY, NH, NY, TN, TX, and WA.
- 65% use soil preparation - AL, AZ, CA, IA, ID, KY, MO, NC, NE, NH, OR, SD, TX, and VA.
- 91% use seed mixtures – Utah and Colorado were the only ones not indicating such use.
- 78% use soil glue or tackifier - AL, AZ, CA, CO, ID, KY, MO, NC, NH, NY, OR, SD, TN, TX, UT, VA, WA, and WI (States not indicating use included: IA, IL, KS, NE, VT). Tackifier is commonly used with mulches, in the category below.

Mulches, directly applied or in rolled products

- 82% use straw mulch – the only states *not indicating use* were AL, CO, UT, and WI.
- 70% use wood mulch or compost -- the only states *not indicating use* were IA, IL, MO, SD, VA, VT, and WI.
- 96% use hydraulic application of mulch, clearly the standard. Only SD did not indicate use.
- 70% use rolled erosion control products – AL, CA, CO, ID, IL, KS, KY, NC, NH, NY, OR, TN, TX, VA, VT, and WA. The only states *not indicating use* were AZ, IA, MO, NE, SD, UT, and WI.

Other

- 48% use non-vegetative practice (e.g., aggregate) – AL, AZ, ID, KS, KY, MO, NC, NH, NY, and WA.
- 22% use plastic sheeting for some applications – AL, CA, NH, OR, and WA.

Temporary Stabilization Practices or Combinations Thereof on FLAT Areas

In the follow-up survey, DOTs were also asked what temporary stabilization practice or combination of practices is typically used on relative flat areas on DOT projects. Of those responding, the following percentages of responding DOTs indicated they use the practice:

Soil and Seeding

- 26% use soil evaluation - CA, KY, NH, TN, TX, and WA.
- 43% soil sampling and analysis – CA, KY, MO, NC, NH, OR, TN, TX, VA, and WA.
- 57% use soil preparation - AL, AZ, CA, IA, ID, KY, MO, NC, NE, NH, SD, TX, and WA.
- 44% use application of soil amendments – AL, AZ, CA, ID, KY, NC, NH, TN, TX, and WA.
- 91% use seed mixtures - Utah and Colorado were the only ones not indicating such use.
- 44% use soil glue or tackifier - AL, AZ, CA, ID, KY, NC, NH, TN, TX, and WA.

- Surface roughening was mentioned by one state: CO, as was soil binders/PAM: NH.

Mulches, directly applied or in rolled products

- 91% use straw mulch – the only states *not indicating use* were AZ and UT.
- 70% use wood mulch or compost -- the only states *not indicating use* were IA, IL, MO, SD, VA, VT, and WI.
- 91% use hydraulic application of mulch. Only Kansas and South Dakota did not indicate use.
- 91% use rolled erosion control products. Only Kansas and South Dakota did not indicate use.

Other

- 39% use non-vegetative practice (i.e., aggregate) – AL, AZ, ID, MO, NC, NH, NY, TX, and WA.
- 22% use plastic sheeting – AL, CA, NH, OR, and WA.

Permanent Stabilization Practices or Combinations Thereof on SLOPED Areas

The in-depth survey also asked DOTs what PERMANENT stabilization practice or combination of practices they typically use on embankment or cut slopes on DOT projects.

Soil and Seeding

- 43% use soil sampling and analysis – CA, KY, MO, NC, NH, OR, TN, TX, VA, and WA.
- 74% use soil preparation - AL, AZ, CA, IA, ID, KY, MO, NC, NE, NH, OR, TN, TX, VA, WA, and WI.
- 52% use application of soil amendments – AL, AZ, CA, ID, KY, MO, NC, NH, OR, TN, TX, and WA.
- 100%   use seed mixtures.
- 44% use sod – AL, CA, ID, KS, KY, NC, SD, TN, TX, and WA.

Mulches, directly applied or in rolled products

- 74% use straw mulch – the only states *not indicating use* were AZ, CO, IL, OR, UT, and VA.
- 61% use wood mulch or compost -- the only states *not indicating use* were CO, IA, IL, MO, NH, TN, VA, VT, and WI.
- 87% use hydraulic application of mulch -- the only states *not indicating use* were IA, KS, and VA.
- 78% use rolled erosion control products -- the only states *not indicating use* were AZ, IA, NE, OR, and VA.

Illinois noted that the mulch and rolled erosion control products that are temporary are also intended to assist in the establishment of permanent seed.

Other

- 65% use non-vegetative practice (e.g., aggregate) -- the only states *not indicating use* were IA, KS, NE, and OR
- Caltrans also used slope paving, contour grading, benching, terracing, and stepping.

Permanent Stabilization Practices or Combinations Thereof on FLATTER Areas

With regard to flatter areas, the in-depth survey also asked DOTs what PERMANENT stabilization practice or combination of practices they typically used on DOT projects.

Soil, Seeding, and Sod

- 43% use soil sampling and analysis – CA, KY, MO, NC, NH, NY, TN, TX, VA, and WA.
- 70% use soil preparation - the only states *not indicating use* were CO, IL, KS, SD, UT, VA, and VT.
- 49% use application of soil amendments – AL, AZ, CA, ID, KY, MO, NC, NY, TN, TX, and WA.
- 100% use seed mixtures.
- 56% use sod – states not using included AZ, CO, IA, MO, NE, NH, OR, UT, VA, and VT.

Mulches, directly applied or in rolled products

- 87% use straw mulch – the only states *not indicating use* were AZ, UT, and VA.
- 74% wood mulch or compost -- the only states *not indicating use* were IA, MO, SD, VA, VT, and WI.
- 87% hydraulic application of mulch -- the only states *not indicating use* were IA, KS, and VA.
- 70% rolled erosion control products -- the only states *not indicating use* were AZ, CO, IA, NE, NH, OR, and VA.

Illinois noted that the mulch and rolled erosion control products that are temporary are also intended to assist in the establishment of permanent seed. TRMs are used if high velocities are anticipated.

Other

- 52% non-vegetative practice (i.e., aggregate) -- the states *not indicating use* were CO, IA, KS, KY NE, NH, OR, SD, VA, VT, and WI.
- CA – miscellaneous pavements are used.

State DOT Guidelines, Policies, and Protocols on ESC Measures

Seven state DOTs also generously shared their guidelines, policies, and protocols:

- AL: www.dot.state.al.us/conweb/doc/Specifications/2008%20Standard%20Specifications%20for%20Highway%20Construction.pdf (Standard specifications for highway construction)

- CA: www.dot.ca.gov/hq/LandArch/ec/index.htm (Excellent graphical executive summary of erosion control treatment and a link to a document entitled "Key Concepts of Sustainable Erosion Control: Technical Guide") www.dot.ca.gov/hq/oppd/stormwtr/guidance.htm (Links to various stormwater guidance documents)
- CO: www.coloradodot.info/business/designsupport/construction-specifications/2011-Specs/2011-specs-book/section-200.pdf/view (Colorado DOT Construction Specification Handbook)
- ID: www.itd.idaho.gov/design/cadd/SpecialProvisions/bidinsert04.htm (Bid inserts)
- NY: 13393D and 13393E Contract, See Section 209 (page 243) - www.nysdot.gov/main/business-center/engineering/specifications/english-spec-repository/espec9-1-11english.pdf
- OR: www.oregon.gov/ODOT/HWY/SPECS/docs/08book/08_00200.pdf (2008 Construction Standard Specifications – see section 00280)
- TN: www.tdot.state.tn.us/construction/specbook/2006_Spec200.pdf (Earthwork specifications)

A-5. BMP Effectiveness Research/Data Collection

In the initial survey of two-thirds of all DOTs, 42% of respondents said that their state DOT had conducted studies, implemented organizational practices, or prepared reports that evaluate the effectiveness, efficiency, or performance of turbidity reduction technologies or conventional erosion and sediment controls at DOT facilities. State DOTs indicating they had conducted technology efficiency/effectiveness studies included: AK, AL, CA, CO, DE, FL, IA, MN, MT, NC, NJ, WA, WI, and WV.

Increasingly, DOTs are tracking inspections and results in databases; one-third of respondents said they have been accumulating BMP effectiveness information in those, but on further investigation, little such information seemed to be available. Nevertheless, the following DOTs said they would be willing to share their databases and/or results in this area: CA, CO, KS, MA, MT, NC, NJ, OR, UT, WA, and WI.

Only four states, (AL, CA, NC, and NJ) reported that they had conducted studies or prepared reports on the maintenance of turbidity reduction technologies at DOT facilities; however, some states likely to have research in this area did not answer this question, including Maryland and Washington State. Of potential interest, responses in this area also indicate that 58% of DOTs are doing no BMP efficiency or effectiveness evaluation, presumably outside of the minimum reporting required for NPDES MS4 and construction permits on maintenance of BMPs. Further, two-thirds of respondents are not using any inspection databases they have to capture such information.

In the more detailed follow-up survey, all 23 responding states indicated that they have been able to predict long-term performance and service life for ESC and turbidity control BMPs; however, none indicated they could provide a copy of this information and the maintenance schedules they are using. NYSDOT's GreenLITES for Maintenance and Operations does indicate cycle times and was known to the research team; that is available at: https://www.dot.ny.gov/programs/greenlites/repository/GREENLITES%20MOP%20TEMPLATE%2020 10-11.xls.

None of the DOTs in the follow-up survey said they had incorporated long-term performance and life-cycle costs into the BMP selection process. NHDOT indicated that most last for the length of the construction period; the agency has an informal process for choosing BMPs appropriate for the duration of need. Likewise, none of the DOTs had done any comparison of the long-term performance of structural BMPs to non-structural approaches.

Process: Stormwater Pollution Prevention Plan Development, Certifications

Regarding projects that require a Storm Water Pollution Prevention Plan (SWPPP) or Erosion and Sediment Control Plan (ESCP) or similar document, we asked for an approximate percentage of those projects in which the selected General Contractor has the responsibility for developing the SWPPP (ESCP or similar document). States answered as follows:

- 0% - AL, IA, MO, NC, NE, NY, TX, UT, and VA. In many cases, the state DOTs develop the SWPPPs or SWMPs. In Alabama, the contractor submits an implementation plan (ALDOT template required) that becomes a part of ALDOT's SWPPP.
- 5% - KY
- 40% - Colorado DOT said approximately 40% of the SWMPs are prepared by consultants. The rest are prepared in house; however, the contractor is responsible for implementing the SWMP once construction begins, so it is often modified at that point.
- 80% and above - OR
- 98% - VT
- 100% - AZ, CA, KS, NH, and WI. For example, the WisDOT, requires an Erosion Control Implementation Plan on all projects that have ANY land disturbance and/or have an erosion control bid item, including seed.
- Other – Tennessee DOT said the contractor is responsible for installing the measures required on the plans except for Design/Build projects. The Department makes revisions as necessary for the low bid contracts.

48% of states require professional certifications for preparing plans. Similarly, 48% of responding DOTs provide a SWPPP template to general contractors who have responsibility for developing those (AZ, CA, CO, ID, KS, KY, OR, SD, UT, VT, and WI). Areas in which templates were provided for better compliance were:

- Communication of better compliance objectives – 35%
- Minimizing disturbance – 26%
- Stabilization of disturbed area – 26%
- Sediment control performance – 26%
- Checklists for monitoring and reporting – 22%
- Training requirements – 17%
- Sediment-laden discharges – 17%

- Project sequencing or timing – 17%
- Treatment Train (Combination of BMPs from different categories) – 13%
- Other:
    - Better document control
    - SWMP preparation checklist ensures all required sections are completed
    - Regulatory inspections no longer result in Notice of Violations (NOVs)
    - Contractor has better understanding of environmental and erosion issues

In 35% of responding states, professional certifications are required for monitoring and implementation. In some states (e.g., AZ) such certifications are required if the project is within a quarter mile of an impaired or outstanding resource water, or if the project is in a sensitive area. In other states, such as Illinois, the requirement for professional certification is tempered by inclusion of the statement "or other knowledgeable person who possesses the skills to assess conditions at the construction site that could impact storm water quality."

Institutional Incentives

A number of DOTs employ institutional mechanisms or incentives to encourage stormwater compliance, accountability, and performance. Of responding DOTs:

- 30% employ liquidated damages for non-compliance – CA, CO, KS, KY, OR, SD, and WI.
- 26% utilize contractor certification – CA, CO, KS, SD, UT, and VT.
- 9% offered non-monetary recognition – CO and OR
- None offered monetary incentives for compliance – compliance is a requirement.

Further:

- Maryland and Utah employ contractor decertification in cases of poor performance or non-response.
- In Vermont, the contractor rating/score is considered during procurement of future work.
- Colorado requires:
    - Daily inspections by contractor/ECS
    - Bi-weekly inspections by project staff
    - Monthly inspections by Regional CDOT Inspectors
    - Periodic inspections by a HQ inspection team.
- Colorado has implemented a Chief Engineer's performance objective. (Performance also factors into engineer's evaluations in MD and NC, though none of these states checked this item. Maryland did not participate in the in-depth survey; these results are reported from previous interviews.)
- California withholds payment.

- Utah employs monetary penalties for non-compliance.
- On occasion, Wisconsin may use monetary incentives or disincentives for highly sensitive projects. Current damages are $300 per day per violation.

Using Online and Other Systems to Improve Processes, BMP Selection

Only three states (13% of those responding to the in-depth survey) have an electronic/online inspection tracking system (CO, SD, VT). Many states did not respond to this question. Some are believed to have such tracking systems; for example, the research team is aware of MDSHA's. Colorado notes that such systems have:

- Made it easier/faster to issue letters or notices of non-compliance, with documentation, to the contractor.
- Improved turnaround times with corrective action.
- Improved overall compliance.
- Produced information on BMP effectiveness.
- Streamlined documentation and reporting.

No states could say if their inspection tracking systems were reducing turbidity, a key outcome in the field. This will be a potential connection to make as these systems evolve.

When asked if their DOT used BMP effectiveness information to prioritize the selection of individual erosion and sediment controls BMPs on a project, 57% said yes (AZ, CO, ID, IL, KS, MO, NC, NE, NH, OR, SD, WA, WI). DOTs said that personal experience was typically the best source of knowledge, but Colorado had distilled theirs in a manual (though they pointed out this was not mandatory to use): http://www.udfcd.org/downloads/down_critmanual_volIII.htm. Several states commented as follows:

- WisDOT said this varies depending on BMP. They use federal, state, university research, and come to agreement with resource agency.
- Illinois said they base their assessment on slope, area, and velocities.
- MoDOT remarked that experience is best, but there are a plethora of BMP guidance documents available from USEPA and state DNRs.
- Oregon DOT referenced "past studies and reports."

A-6. Efforts Undertaken to Prepare for National Effluent Limits

Policy/Guidance for NELs

Just over a third (36.4%) of responding states have developed or started to develop policy or guidance for erosion or sediment control practices to meet numeric effluent limitations (NELs) for turbidity on construction site discharges. Those states include: CA, FL, IA, MN, MT, NC, NJ, VA, VT, WA, WI, and WV.

Maintenance Studies

Only 12% of respondents reported that they had conducted studies on the maintenance of turbidity reduction technologies at DOT facilities. These include four states: AL, CA, NC, and NJ.

Anticipated Changes in Contract Needs and Specifications

At this point in time, many DOTs utilize lump sum bidding for temporary erosion/sediment control; however, states anticipate they will have additional needs that require changes to current ways of doing business. They anticipate the need for specifications for contractor testing and recording, developing sampling plans, taking samples, and conducting lab analyses. They also anticipate greater need for contingent items and/or budget contingencies.

Many DOTs foresee the need to add components to their agencies' bid item lists to increase their ability to comply with NELs:

General Contracting Provisions

- More performance based criteria that will allow contractors to adapt to changing conditions as the project is constructed.

Phasing and Incentives

- Reducing the amount of disturbed area (restrictions on open acreage) currently allowed at any one time.
- Incentives for early stabilization of disturbed areas, vegetation of areas on multi-year contracts.
- New contract provisions that will hold contractors responsible for any increased costs related to erosion control and sampling in the event that a contractor does not plan to phase a project into smaller sections.

Additional BMPs, Maintenance, and Incentives/Disincentives

- Active treatment systems (dewatering dumpsters, lift stations, chemically enhanced sand, and mechanical filters)
- Flocculants
- Proprietary BMPs
- Erosion control supervisors, where previously unrequired
- Basins, including riser pipes
- Skimmers
- Improved BMP maintenance items
- Potential third-party erosion and sedimentation control contractors
- Improved incentives/disincentives

Monitoring/Sampling

- Turbidimeters

- Items for monitoring
- Monitoring stations and testing protocols.
- Line items specifically for the testing and removal of turbidity to meet NEL

Some DOTs say more government-industry discussions will be needed to identify common goals. Others say more will become clear when EPA sets monitoring guidelines, NELs, enforcement actions, and potential fines.

Turbidity Reduction Technologies

When asked in the in-depth survey, 78% of responding state DOTs pointed to turbidity reduction technologies they have found or determined to be most effective for runoff from construction sites subject to numeric turbidity limits. These include:

- Sediment basins (or other trapping device) with flocculant pretreatment (AL, NC, NE, NH, and TN)
- Combination of traditional ESC controls, without the use of flocculants (AZ, CA, CO, ID, KS, KY, MO, SD, and UT). Colorado added this was only because they are not allowed to use flocculants. Idaho noted they use chitosan sand filtration. Some states are not subject to turbidity limits (yet).

Notably, only 3 states listed active treatment systems which typically collect runoff and then pump it through a pretreatment system including flocculation and filtration prior to discharge; those states were New York, Vermont, and Virginia.

When asked what turbidity reduction technologies states anticipate they will use **for projects with limited space (e.g., where full sediment basins are not feasible)**, states said:

- Active treatment systems, which typically collect runoff and then pump it through a pretreatment system including flocculation and filtration prior to discharge (10% - IL, NY, VT).
- Distributed small-scale sediment traps or basins (or other trapping device) with flocculant pretreatment (31% - AL, IA, KY, NC, NE, NY, OR, TN, and WI).
- Combination of traditional ESC controls, without the use of flocculants (31% - AZ, CA, CO, KS, MO, SD, TX, UT, and WA).

NHDOT representatives offer assistance to the successful bidder with pumps, frac tanks, etc. Only Caltrans and NHDOT said they have example bid approaches for active treatment systems, and NHDOT is the only agency that has an estimate of project costs for active treatment systems. Estimates are based on past experience with similar systems. Other states may find the following Caltrans resource useful: http://www.dot.ca.gov/hq/esc/oe/specifications/SSPs/2006-SSPs/Sec_10/05-12/07-347_E_A08-05-11.doc

When asked what hurdles must be overcome before their agency is able to utilize turbidity reduction technologies, of responding states:

- 74% said that they needed to develop standard specifications.

- 83% said that they needed guidance for design and maintenance.
- 79% said training is needed for inspectors.
- 83% said training is needed for contractors.
- Caltrans said performance based industry standards and national standards for products are needed.
- Colorado DOT called for change in regulations pertaining to the use of flocculants. MoDOT and NHDOT also indicated the need for the concurrence of their DNR.
- Also needed is clarification how/when to sample and determine excessive events.
- NYSDOT noted the need for an approved list of products.

DOTs were asked what methods they had used or evaluated to reduce potential for re-suspension of sediment. Of responding DOTs:

- 65% said removal of captured sediment.
- 17% said covering captured sediment with coarse aggregate, erosion control blankets, mulch with tackifier (e.g. PAM), or other barrier.
- 65% said sweeping tracked sediment from site entrances, exits, and interior paved areas.
- Iowa DOT said it depends on project conditions. For silt fences, a contractor is more likely to install new silt fence. South Dakota requires that silt fences be mucked out at one-third full.
- MoDOT said in their SWPPP, they prescribe that sediment removal shall occur when ditch checks and sediment traps reach half full, and cleanout of sediment basins when they are one-third full (AZDOT also indicated the latter). Likewise, Alabama DOT performs maintenance at one-third to half of device capacity or height.
- TxDOT requires captured sediment to be removed when the BMP is at 1/2 capacity, but estimates that actually happens probably less than 75% of the time.

Regional Challenges

In the more detailed follow-up survey completed by 23 DOTs, the following percentages of respondents said they faced unique erosion or sedimentation control challenges in their regions, related to:

- High altitude (26%)
- Cold climate (57%)
- Receiving waters with widespread threatened or endangered species (61%)
- Receiving waters with sediment or nutrient impairments, TMDLs (61%)
- Sterile soils; i.e., inability to quickly establish vegetation (70%)
- Seasonal dry and wet seasons (78%)
- Intense rainfall (83%)
- Difficult to settle soils (91%)

- Steep slopes (96%)
- Highly erodible soils (96%)

NHDOT added that lake associations, sensitive residents on high quality lakes, and regulators were unique regional challenges as well.

A-7. Monitoring Activities to Support Compliance and Research

When state DOTs were asked, if they had discharge monitoring requirements for all or a subset of construction sites, then do they have specific treatment requirements and/or a list of accepted technologies that may be used in meeting turbidity discharge requirements; 17% of states said that they do: NH, SD, VT, and WA. MoDOT said that their permit limit is tied to settleable solids, rather than turbidity. NHDOT indicated that their requirement is to not raise surface water turbidity more than 10 NTUs above background.

Sampling and Reporting

Just over a quarter (27%) of states reported that sampling of construction site discharge turbidity is currently required of their DOTs (27.3%). These include: AL, AZ, CA, FL, GA, MN, OR, VT, and WA. SD and NH are also known to require turbidity sampling in special circumstances. Many of these states require sampling only in circumstances with special ecological risk due to protected waters, endangered species, or construction sites capable of delivering high amounts of sediment into receiving waters. Just 15% of responding DOTs had conducted studies, prepared reports, or compiled information related to sampling cost, reliability, or accuracy (CA, CO, IA, NC, and VA).

Construction site sampling has not been a big part of NPDES requirements for DOTs to date. **Less than a quarter of respondents (24.2%) said they had developed guidelines, policies, or protocols for selecting sampling methods for construction site or MS4 discharges.** AZ, CA, CO, DE, OR, VA, WA, WV were states that had developed such policies or guidelines. A greater number (60%) of state DOT respondents said they keep or are required to keep readily retrievable records of construction site characteristics or statistics (e.g., size of disturbed area, size and number of drainage areas).

Sampling Requirements and Methods

In the more in-depth follow-up survey, 10 responding state DOTs said their MS4 permit included sampling requirements. A few provided links with additional information on the sampling requirements, to share with other DOTs:

- AL: http://adem.alabama.gov/programs/water/municipal.cnt
- AZ: http://www.azdot.gov/Inside_ADOT/OES/Water_Quality/stormwater_permit.asp (Arizona DOT's stormwater permit)
- CA: available at the California State Water Board website
- ID: http://itd.idaho.gov/enviro/storm%20water/ms4/default.htm (Idaho Transportation Department's MS4 permits)

No DOT had developed guidelines, policies, or protocols for selecting sampling frequency to yield representative results, but Caltrans and TxDOT had drafts or were investing in research.

States were surveyed as to the frequency with which they used various sampling methods. A graphical summary of the results is shown in Figure A-6 and details are given in the text below.

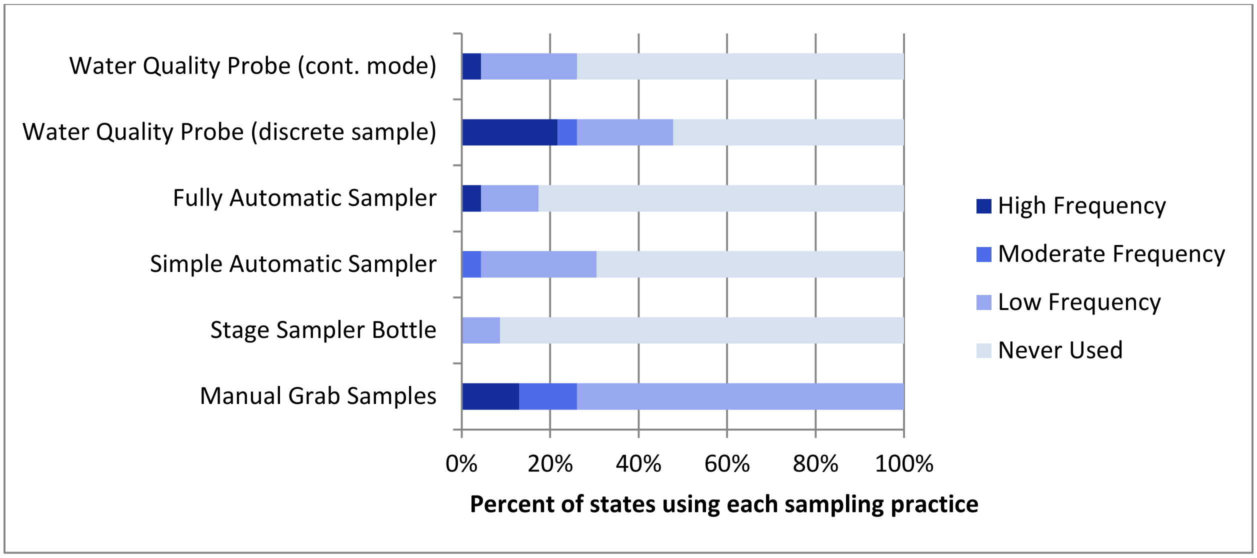

Figure A-6. Turbidity Sampling Methods and Their Frequency of Use by State DOTs

Only 3 of 23 responding states indicated a high frequency of use for **obtaining samples manually at discharge points**. Those three states were California, New Hampshire, and Washington. Similarly, only 3 states said they employed grab samples at a moderate frequency (ID, VT, NC). The remainder of states indicated a low frequency of use or that they never use grab samples.

Even fewer states had installed **stage sampler bottle**s in a basin or outlet so that they fill as the water rises during storm events; only 2 of the 23 indicated a low frequency of use. The remainder said they had never used this sampling method.

Six of 22 (AZ, CA, IA, ID, OR, TN) had infrequently used a **simple automatic sample**, a device designed to obtain one or more samples after flow or rainfall is detected, with time-weighted composites. Only Illinois DOT indicated a moderate frequency of use and no DOTs used simple automatic samplers with a high frequency.

Of 23 responding states, Colorado DOT was the only one that had made frequent use of a **fully automated sampler**, a programmable device that obtains samples based on flow or stage and which records flow and rainfall, with flow-weighted composite samples. Idaho, New York, and North Carolina indicated a low frequency of use of a fully automated sampler. The remaining states had never used one.

More states had used a **water quality probe/turbidity meter**, a device which records turbidity directly in discharge **for a discrete sample** (e.g., once a day, week, etc.). Nearly half (11) of the 23 responding states had used one infrequently, at least. Five states (CA, ID, SD, WA, and NH) said they had used one quite frequently (high frequency) and VTrans (Vermont) said they had used one with moderate frequency.

Only Caltrans had frequently used a **water quality probe/turbidity meter in continuous recording mode** (15 minute data during runoff for example). Five states (ID, NC, VT, WA, and NH) had used this sampling method infrequently. The remaining responding states had never used one.

Influencing Factors in Selecting a Sampling Method

DOTs responding to the in-depth survey also rated the influencing factors they consider when selecting a sampling method. Non-responses were involved where answers do not total 100%.

- Safety:
  - High influence – 58%
  - Moderate influence – 32%
  - Low influence -- 2%
- Cost:
  - High influence – 68%
  - Moderate influence – 32%
  - Low influence -- 0%
- Required sampling frequency (per discharge point):
  - High influence – 42%
  - Moderate influence – 47%
  - Low influence – 10.5%
- Required sampling locations:
  - High influence – 58%
  - Moderate influence – 37%
  - Low influence – 5%
- Permit requirement:
  - High influence – 79%
  - Moderate influence – 21%
  - Low influence – 0%
- Reliability:
  - High influence – 37%
  - Moderate influence – 58%
  - Low influence – 5%
- Adaptability to Changing Conditions:
  - High influence – 47%

- Moderate influence – 32%
- Low influence – 21%

- Seasonality:
  - High influence – 15.8%
  - Moderate influence – 52.6%
  - Low influence – 31.6%
- Size of disturbance:
  - High influence – 16%
  - Moderate influence – 63%
  - Low influence – 21%
- Compatibility with dynamic construction site:
  - High influence – 21%
  - Moderate influence – 63%
  - Low influence – 16%
- Accuracy:
  - High influence – 42%
  - Moderate influence – 53%
  - Low influence – 5%

With the in-depth survey, responding states also indicated what types of samples are evaluated:

- 65% said discrete samples (an individual sample collected over a short period)
- 17% said composite (obtained by continuous sampling or mixing discrete samples). States using this method included CA, CO, NY, and TN.

When asked if their DOT would consider it appropriate to use visual or photographic monitoring methods in lieu of measuring turbidity, 61% answered yes. Circumstances included:

- When allowed by state regulators or EPA.
- If the water is leaving the site, but not entering receiving waters.
- In low turbidity streams where it is easy to visually assess if additional turbidity has been added from DOT construction sites.
- If a set of "standard" samples was developed to give field staff something visual to compare their site discharge against (a background).
- No visible plume.
- One state now visually assesses discharge to see if it is more turbid than receiving water.

Changing Monitoring and Reporting with NELs

With proposed numeric effluent limitations from the EPA, states are anticipating increased oversight and reporting, but 96% of responding states expect to continue using the same sampling methods to document regulatory compliance with the upcoming NELs. North Carolina said they were currently researching monitoring possibilities. Another state said they needed to develop sampling methods; they had only done sampling on a few projects, to see how it works. Two states indicated that grab samples would be taken at defined discharge points.

When asked about the level of oversight DOTs thought their agency would provide to the upcoming NEL monitoring and reporting requirements, the largest percentage of DOTs (40%) indicated that "the selected project contractor will be responsible for monitoring and reporting, and our agency will provide staff to regularly oversee monitoring and reporting" (Figure A-7). The next largest percentage, one-third, indicated that they did not know what level of oversight their agency would provide. This was followed by a relatively small number of affirmative responses for the following items:

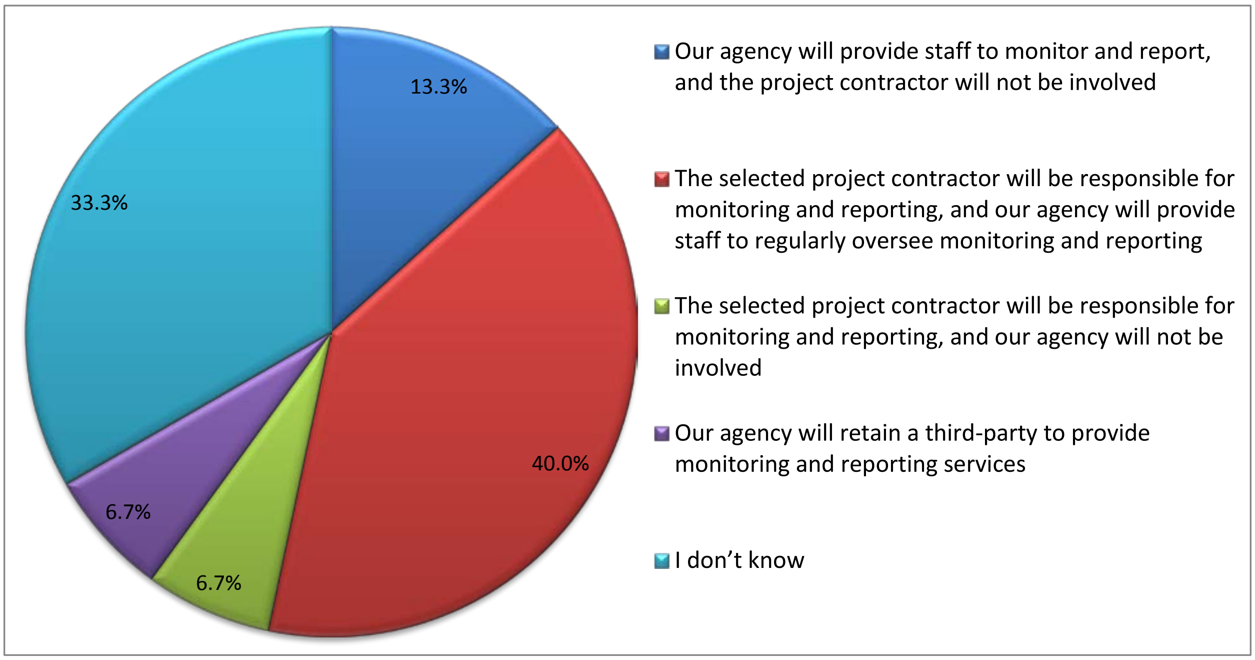

Figure A-7. Level of oversight DOTs expect to provide in new NEL monitoring and reporting requirements

- Our agency will provide staff to monitor and report, and the project contractor will not be involved (13%)
- The selected project contractor will be responsible for monitoring and reporting, and our agency will not be involved (6.7%)
- Our agency will retain a third-party to provide monitoring and reporting services (6.7%)

Other states indicated that their agencies would employ the following methods:

- Perform internal monitoring and reporting with contractor involvement and assistance.

- Hire third party construction site inspections teams for independent assurance.
- Have their contractors monitor and sample with the DOT performing reporting duties.
- Have greater flexibility to respond to unforeseen or changing conditions – currently their ESC plans and subsequent modifications are submitted to the state Department of Environment for approval, an approach that may not be as viable in the future.
- Perform discharge sampling and reporting in-house (at the DOT) on typical design-bid-build projects. Design build projects and projects where the contractor owns the permit are often handled differently depending on how the contract is written.
- Continue implementing contract specifications that limit the amount of soil that can be disturbed at one time without the approval of the Engineer. If the contractor proposes to exceed these disturbance limits, the DOT expects that Engineers may not approve the plan unless the contractor takes on the burden of the additional sampling requirements and erosion-related risks. Contract language will need to be developed.

For linear projects, the proposed EPA rule will allow DOTs to sample discharges from selected discharge point(s) if it is substantially identical to other discharge points based on similarities of exposed soils, slope, and type of stormwater controls used. Thus, DOTs were asked whether they anticipated using this approach on projects to reduce the number of monitoring locations; 61% answered yes and only one (NHDOT) answered no. Only Alabama had developed guidelines, policies, or protocols for determining representative discharge locations for DOT construction sites or MS4s. Alabama said theirs was in draft form. Caltrans said theirs was anticipated in 2012; however, they have specs to guide contractors. TxDOT has a research project looking into this question, and WisDOT started to develop a draft, but put it on hold until the final NEL comes out.

The EPA rule also indicates that diffuse stormwater, such as non-channelized flow through a silt fence or other perimeter control that infiltrates into a vegetated area and does not then discharge to surface waters, would not generally require sampling. DOTs were asked whether they had considered or developed design practices or project specifications to maximize use of non-channelized (diffuse) flow through perimeter controls. A quarter of those responding to the in-depth survey had: NC, NE, NH, OR, TN, and WA. One state (OR) provided a copy of their work:
http://www.oregon.gov/ODOT/HWY/GEOENVIRONMENTAL/erosion_control_manuals.shtml.

A-8. Unaddressed Research Needs Relating to NEL Compliance for DOTs

Just over 90% of responding DOTs said their agency had not initiated or completed any studies or research to facilitate the transition to NELs. Colorado, Minnesota, and Montana were among the few that indicated they had, though California, Georgia, and Washington State are known to be doing work in this area as well.

States indicated research needs that would increase their ability to comply with NELs:

Policy and Economics

- What are the economic, policy and natural environment consequences of setting turbidity limits for construction storm water run-off that is cleaner than what occurs naturally in stormwater runoff from undisturbed ground particularly in the arid and semi-arid West or in other areas with naturally turbid waters?

- Cost-benefit analyses of approaches.

Sampling

- How to obtain the samples and meet the required levels
- Selecting representative samples - unrealistic to sample all discharge points.
- How do other DOTs define "representative sampling"? What sampling methods and equipment are acceptable among DOTs?
- Will different models of turbidimeters give consistent results?
- Sampling protocols, effectiveness of the various controls.
- We need to know the repeatability and reliability of the various sampling methods.
- How do we properly store samples for future verification if necessary?

BMP Effectiveness

- Field performance of BMPs.
- BMP effectiveness in terms of percent load reduction.
- Effectiveness of traditional BMPs for NEL compliance (hope to meet the new limitations without having to rely on chemical treatment).
- Background information concerning pre- and post-project runoff.
- Effectiveness of controls (both sediment and erosion) on reducing turbidity.
- Combination of passive and active BMPs and knowledge when to use during construction (when it rains)
- Effectiveness of BMPs when factoring in location, soil type, weather, etc. Use of polymers (currently not allowed in Montana)
- Screening out products that are ineffective
- Critical need for performance based criteria & specs for all types of BMPs
- Appropriate BMPs for the arid southwest. If the background turbidity is naturally high (nature of a desert or semi-arid) then does it really make sense to be discharging water that is lower than background level and where native fish are adapted to turbid water? This could also apply to areas of the South/Midwest with naturally turbid waters
- Cost/benefit analysis of many methods.

Flocculants and Alternatives

- Other viable solutions (besides flocculants) will need to be identified. States that mentioned that flocculants were not allowed by their state water quality agencies included Colorado and

Montana. Other states indicated a desire to not rely on chemical treatments (Nebraska DOR), but did not indicate if flocculants are outlawed.

- The ability to identify the correct flocculant for use during the various stages of highway construction.
- The effectiveness of flocculants without sufficient hydraulic head to accommodate non-mechanical mixing.
- Understanding what site characteristics represent a need for ATS to comply, and how that will increase the budget for construction projects.
- Secondary effects of flocculants outside of erosion prevention. Reliable data for regulators to feel comfortable allowing the use of flocculants.

Personnel and Training

- Designating lead personnel
- Developing training

Attachment A-1

DOT Survey Questions

Meeting the New EPA Effluent Limitations Guideline for Construction Site Discharge Turbidity: Effectiveness of Different Turbidity Control Systems and Monitoring Methods

Please provide your current contact information.

Name:

Position:

Organization:

Phone:

Email:

Please provide contact information for individuals at your agency or partnering organization who may provide feedback or share experiences related to construction site stormwater compliance.

Name:

Position:

Organization:

Phone:

Email:

1. What design practices, standard specifications and/or contractual requirements does your agency use to address timing and size of disturbance? Please check all that apply:
    a. Designate general sequence of construction activities in SWPPP and BMPs associated with each phase of construction
    b. Designate timing of construction activities in SWPPP
    c. Define separate limits of disturbance for each phase of the project
    d. Limit area that can be disturbed (unstabilized) at one time
    e. Limit the size of the work area by the grading, seeding, and final slope protection the Contractor can complete within a defined timeframe
    f. Consider work as being started with grubbing and complete when the specified cover material is applied, or final stabilization is otherwise accomplished
    g. Provide both a work progression schedule and a contingency plan
    h. Require work to be continuously active from grubbing through placement of seed and final slope protection, where required
    i. Identify measures (e.g., penalties, fines, reporting to permitting agencies, etc.) for non-compliance
    j. Regularly implement measures for non-compliance

k. Other (please describe)

2. Has your agency conducted any studies, implemented organizational practices, or prepared reports that evaluate the effectiveness, efficiency, or performance of turbidity reduction technologies or conventional erosion and sediment controls at DOT facilities?
    a. Yes
    b. No
    c. If yes, please provide the web link(s) or contact information for obtaining copies of such studies and/or reports. (include field for weblink, autofill my contact info, autofill same contact information provided at beginning of survey, other contact. Use same format for all "If yes, follow-ups"
3. Has your agency conducted any studies or prepared reports on the maintenance of turbidity reduction technologies at DOT facilities?
    a. Yes
    b. No
    c. If yes, please provide the web link or contact information for obtaining copies of such studies and/or reports.
4. Do you have BMP effectiveness information in your inspection or other databases?
    a. Yes
    b. No
    c. If yes, who is the best contact to speak with about that database?
5. Has your agency developed or employed any innovative construction phase erosion or sediment control best management practices or combination of practices that you've found to be particularly effective or cost-efficient for the purpose of reducing construction site discharge turbidity?
    a. Yes
    b. No
    c. If yes, please check all that apply:
        i. Grassed/Vegetated Swales or Buffer Strips
        ii. Sedimentation Basins with physical enhancements such as silt curtains, baffles, skimmers and/or settling tubes
        iii. Infiltration Basin/Trench
        iv. Sand Filter
        v. Erosion Control Compost/Mulch
        vi. Distributed Small-Scale Controls or Low Impact Development (LID)
        vii. Level Spreaders
        viii. Active Treatment Systems with Flocculating Agents
        ix. Passive Treatment Systems with Flocculating Agents
        x. Other. Comment

6. Has your agency developed or started to develop policy or guidance for erosion or sediment control practices to meet numeric effluent limitations (NELs) for turbidity on construction site discharges?
    a. Yes
    b. No
    c. If yes, please provide the web link or contact information for obtaining copies of such guidelines, policies, or protocols.
7. Has your agency used enhanced coagulation or flocculation technologies (e.g., chitosan, polyacrylamides (PAMs), alum, or electrocoagulation) at construction sites?
    a. Yes
    b. No
    c. If yes, please provide the web link or contact information for obtaining additional information
8. Has your agency approved or developed any specifications for usage or conducted research related to use of flocculants or PAMs at construction sites (including hydraulic application of PAM as a component in hydraulic slurries applied for erosion control and revegetation)?
    a. Yes
    b. No
    c. If yes, please provide the web link or contact information for obtaining copies of such studies or specifications.
9. Is sampling of construction site discharge turbidity currently required for your DOT projects?
    a. Yes
    b. No
    c. If yes, who is the best contact to speak with about the sampling methods (or web link)?
10. Has your agency conducted any studies, prepared reports, or compiled information related to sampling cost, reliability, or accuracy?
    a. Yes
    b. No
    c. If yes, please provide the web link(s) or contact information for obtaining copies of such studies, reports, or additional information.
11. Has your agency developed guidelines, policies, or protocols for selecting sampling methods for construction site or MS4 discharges?
    a. Yes
    b. No
    c. If yes, please provide the web link or contact information for obtaining copies of such guidelines, policies, or protocols.

12. Does your agency keep or are they required to keep readily retrievable records of construction site characteristics or statistics (e.g., size of disturbed area, size and number of drainage areas)?
    a. Yes
    b. No
    c. If yes, please provide the web link(s) or contact information for obtaining copies of such records.
13. Has your agency initiated or completed any studies or research to facilitate the transition to NELs?
    a. Yes
    b. No
    c. If yes, please provide the web link or contact information for obtaining additional information.
14. What has made your construction stormwater compliance (and turbidity prevention) program particularly rigorous and effective, if you consider it so?
15. What do you consider to be the ultimate primary factors in successful erosion and sediment control and turbidity prevention, at your agency (check all that apply):
    a. BMP implementation
    b. BMP maintenance
    c. Enforcement of BMP implementation and maintenance
    d. Incentives for agency staff to enforce/use penalties at hand
    e. Agency priority
    f. Phasing rules
    g. Use of flocculants
    h. Agency leadership priority
    i. Other, please describe
16. What are your most important unaddressed research needs in this area that would increase your ability to comply with NELs?
17. What additional components do you anticipate will be needed on your agency's bid item list to comply with NELs?
18. What level of oversight do you think your agency will provide to the upcoming NEL monitoring and reporting requirements?
    a. Our agency will provide staff to monitor and report, and the project contractor will not be involved
    b. The selected project contractor will be responsible for monitoring and reporting, and our agency will provide staff to regularly oversee monitoring and reporting
    c. The selected project contractor will be responsible for monitoring and reporting, and our agency will not be involved
    d. Our agency will retain a third-party to provide monitoring and reporting services
    e. Other
    f. I don't know

Attachment A-2

DOT Follow-Up Survey Questions

Meeting the New EPA Effluent Limitations Guideline for Construction Site Discharge Turbidity: Effectiveness of Different Turbidity Control Systems and Monitoring Methods

Please provide your current contact information.

Name:

Position:

Organization:

Phone:

Email:

Please provide contact information for individuals at your agency or partnering organization who may provide feedback or share experiences related to construction site stormwater compliance.

Name:

Position:

Organization:

Phone:

Email:

Design practices, standard specification or special provisions to minimize disturbance, preserve existing vegetation, and address timing of disturbance

1. What design practices does your agency use to minimize disturbance and preserve existing vegetation? Please check all that apply:
    a. Designate limits of disturbance (LOD) on project drawings
    b. Require General Contractor to certify that no earth disturbance or construction related activities will occur outside the LOD
    c. Require installation and maintenance of stakes, tape, high visibility fencing, or other visual reference points to delineate the LOD
    d. Require installation and maintenance of perimeter controls (e.g., silt fence) along portions of the LOD located down gradient of disturbed areas
    e. Other
2. Does your agency schedule projects so that major soil disturbance and mass grading activities occur during periods with lower expected runoff or precipitation?
    a. Yes

b. No
c. If yes, what periods

3. Does your agency perform risk assessments ahead of seasons with pronounced heavy runoff to identify projects that may need extra attention or effort to maintain compliance?
   a. Yes
   b. No
4. Has your agency developed or started to develop policy or guidance to minimize soil disturbance to meet numeric effluent limitations (NELs) for turbidity on construction site discharges?
   a. Yes
   b. No
   c. If yes, what is the status for completion and availability?
5. Has your agency been involved with any projects that used, in your judgment, innovative or unique project phasing or approaches to successfully limit disturbed areas?
   a. Yes
   b. No
   c. If yes, briefly describe the successful approach

Best practices to stabilize slopes and open graded areas after disturbance

6. Has your agency developed or started to develop project specifications, policy or guidance for temporary or permanent stabilization practices to meet numeric effluent limitations (NELs) for turbidity on construction site discharges?
   a. Yes
   b. No
   c. If yes, what is its status and availability?
7. What *temporary* stabilization practice or combination of practices is typically used on embankment or cut *slopes* on DOT projects? Please check all that apply:
   a. Soil evaluation
   b. Soil preparation
   c. Soil glue or tackifier
   d. Seed mixture
   e. Straw mulch
   f. Wood mulch or compost
   g. Hydraulic application of mulch
   h. Rolled erosion control products
   i. Non-vegetative practice (i.e., aggregate)
   j. Plastic sheeting

k. Other (Please list)

8. What *temporary* stabilization practice or combination of practices is typically used on *flatter areas* (e.g., less than 10% slopes) on DOT projects? Please check all that apply:

    a. Soil evaluation
    b. Soil preparation
    c. Application of soil amendments
    d. Soil glue or tackifier
    e. Seed mixture
    f. Straw mulch
    g. Wood mulch or compost
    h. Hydraulic application of mulch
    i. Rolled erosion control products
    j. Non-vegetative practice (i.e., aggregate)
    k. Plastic sheeting
    l. Other (Please List)

9. What *permanent* stabilization practice or combination of practices are typically used on embankment or cut *slopes* on DOT projects? Please check all that apply:

    a. Soil sampling and analysis
    b. Soil preparation
    c. Application of soil amendments
    d. Seed mixture
    e. Straw mulch
    f. Wood mulch or compost
    g. Hydraulic application of mulch
    h. Rolled erosion control products
    i. Sod
    j. Non-vegetative practices (i.e., aggregate, rip rap, concrete)
    k. Other (Please List)

10. What *permanent* stabilization practice or combination of practices are typically used on *flatter areas* (e.g., less than 10% slopes) on DOT projects? Please check all that apply:

    a. Soil sampling and analysis
    b. Soil preparation
    c. Application of soil amendments
    d. Seed
    e. Straw mulch
    f. Wood mulch or compost

g. Hydraulic application of mulch

h. Rolled erosion control products

i. Sod

j. Non-vegetative practices (i.e., aggregate)

k. Other (Please List)

11. Has your agency developed contract specifications, guidelines or policies for temporary or permanent stabilization that are more stringent than the applicable construction general permit?

    a. Yes

    b. No

    c. If yes, please provide the web link or contact information for obtaining copies of such guidelines, policies, or protocols.

Turbidity reduction technologies

12. What turbidity reduction technologies have you found or determined to be most effective for runoff from construction sites subject to numeric turbidity limits?

    a. Active treatment systems which typically collect runoff and then pump it through a treatment system including flocculation and filtration prior to discharge

    b. Sediment basins (or other trapping device) with flocculant pretreatment.

    c. Combination of traditional erosion and sediment controls (without the use of flocculants)

    d. Other (Please List)

13. What turbidity reduction technologies do you anticipate your agency will use for projects with limited space (i.e., where full sediment basins are not feasible)?

    a. Active treatment systems which typically collect runoff and then pump it through a treatment system including flocculation and filtration prior to discharge

    b. Distributed small-scale sediment traps or basins (or other trapping device) with flocculent pretreatment.

    c. Combination of traditional erosion and sediment controls (without the use of flocculants)

    d. Other (Please List)

14. What hurdles must be overcome before your agency is able to utilize turbidity reduction technologies?

    a. Need to develop standard specifications

    b. Need guidance for design and maintenance

    c. Need training for inspectors

    d. Need training for contractors

    e. Other

15. What methods has your agency used or evaluated to reduce potential for re-suspension of sediment?

a. Removal of captured sediment (please indicate in comments an estimate of how often this really occurs)

b. Covering captured sediment with coarse aggregate, erosion control blankets, mulch with tackifier (e.g. PAM), or other barrier

c. Installing silt curtains, berms/baffles, or settling tubes in sedimentation facilities

d. Sweeping tracked sediment from site entrances, exits, and interior paved areas

e. Other (Please List)

f. Comment

16. Does your agency have example bid approaches for active treatment systems?

    a. Yes

    b. No

    c. If yes, please provide example.

17. Does your agency have an estimate of project costs for active treatment systems?

    a. Yes

    b. No

    c. If yes, please provide

18. What unique erosion or sediment control challenges do you have in your region related to…

    a. Climate:

        i. Seasonal dry and wet conditions

        ii. High altitude

        iii. Cold climate (below freezing for long periods)

        iv. Intense rainfall

        v. Other

    b. Soil type:

        i. Highly erodible

        ii. Difficult to settle (e.g., clay particles)

        iii. Sterile (i.e., inability to quickly establish vegetation)

        iv. Other

    c. Slope condition:

        i. Steep slopes

        ii. Other

    d. Receiving waters:

        i. Wide-scale endangered or sensitive species

        ii. Sediment and/or nutrient impaired, TMDLs

        iii. Other

e. Other? Comment

Sampling methods for discharge turbidity levels in order to document regulatory compliance

19. How often, generally at your agency, is each sampling method employed (0 = never used, 1 = low frequency of use, 2 = moderate frequency of use, 3 = high frequency of use):
    a. Grab: obtaining samples manually at discharge points
    b. Stage: installing sample bottles in a basin or outlet so that they fill as the water rises (stage) during storm events
    c. Simple automatic sampler: a device designed to obtain one or more samples after flow or rainfall is detected; time-weighted composites
    d. Fully automated sampler: a programmable device which obtains samples based on flow or stage and which records flow and rainfall; flow-weighted composite samples
    e. Water quality probe/turbidity meter: a device which records turbidity directly in discharge for a discrete sample (e.g., once a day, week, etc.)
    f. Water quality probe/turbidity meter: a device which records turbidity directly used in a continuous recording mode (15 minute data for example during runoff).
20. Do you expect to continue using the same sampling methods to document regulatory compliance with the upcoming NELs?
    a. Yes
    b. No
    c. If no, please provide comments
21. Please rate the influencing factors you consider when selecting a sampling method from 1 (low influence) to 3 (high influence)
    a. Safety
    b. Cost
    c. Required sampling frequency (per discharge point)
    d. Required number of sampling locations
    e. Permit requirement
    f. Reliability
    g. Adaptability to changing discharge conditions
    h. Seasonality (i.e., rainy vs. dry season)
    i. Size of disturbance area
    j. Compatibility with dynamic construction site
    k. Accuracy
    l. Other (please list)
22. What types of samples are evaluated (check all that apply):
    a. Discrete (an individual sample collected over a short period)
    b. Composite (obtained by continuous sampling or mixing discrete samples)

23. Does your agency MS4 permit include sampling requirements?
    a. Yes
    b. No
    c. If yes, please provide the web link or contact information for obtaining additional information on the sampling requirements.
    d. Our agency is not subjected to MS4 permit requirements

Monitoring Guidelines

24. For linear projects, the proposed EPA rule will allow you to sample discharges from selected discharge point(s) if it is substantially identical to other discharge points based on similarities of exposed soils, slope, and type of stormwater controls used. Does your agency anticipate using this approach on your projects to reduce the number of monitoring locations?
    a. Yes
    b. No
    c. Have not determined
25. Has your agency developed guidelines, policies, or protocols for determining representative discharge locations for DOT construction sites or MS4s?
    a. Yes
    b. No
    c. If so, please provide the web link or contact information for obtaining copies of such guidelines, policies, or protocols.
26. Has your agency developed guidelines, policies, or protocols for selecting sampling frequency to yield representative results?
    a. Yes
    b. No
    c. If so, please provide the web link or contact information for obtaining copies of such guidelines, policies, or protocols.
27. Would your agency consider it appropriate to use visual or photographic monitoring methods in lieu of measuring turbidity?
    a. Yes
    b. No
    c. If yes, under what circumstances?
28. Has your agency considered or developed design practices or project specifications to minimize the number of discharge locations (outfalls)?
    a. Yes
    b. No
    c. If so, please provide the web link(s) or contact information for obtaining copies of such guidelines, policies, or protocols.

29. The EPA rule indicates that diffuse stormwater, such as non-channelized flow through a silt fence or other perimeter control that infiltrates into a vegetated area, and does not then discharge to surface waters, would not generally require sampling. Has your agency considered or developed design practices or project specifications to maximize use of non-channelized (diffuse) flow through perimeter controls?
    a. Yes
    b. No
    c. If so, please provide the web link(s) or contact information for obtaining copies of such guidelines, policies, or protocols.

Storm water pollution planning during project development

30. For projects that require a Storm Water Pollution Prevention Plan (SWPPP) or Erosion and Sediment Control Plan (ESCP) or similar document, approximately what percentage of those projects does the selected General Contractor have the responsibility for developing the SWPPP (ESCP or similar document)?
31. If the General Contractor has responsibility for developing the SWPPP, does your agency provide a SWPPP template?
    a. Yes
    b. No
    c. If yes, in what areas has the SWPPP template led to better compliance (Check all that apply)?
        i. None
        ii. Communication of compliance objectives
        iii. Project sequencing or timing
        iv. Minimizing disturbance
        v. Stabilization of disturbed areas
        vi. Sediment control performance
        vii. Sediment/sediment-laden discharges
        viii. Treatment Train (Combination of BMPs from different categories)
        ix. Checklists for Monitoring and Reporting
        x. Training Requirements
        xi. Other
32. Does your agency use BMP effectiveness information to prioritize the selection of individual erosion and sediment controls BMPs on a project?
    a. Yes
    b. No
    c. If yes, what is your source for BMP effectiveness information?

33. Does your agency (or state permit) require formal training and certification related to permit compliance?
    a. Yes
    b. No
    c. If yes, please describe (please include whether training is for DOT staff, contractors, or both)
34. Are professional certifications (CPESC, PE, etc) required for preparing plans and or for monitoring and implementation?
    a. Yes
    b. No
    c. If yes, please describe
35. Does your agency provide construction stormwater training internally (i.e., to staff)
    a. Yes
    b. No
    c. If yes, please also indicate if your agency certifies contractors or others to do the training
36. Does your agency provide construction stormwater training externally (i.e., to contractors)
    a. Yes
    b. No
    c. If yes, please also indicate if your agency certifies contractors or others to do the training

Institutional mechanisms and incentives to encourage compliance, accountability, and performance

37. What institutional mechanisms or incentives does your agency employ to encourage stormwater compliance, accountability, and performance? Please check all that apply:
    i. None
    ii. Liquidated damages for non-compliance
    iii. Non-monetary recognition
    iv. Monetary incentives compliance
    v. Performance measurement and external reporting
    vi. Assign score to be considered during procurement of future work
    vii. Other (please list)
    viii. Please describe fines, penalties, or monetary incentives.
38. Do you have an electronic/online inspection tracking system?
    a. Yes
    b. No

c. If yes, select all that apply:

    i. It has made it easier/faster to issue letters or notices of non-compliance, with documentation, to the contractor
    ii. It has improved turnaround times with corrective action
    iii. It has improved overall compliance
    iv. It is producing information on BMP effectiveness
    v. It has streamlined documentation and reporting
    vi. Is it reducing turbidity

Representative site characteristics (disturbed areas, drainage areas)

39. Of the construction projects has your agency started during the last 4 years, approximately how many had disturbed areas exceeding 10 acres? What percentage are these of the total?