



NCHRP 25-25(74)

Turbidity Reduction and Monitoring Strategies for Highway Construction Projects

Project Overview

Regulatory Driver: USEPA's C&D Rule (2009), which imposed Numeric Effluent Limitations (NELs) for turbidity on construction sites over 20 acres (10 acres when fully implemented)

Project Focus:

- **Current Practices**
 - First and follow-up surveys sent to AASHTO Water Quality Community of Practice members
- **Turbidity Reduction**
 - How can construction sites meet more stringent turbidity standards?
- **Turbidity Monitoring**
 - What research and guidance is available to help states who are new to turbidity monitoring requirements?

- Don't go into detail on the C&D (construction and development) Rule here, but mention that the history is covered in more detail in the next slide
- AASHTO CoP members surveyed are generally representatives of state DOTs. Not all states returned surveys.
- Surveys covered current practices in turbidity prevention, treatment, monitoring, and administration of such programs.

History of Legislation

- **December 2009** – USEPA C&D Rule imposed Numeric Effluent Limitation (NEL) of 280 NTU for turbidity on construction sites with ≥ 20 acres of disturbed soils (10 acres when fully implemented).
- **November 2010** – Numeric limitation and associated monitoring requirements were stayed by USEPA indefinitely due to legal challenges.
- **April 2011** – USEPA issued a proposed Construction General Permit (CGP) that included monitoring requirements for construction sites and left placeholders for numeric limitations
- **January 2012** – USEPA solicited additional information on many aspects (costs, methods, etc.) of turbidity monitoring
- **February 2012** – Final USEPA CGP is issued with no turbidity monitoring or numeric limitations

C&D Rule formally known as “Guidelines and Standards for the Construction and Development Point Source Category”

Good place to explain numeric effluent limit (permit violation for exceeding limitation), as opposed to a Numeric Action Level (simply requiring additional actions be taken).

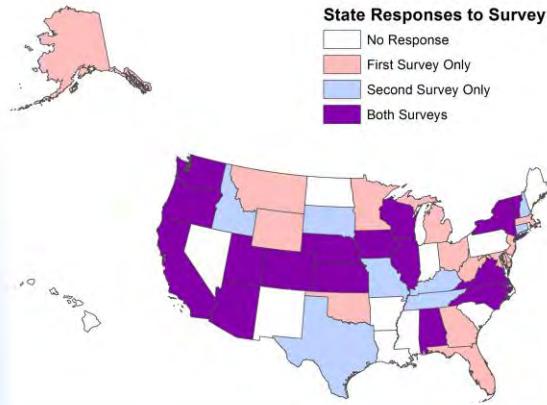
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Current Practices

Summary of DOT Survey

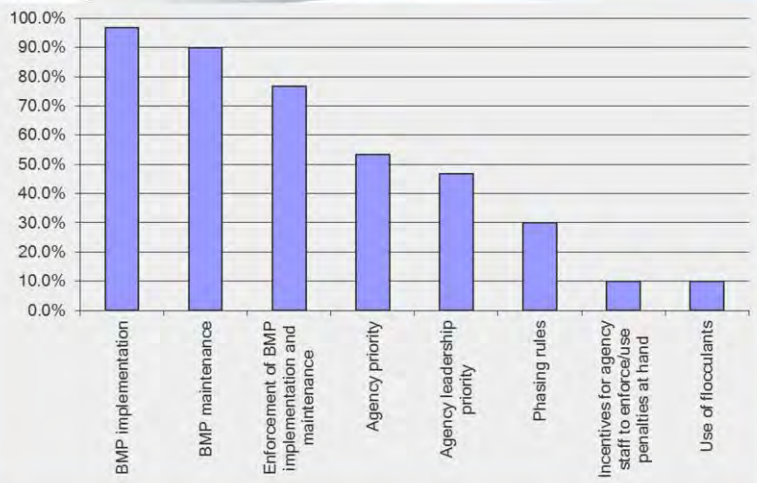
Summary of DOT Survey

- Two surveys sent to state DOTs in August and September 2011
- 33 responded to the first survey, 23 responded to the second survey



First survey included more general questions about practices, the second survey included more detailed follow-up questions intended to gather more information.

Summary of DOT Survey (cont.)



Factors shown to be successful in DOT erosion and sediment control

Nearly all respondents agreed that BMP implementation and maintenance are important factors for successful erosion and sediment control

At 77%, enforcement ranked nearly as high.

Only 10% of state DOTs indicated that flocculant use was an important factor – 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.

Summary of DOT Survey (cont.)

Regarding Polyacrylamide (PAM) Use:

- 30% of responding states have approval procedures for PAMs (AL, CA, GA, MD, MN, NC, NY, VT, WA, and WI)
- 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)

Summary of DOT Survey (cont.)

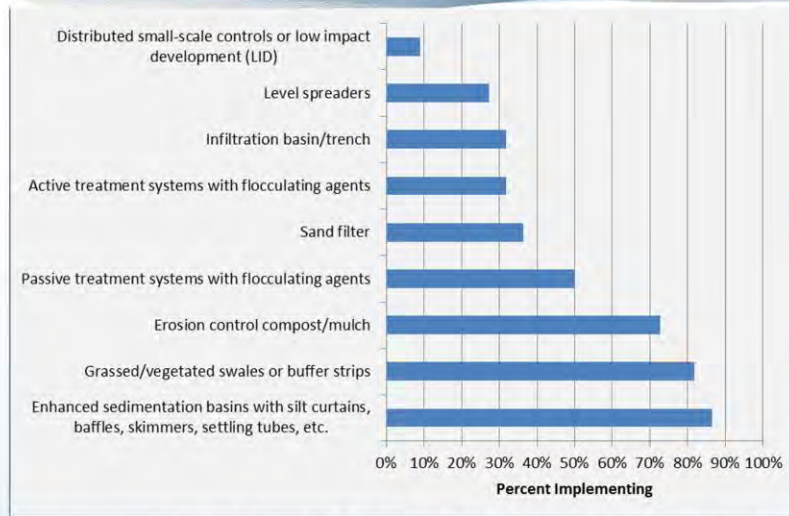
Regarding Project Phasing and Source Control Methods:

- Most states only require marking limits of disturbance on project drawings, while others also require field staking
- Several states must identify limits of disturbance for each phase of the project (AL, AK, DE, FL, MD, MI, NJ, NY, and VT)
- Most states utilize conventional stabilization practices such as wood and straw mulch, hydroseeding, and rolled erosion control products
- Tackifiers were only identified as being used by 44% of the responding states

Most responding states have design practices, standard specifications and/or contractual requirements to address the timing and size of disturbance

How these practices/requirements are implemented or enforced varies widely

Summary of DOT Survey (cont.)



Innovative BMPs identified by DOTs to be effective or cost-efficient

Top responses 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.

Summary of DOT Survey (cont.)

Regarding BMP Effectiveness Research/Data Collection:

- One-third of respondents accumulating field BMP effectiveness information, but on further investigation, little such information seemed to be available
- 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
- 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

Summary of DOT Survey (cont.)

Efforts Taken to Prepare for National Effluent Limits :

- Just over a third (36.4%) of responding states have developed or started to develop policy or guidance associated with NELs
- Only 12% of respondents reported that they had conducted studies on the maintenance of turbidity reduction technologies at DOT facilities (AL, CA, NC, and NJ)
- Many DOTs foresee the need to add components to their agencies' bid item lists to increase their ability to comply with NELs
- Over a quarter (27%) of states reported that sampling of construction site discharge turbidity is currently required of their DOTs (AL, AZ, CA, FL, GA, MN, OR, VT, and WA)



Turbidity Reduction

Turbidity Reduction Technologies

- Conventional Practices in Erosion and Sediment Controls
- Enhanced Erosion and Sediment Controls
- Coagulation and Flocculation
 - Chemicals Used
 - Passive Treatment Methods
 - Active Treatment Systems (Chemical and Electrocoagulation)
 - Residual Toxicity
 - pH Management
 - Treatment Costs and Reliability
- Current Turbidity Treatment Requirements Identified by DOTs

The next several slides will provide an overview of conventional and enhanced erosion and sediment control controls followed by a discussion of more advanced coagulation and flocculation technologies that can be used to reduce turbidity in construction site runoff.

Conventional Practices in Erosion and Sediment Control

- Minimization of disturbance
- Site drainage planning
- Soil stabilization
- Perimeter controls
- Structural sediment controls
 - Swales and trenches
 - Berms and flow spreaders
 - Inlet protection
 - Sediment traps and basins
 - Filtration systems
- Site inspections and corrective actions



Hydroseeding for Temporary Erosion Control
(Caltrans, n.d.)

Site drainage planning may incorporate either dispersal of runoff or alternatively may focus on minimizing the number of outfalls

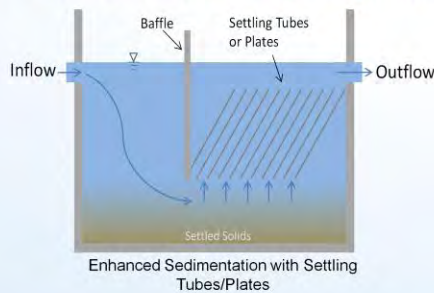
Perimeter controls may include

- special construction entrances with coarse stone that helps to remove sediment from tires. This may require maintenance as the pore spaces fill with sediment.

- silt fences, fiber rolls, silt dikes
- berms or diversion ditches
- vegetated buffer strips

Enhanced Erosion and Sediment Controls

- More rigorous/redundant application of standard controls
 - Slope stabilization
 - Silt fences
 - Stabilized conveyances and check dams
- Tackifier use in erosion control and hydroseeding
- Sedimentation facility design enhancements



Faircloth Skimmer® Floating Riser Outlet.

- Improper installation of silt fences appears to be common (e.g., in areas of concentrated flow, not trenched in, or with filter fabric on the wrong side of the wire backing), and this highly degrades their effectiveness/reliability.
- The 2012 USEPA construction general permit actually requires outlet structures that withdraw water the surface (like the one pictured above) in order to minimize discharge of pollutants, unless it is infeasible.

Coagulation/Flocculation - Chemicals Used

- **Natural polymers**
 - Chitosan – widely accepted cationic polymer derived from shellfish exoskeletons
 - Others include Moringa oleifera, guar gum, and tannins (e.g., extracts from Mimosa bark and Valonia acorns), but none commonly used
- **Synthetic polymers**
 - PAM – many different formulations, used in agriculture for decades. Use anionic forms with longer polymer chain length.
 - DADMAC – slightly more toxic option
 - PAC – similar to alum, but less impact on pH
- **Inorganic salts** – salts containing highly charged cations, such as iron (Fe^{3+}), aluminum, calcium, or magnesium
- **Microcarriers** – inert fine grained sands that provide a weighty nucleus for floc formation and enhanced settling

PAM – polyacrylamide

DADMAC (actually poly-DADMAC): diallyldimethyl ammonium chloride

PAC – polyaluminum chloride

Passive Chemical Treatment

- **Passive chemical treatment** – unattended, unmetered. Chemicals released in response to gravity or dissolution of chemicals.
- A few methods of dosing that have been used and studied for stormwater treatment:
 - New Zealand method: dose mechanically released proportional to rainfall volume
 - Floc Blocks (a.k.a. floc logs) – solid blocks of polymer that dissolve as discharge flows over them
 - Manually dosing check dams with powdered PAM

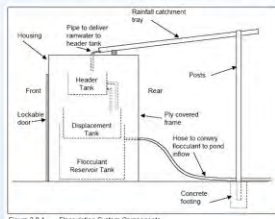


Figure 2.8.1 Flocculation System Components



Floc blocks can get buried in sediment very easily, and must be placed carefully to avoid this. Floc blocks can be tailored to meet the needs of that site's soil type.

Passive Chemical Treatment

New Zealand Method

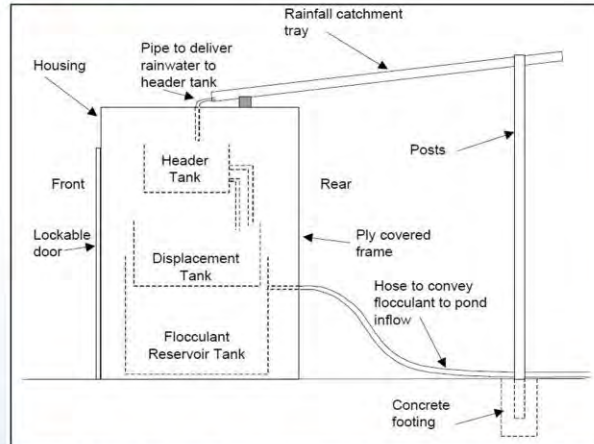


Diagram of New Zealand Method Set-up (Beca Carter Hollings & Ferner Ltd, 2003)

Note that the header tank allows there to be a delay between initial rainfall and delivery of chemical, since runoff will likely not reach the treatment area precisely when rainfall commences.

Active Treatment Systems

- Chemical Treatment – Accomplished by adding a chemical coagulant/flocculant and then filtering or settling flocs.
 - Batch treatment
 - Collects stormwater in a storage pond or in tanks
 - pH is adjusted and polymer is added
 - Sedimentation is used to remove flocs, and water is discharged when turbidity/pH are appropriate
 - Flow-through treatment
 - Collect stormwater in a storage pond or tanks
 - pH adjustment and polymer are added en route to filtration
 - Effluent from filtration is checked for pH and turbidity and recycled to the storage tank for further treatment as necessary
- Often includes continuous monitoring of effluent pH, turbidity, and residual chemicals

Four Chambered
Sand Filter



Active treatment systems generally have pH and turbidity sensors, along with valves to recycle water that needs retreatment. Retreatment (recycling) is common in areas with high turbidity.

Electrocoagulation

- Form of active treatment
- Uses electricity to create charged particles
- Automatic adjustment of treatment to incoming turbidity
- Requires less oversight by operator
- No chemical costs, although electrodes need to be replaced monthly and electricity costs must be considered



An Electrocoagulation Trailer with Control Panel (left) and Electrocoagulation Treatment Cells (right) (Mothersbaugh, 2010)

- Electrocoagulation automatically adjusts to the level of incoming turbidity, because higher turbidity is associated with higher conductivity. The higher conductivity allows more electricity to flow. Therefore more treatment results without operator control.
- Electrocoagulation systems have been approved for use in Washington State without an operator on the site, but the operator must be able to respond quickly to automatically generated phone/pager notification.

Residual Toxicity

| Chemical | Toxicity | Factors Affecting Toxicity | Methods of Controlling Toxicity | Overall Toxicity Management Ease |
|-----------------------------|----------------------------|---|---|--|
| Chitosan | Moderate | Worse with low turbidity | Simple effluent test. Very safe when used in highly 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 weight, 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 |

pH Management

- Coagulants and flocculants can affect pH
- Coagulants and flocculants often have a pH range in which they operate most effectively
- Discharge may also need to be treated for pH before discharge, especially if there has been concrete work on site

Chemical Treatment Costs and Reliability

- Costs for treatment vary tremendously from site to site, even for sites with the same treatment method
- Of the studies identified, active treatment costs ranged from \$4 - \$83 per thousand gallons treated, with a median of \$15
- Passive treatment costs (per USEPA estimates using New Zealand method) would range from \$1.80 to \$13 per thousand gallons treated
- Electrocoagulation is roughly the same price as other forms of active treatment
- Active systems are much more reliable (as compared to passive systems) in achieving a specific turbidity value for discharge

Current Turbidity Treatment Requirements

A minority of states already have turbidity treatment requirements:

- Turbidity limitations based on ecological risk of the site – AK, CA, GA
- Turbidity limitations based on turbidity increase in sensitive waters – AK, AZ, NH, SD
- Exemptions for large storms – AK, CA
- GA has the highest and lowest effluent limitations (20 – 750 NTU) that are set based on the ecological risk
- Washington State has a program for approval of chemical treatment technologies



Turbidity Monitoring

Turbidity Monitoring Overview

- Sampling Techniques
 - Grab vs. composite
 - Manual vs. automated
 - In-situ water quality probes
 - Stage sampling
 - Remote communication
- Measurement of Turbidity
- Regulatory Drivers
- Accuracy, Reliability, and Cost Comparisons

The next several slides will provide an overview of turbidity monitoring techniques including sampling, turbidity measurement, and a comparison of methods.

Monitoring Guidance Available

| Title | Author and Date | Link |
|---|--|---|
| Stormwater Monitoring Guidance Manual for Construction Activities | Arizona Department of Transportation. (2009) | http://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) | http://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) | http://www.dot.ca.gov/hq/construct/stormwater/SamplingGuidanceManual.pdf |
| Standard Operating Procedures for Manual Field Measurement of Turbidity | California Department of Transportation. (2012b) | http://www.dot.ca.gov/hq/construct/stormwater/Caltrans_SOPs_CD.pdf |
| Construction Storm Water Sampling and Analysis Guidance Document | California Stormwater Quality Task Force. (2001) | http://www.cabmphandbooks.com/Documents/Construction/Appendix_C.pdf |
| Monitoring of Turbidity in Stormwater Runoff from Construction Activities | Vermont Department of Environmental Conservation. (2008) | http://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) | http://www.eco-3.com/manuals/DOE_Guide_to_SW_Monitoring.pdf |

Sampling Techniques

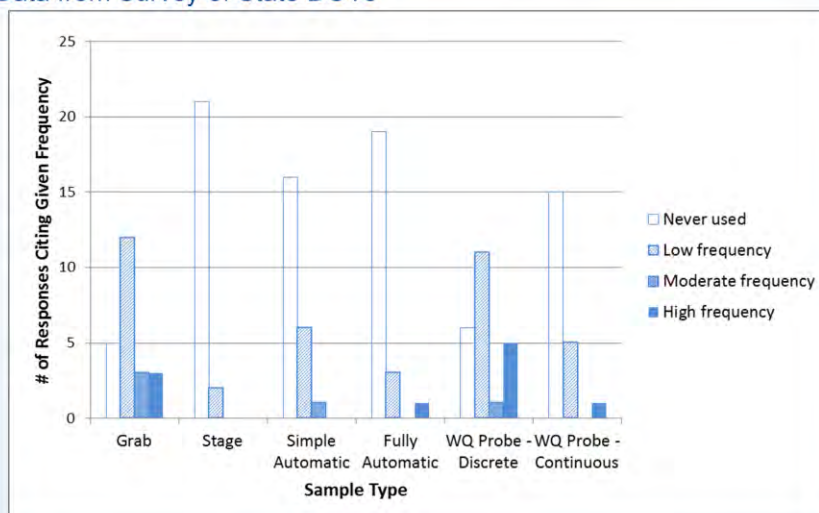
- Grab Samples – Manual collection of a sample
- Stage Samplers – Configuring a sample bottle with intake and exit tubes so that the bottle fills as the water level rises
- Automated Samplers – Configuring a programmable mechanical device to collect one or more samples after flow or rainfall is detected
- In-Situ Probe – using a device that measures turbidity directly in the water column or in a flow-through cell (no actual sample collected)

Stage samplers do not accept any fluid after they are filled. They were primarily designed for collecting samples in remote locations.

Note that these methods must be combined with other procedural considerations, such as on-site analysis vs. laboratory analysis or not compositing vs. time-weighted-compositing vs. flow-weighted compositing of samples

Prevalence of Sampling Techniques

Data from Survey of State DOTs



Two surveys were sent to AASHTO Water Quality Community of Practice Members as part of this project.

Note that five respondents stated that they did not use any sampling technique, so that all states that sample use grab sampling at least occasionally, and all but one that sample use in-situ WQ probes at least occasionally.

The actual language in the survey was:

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):

Grab: obtaining samples manually at discharge points – Frequency

Stage: installing sample bottles in a basin or outlet so that they fill as the water rises (stage) during storm events – Frequency

Simple automatic sampler: a device designed to obtain one or more samples after flow or rainfall is detected; time-weighted composites – Frequency

Fully automated sampler: a programmable device which obtains samples based on flow or stage and which records flow and rainfall; flow-weighted composite samples – Frequency

Water quality probe/turbidity meter: a device which records turbidity directly in discharge for a discrete sample (e.g., once a day, week, etc.) – Frequency

Water quality probe/turbidity meter: a device which records turbidity directly used in a continuous recording mode (15 minute data for example during runoff). - Frequency

Compositing Samples

- Compositing samples – combining samples before analysis
- Can be done in two ways
 - Time-weighted – does not account for changes in flow
 - Flow-weighted – accounts for changes in flow
- Manual compositing can be done, but may introduce errors and is labor intensive if there are many locations to sample
- Automatic compositing can be done by automatic samplers, and can give a much more representative turbidity, while decreasing analysis time/costs.

An example of time-weighted compositing would be to take a sample every hour of discharge and average them

An example of flow-weighted compositing would be to take a sample after a specified amount of flow has gone past a flow meter. This method, of course, requires installation of a flow meter.

Manual Sampling

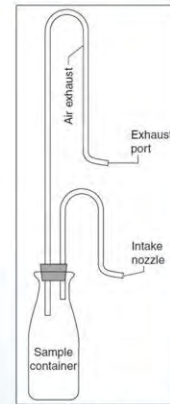
- Easiest and most cost-effective method for programs with few storm events and sampling locations
- Most flexible in changing conditions
- Accuracy of results depends on good technique
- Requires sampling crews to be on-site and ready on short notice



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

Stage Sampling

- Very inexpensive
- Can only capture samples as water level rises
- Compositing can be done by putting samplers at different levels
- No control over or record of sample collection time
- No way to determine an event mean turbidity, because of little control over compositing
- Developed for remote streams and is more appropriate for that application than regulatory compliance at active construction sites



Stage Sampler Designed to Take Samples as the Stage Rises (Lane, Flanagan, & Wilde, 2003)

Interestingly, one state (GA) specifically has allowed their use.

Because of the limitations of stage samplers, they were not included in the rest of the comparative analysis of sampling methods.

Automated Samplers

- Can sample without being directly human operated
- Can automatically do compositing or collect discrete samples
- Are programmable
- Can be connected with remote communication equipment to change settings remotely
- Can be connected to flow meters to do flow-weighted compositing
- Can be connected to rain gauges for triggering of first sample
- Require refrigeration (or ice) to keep samples cool
- Can have trouble with clogging of intake tubes



Programming an Automatic Sampler (Geosyntec Consultants and Wright Water Engineers, 2009)

These have electromechanical systems to deliver samples to different bottles. There are many configurations for sample bottles, and it is possible to use one large one or many smaller bottles. In theory, it is possible to composite over a hundred aliquots into a sample, although the practical maximum might be notably lower, because these systems require some time to process any given sample (taking sample, flushing lines, etc.). For short, intense rains and flow-weighted compositing, sample collection might get queued, with samples not actually getting taken when they are supposed to.

In-situ Water Quality Probes

- Probes eliminate the laboratory cost of analyzing samples because turbidity is measured on-site
- Commonly used in environmentally sensitive streams
- When combined with real-time communication equipment, can provide real-time alerts of turbidity problems
- One sonde may contain many different sensors, so that many water quality parameters may be recorded simultaneously
- If not in receiving waters, can require careful installation to avoid being covered in sediment or partial sensor coverage
- Many probes have wipers to prevent fouling of the sensor window
- Data can be used to calculate a flow-weighted (if flow data available) or time weighted turbidity

Battery use is affected by the frequency of turbidity readings that are taken. One reading every 15 minutes is common.

Although turbidity sensors can be dried out without damaging the sensor, a partially covered sensor can result in erroneous readings. Also, some (non-turbidity) sensors can be damaged by drying out.

Remote Communication Equipment

- Modem or wireless access to automated samplers and water quality probes
- Can increase capital costs significantly, but decrease labor and training costs
- Provides ability to adapt an automatic sampling program on the fly, based upon Doppler radar or weather forecasts
- Can provide real-time feedback on field conditions



Labor and training costs drop because the more technical aspects of automatic samplers can be controlled by one system supervisor

Measurement of Turbidity

- Several standard methods exist
 - EPA 180.1 – uses tungsten lamp (white light)
 - ISO 7027 – uses LED (near infrared “light”)
 - GLI-2 – two source-detector pairs at right angles to each other
- Nephelometry – measurement of scattered light at 90° to incoming light.
- Ratiometric turbidimeters use more than one light sensor to compensate for effects of color and measurement noise.
- Backscatter sensors – measure light at greater than 90° to incoming light; good for high turbidities (roughly 5 NTU to 4000 NTU).



There are some pretty wide tolerances in each standard. For instance, ISO 7027 turbidimeters may use light with a wavelength of 860 ± 60 nm, and EPA Method 180.1 allows the sensor to be at $90 \pm 30^\circ$ to incoming light. Both detection angle and wavelength of light used will affect the response of the turbidimeter to various sources of turbidity.

Measurement of Turbidity (cont.)

- Calibration of turbidimeters uses formazin
- Each standard method has tolerances → Meters from different manufacturers can vary widely in their readings of the same sample
- Standardizing the turbidimeter models used for a study or within a compliance program can result in more comparable data
- Some states have already started to standardize (e.g. Washington, South Dakota, Caltrans)



Each turbidimeter should be calibrated to the formazin standard (or a secondary standard if necessary), and must read the same value for formazin, but the substances causing turbidity in stormwater runoff are very different than formazin in color, particle size distribution, and particle shape, all of which affect turbidity readings differently for different meters.

Turbidimeter Standardization Notes:

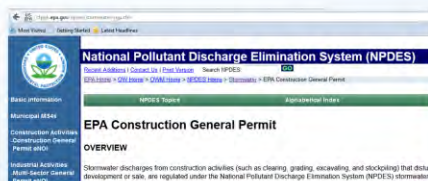
Washington State Department of Transportation (2010) specifies a model of turbidimeter in the Standard Sampling Procedures section of its *Highway Runoff Manual*.

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.

Regulatory Drivers in the Selection Process

- EPA's proposed Construction General Permit (CGP) stated that
 - A minimum of three samples should be taken each day there is discharge
 - The first sample should be taken within 1 hour of the start of discharge
 - Combination of substantially identical discharge locations is limited to linear projects
- State monitoring requirements differ noticeably from each other and those of the proposed CGP
 - In-stream sampling requirements
 - Different methods possible



-Be sure to point out that the monitoring requirements for the proposed permit were stricken from the final CGP, but that this proposed permit represents the best guess as to current thinking of the EPA on how they might implement monitoring requirements in the future, should they choose to do so.

-Proposed CGP: Three samples should be taken such that the beginning, middle, end of the work day's discharge are sampled.

-In-stream monitoring is sometimes required for sensitive waters in state CGPs

-Washington specifically allows the use of transparency tubes on smaller sites, while Georgia specifically allows stage samplers

Accuracy Comparison

Proper installation and technique is very important for all methods.

- **Manual grab samples**
 - Can adapt easily, but prone to inconsistent technique especially if crews change
 - Prone to errors in compositing
- **Automatic samplers**
 - Consistent technique, but intake tubes can clog, and larger particles may be discriminated against (maybe not a problem for turbidity measurement)
 - Less able to adapt to changing site conditions
 - Can do flow- or time-weighted compositing

Larger particles may have a slight tendency toward settling. Models using vacuum/compressor pumps may help in this by using faster sampling velocities.

Accuracy Comparison (cont.)

- In-situ water quality probes
 - “Samples” not affected by delay in measurement, settling, or temperature change
 - Fouling can occur in biologically active waters
 - Requires careful installation and maintenance
 - Calibration drift can be a problem
 - Can calculate flow or time-weighted averages

Larger particles may have a slight tendency toward settling. Models using vacuum/compressor pumps may help in this by using faster sampling velocities.

WQ require careful installation and maintenance to ensure probe is fully covered during storms, protected from damage by large objects and doesn't get buried in sediment. Sediment may accumulate and may need to be removed on a regular basis to ensure the probe does not get buried.

Reliability

- **Manual grab samples**
 - Offsite crews may have trouble getting onsite in time, and have less accurate knowledge of the runoff start time
 - Unsafe sampling conditions may prevent sampling
- **Automatic samplers**
 - Sample intake tubes may clog
 - Power failures/battery failure possible
 - Sampler loss/damage
- **In-situ probes**
 - Probes may get buried in sediment or exposed during low flow
 - If in receiving waters, can be damaged if not protected well
 - Battery/wiper blade maintenance important
 - Calibration drift may bias results

Unsafe sampling conditions during storms may be a serious consideration in the decision of which sampling method to use. Each site is different.

Automatic samplers do get stolen or damage, or even washed away into streams if not secured properly.

Cost Comparison – Hard Costs

| 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 |

These are just a few of the costs that may be incurred. Additional costs are on the next page.

Cost Comparison – Additional Costs

Additional sampling program costs to consider

- Weather tracking
- Station set-up/calibration
- Mobilization
- Sample collection and handling
- Analytical lab costs, if used
- Data validation, analysis, reporting, as necessary
- Equipment maintenance, breakage, loss
- Manual sampling much cheaper for small programs

Automatic samplers can become less costly for programs with large numbers of sampling locations, lots of sampling events per year, or programs where locations will not change for long periods of time.

Estimates of labor or outsourced services must be considered for these tasks and combined with hard costs from the previous slide to arrive at an estimate of total program costs.

Regulatory Drivers and Sampling Frequency

- Regulations requiring sampling in the first hour of discharge may discourage manual sampling in some situations.
- Regulations set the baseline sampling frequency requirement
- Because turbidity can vary widely within a storm, a small number of samples may more easily result in an unnecessary (inaccurate) numeric limit exceedance.
- When sampling above the baseline frequency may be warranted
 - Numeric Effluent Limitations (NELs) instead of Numeric Action Levels (NALs)
 - Sites at high risk of regulatory exceedance, which may depend on
 - Receiving water type and impairment
 - Climate – arid regions may have naturally high turbidity in discharge
 - Distance to receiving water
 - Project slope, soil type and drainage path length

-As every state may have different requirements, these must be consulted for each project.

-NALs require reactive measures to improve discharge quality

-NELs exceedance is a violation of the permit. This is a more serious consequence, and warrants more caution to avoid unnecessary exceedance. By increasing sampling, the reported turbidity is more likely to be close to the actual event mean turbidity, and unnecessary exceedances will be avoided.

Choosing a Sampling Method (Manual Grab Samples)

| Monitoring Equipment | Factors Favoring Use of This Approach |
|----------------------|---|
| Manual grab samples | <ul style="list-style-type: none"> • 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.) |

Manual grab sampling is highly adaptable, and has low capital, maintenance and training costs. These are strong drivers for choosing manual sampling in the situations listed above.

Choosing a Sampling Method (Automatic Samplers)

| Monitoring Equipment | Factors Favoring Use of This Approach |
|----------------------|---|
| Automated samplers | <ul style="list-style-type: none"> • 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: <ul style="list-style-type: none"> – 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. |

Automatic sampling can reduce labor costs and logistical headaches, because sampling efforts don’t have to be made at precise time, but can be spread out. It also eliminates safety concerns that may develop during heavy rainfalls. Finally, it can perform flow-weighted compositing automatically (with a flow meter), which not only gives a more accurate representation of the event mean turbidity, but reduces analytical costs and effort. These are strong drivers for choosing automatic sampling in the situations listed above.

Choosing a Sampling Method (In-situ Probes)

| Monitoring Equipment | Factors Favoring Use of This Approach |
|--|--|
| Continuous, in-situ water quality probes | <ul style="list-style-type: none"> • 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 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. |

In-situ probes can provide real-time data with remote communication equipment, dropping response time to problems significantly. They provide near-continuous (usually every 15 minutes) data, to help understand (and potentially resolve) turbidity issues better. There are no analytical costs (although labor would be required to retrieve the data with remote communication. Those factors drive the choice for in-situ probes in the above situations.

These probes are most commonly used in receiving waters.

Representative Discharge Sampling Locations

- Good strategy to reduce sampling requirements
- Many states (and EPA) are allowing this (with justification)
- Dischargers usually have to justify
- States may or may not give specific criteria for justifying
- In general, look for sites in which the following are substantially identical:
 - Slope
 - Imperviousness
 - Soil type
 - Construction activities in progress
 - Stormwater treatment BMPs in use
- Sampling the location predicted to be worst among several locations may also be an option

- Explain what representative discharge sampling locations are.
- This concept has been used for decades (ex. 1992 USEPA's "National Pollutant Discharge Elimination System Stormwater Sampling Guidance Document" for industrial discharges discusses it)

USEPA's 2011 proposed CGP allowed the use of representative discharge sampling locations based on similarities of exposed soils, slope, and type of stormwater controls.

Sampling the location predicted to have the highest turbidity may, of course, make turbidity appear worse than normal, and should only be used when there is a low danger of exceeding regulatory turbidity levels. There is not much regulatory precedent for this logic in representative locations, although it is well-established in other areas of stormwater work.

Project Phasing and Diffuse Flow

Phasing to minimize sampling requirements, whenever possible,

- Plan projects during seasons with less rainfall
- Stabilize soils as soon as possible
- Keep disturbed soils under regulatory thresholds by doing the work in separate phases.

Diffuse flow

- The C&D Rule exempted diffuse (non-channelized) discharge through a perimeter control (e.g. silt fence) from sampling requirements.
- Requires
 - Adequate distance from a receiving water
 - Undisturbed vegetative buffer
 - Low to moderate slopes

The C&D Rule contained provisions that provided sampling exemptions for projects with disturbed areas of less than 10 acres.

Monitoring Plans

After establishing a sampling approach, prepare a monitoring plan with

- 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



Conclusions

Conclusions – Turbidity Reduction

- Preventative (source control) BMPs are more cost-effective than treatment BMPs, but less reliable for meeting numeric limits
- Conventional BMPs or even enhanced conventional BMPs are unlikely to meet turbidity effluent limits reliably
- Passive use of chemical treatment will meet effluent limitations most of the time
- Active treatment systems ARE able to meet or greatly surpass requirements reliably, but are expensive
- All treatment plans and costs are highly site-specific

Conclusions – Turbidity Reduction (cont.)

| Sediment Control Method | Expected Achievable Turbidity Range | Reliability | Monitoring & Maintenance Requirements | 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 |

Conclusions - Turbidity Monitoring

- **Manual grab sampling**
 - Low capital, training and maintenance costs
 - Compositing difficult, require crews to be on site with short notice
 - Good for low budget projects of short duration or changing conditions
- **Stage sampling**
 - Significant limitations – not recommended for regulatory compliance
- **Automatic samplers**
 - Excellent for compositing, no need to be on site during discharge
 - Large capital, training, O&M costs
 - Best for longer projects with consistent sampling locations and frequent storms

Conclusions - Turbidity Monitoring (cont.)

- In-situ probes
 - Near-continuous data (and real-time with remote communication)
 - Higher capital costs, require careful installation and maintenance, especially if not used in a receiving water
 - Best used in highly sensitive receiving waters, but can be used elsewhere
 - Can be used to determine flow- or time-weighted averages

Conclusions – Turbidity Monitoring (cont.)

- Technique and training are important to collecting quality data
- Use knowledge accumulated by other states to develop sampling programs
- To decide if an enhanced sampling program is needed,
 - Determine if the site is at risk for exceeding discharge turbidity limits, and
 - Determine if the consequences (environmental or regulatory) warrant the extra effort/cost.

“Enhanced sampling plan” refers to sampling more often than required by regulations.

Conclusions – Turbidity Monitoring (cont.)

- Use strategies such as representative sampling locations, project phasing, and diffuse discharge to decrease sampling requirements
- Standardize turbidimeter model used or verify that turbidimeters in use respond consistently to real-world discharge samples
- Flow-weighted compositing of samples provides the most representative turbidity value

“Enhanced sampling plan” refers to sampling more often than required by regulations.

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Questions?

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