A Department of Ecology Report

Phosphorus Concentrations in Construction Stormwater Runoff: A Literature Review

Abstract

The purpose of this literature review is to explore current information about phosphorus in construction stormwater discharges, including the relationship between total phosphorus and surrogate parameters such as turbidity or total suspended solids. Currently, there is very little information available on phosphorus in construction stormwater.

This review explores the fate and transport of phosphorus in the environment, as well as discussion topics for any future studies on phosphorus in construction discharges. The review also explores the special conditions that apply when federal Clean Water Act Section 303(d) listed waterbodies are impacted by phosphorus in construction stormwater.

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Project Objectives and Description

The objectives for this study are to (1) provide scientific information on the phosphorus content of stormwater discharges from construction sites, and (2) inform permit writers on whether to include monitoring requirements from these sources in the general construction permit.

This literature review will:

- Present information on phosphorus concentrations from construction activities.
- Explain relationships between total phosphorus and surrogate parameters such as turbidity or total suspended solids.
- Explore management actions to reduce phosphorus in stormwater discharges for impaired waterbodies in Washington State listed on the federal Clean Water Act Section 303(d) list.

Background

The amount of phosphorus present in surface water discharged from construction sites is unknown. The Construction Stormwater General Permit by the Washington State Department of Ecology (Ecology), issued November 16, 2005, only requires sampling of stormwater discharges for turbidity and pH. The basic assumption for the general permit is that if turbidity is controlled in stormwater discharged from a construction site, then phosphorus will also be controlled.

Phosphorus is a parent material in rocks and soils. Concentrations in Washington soil will vary due to the parent rock, weathering patterns, and anthropogenic use. Phosphorus is preferentially bound to soil particles and is used by plants, so the concentration in clean water is generally very low. Particulate matter includes “organic” living and dead plankton, phosphorus adsorbed to particulates, precipitates of phosphorus, and “inorganic” amorphous phosphorus (Mesner et al., 2005). Phosphorus is used extensively in fertilizer and other chemicals, so it can be found in higher concentrations in areas of human activity.

Historical Information

Construction sites can be a source of sediment to surface waters. In the mid 1980s, Ecology evaluated the use of best management practices (BMPs) to control soil erosion from construction sites. BMP effectiveness to reduce turbidity and settleable solids was hindered the most by poor installation and maintenance (Tiffany et al., 1990). Surface water loading of phosphorus from the construction site’s sediments can occur due to sediment-bound phosphorus, particularly if the native soils are high in phosphorus, or if enrichment of the soil by fertilizers or products takes place. Given that construction sites greater than one acre must implement a suite of erosion control practices according to the Construction Stormwater General Permit in Washington State, the question still remains: What is the phosphorus content from construction sites across the state?

An internet survey, literature, and professional websites such as the Center for Watershed Protection (www.cwp.org) were searched for data pertaining to phosphorus concentrations of construction site stormwater discharges.

Bellingham, WA Study

The only data found were from an unpublished pilot study done by Ecology in Bellingham (Steve Hood, personal communication, August 2006). A total of 8 construction stormwater samples were collected on November 16, 2004, from three separate construction sites surrounding Lake Whatcom. Turbidity and total phosphorus were measured at each location to establish a turbidity and phosphorus relationship (Table 1).

Table 1. Bellingham Construction Stormwater Discharge Results

Total Phosphorus (mg/L)	Turbidity (NTU)	Site Description
0.0174	4	Wild Rose Hills Background
0.0812	33	Wild Rose Hills Midpoint
0.0751	17.4	Wild Rose Hills Below Project
0.193	79.8	Geneva Hills Background 1
0.0663	13.1	Geneva Hills Background 2
0.159	63.1	Geneva Hills Below Project
0.109	43.1	Savana Discharge
0.1467	39.8	Savana Background 1

Little is known about the quality of these data; however, a brief examination does reveal a good correlation between turbidity and phosphorus (Figure 1).

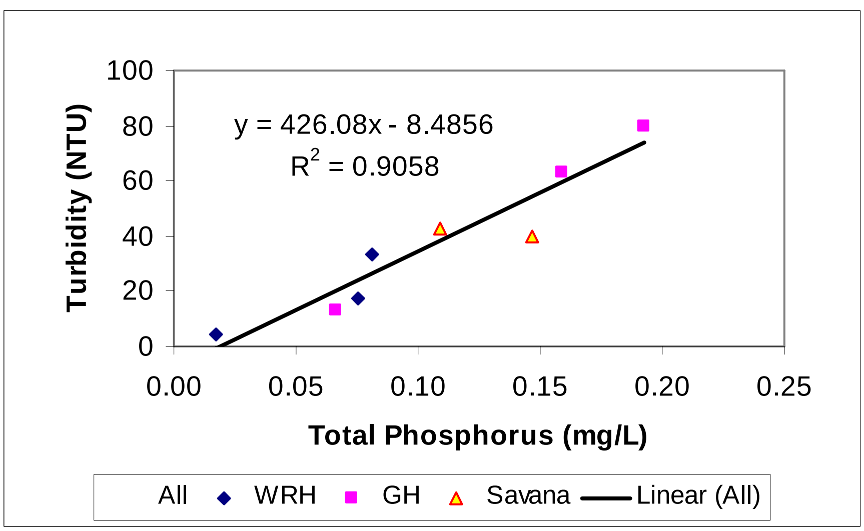

Figure 1. Linear Regression between Turbidity and Phosphorus at Three Bellingham Construction Stormwater Sampling Sites (WRH – Wild Rose Hills; GH – Geneva Hills)

This sampling effort was intended to lead to further studies of phosphorus loads to Lake Whatcom that, to date, have not occurred.

Construction Practices

Unfortunately, there seems to be a lack of data on phosphorus in construction stormwater. Given the data shortcomings across the nation on this topic, there does remain a very good understanding of the fate and transport of phosphorus in the environment. Elements of construction site practices that may affect the phase and transport of phosphorus are herein discussed.

In every watershed, phosphorus can be liberated naturally by weathering from the parent soil. The process of precipitation and de-sorption or sorption of phosphorus is completely dependent on the site characteristics and conditions.

The amount of sediment that could be released to surface waters during a construction site's short life can be substantial. In 1989, Ecology estimated construction site erosion rates with no erosion controls ranged from 50 to 500 ton/ac/yr. Natural erosion rates from forests or well-sodden prairies are 0.01 to 1.0 ton/ac/yr (Ecology, 1989). Results from a soil erosion study by the U.S. Geological Survey (USGS) and Dane County, Wisconsin, found that even small (less than 5 acre) construction sites are potential sources of large amounts of sediment erosion. Sediment load from the active phase of construction was clearly the highest solids event mean concentration of 15,000 mg/L, seven times higher than any other phase of construction (Owens et al., 2000).

Several construction practices may affect phosphorus concentrations in surface waters. Development can release phosphorus from natural sinks. If swamps and wetlands are drained for development, phosphorus that was buried can be exposed. During the building phase, and after everything has stabilized, phosphorus concentrations in stormwater can increase because natural filters such as trees, shrubs, and puddles have been eliminated. Stripping away the littoral and top soil layers may remove a source of phosphorus. However, these top soils have large assimilative binding capacities to "recapture" dissolved phosphorus.

Some construction sites use a stormwater detention pond to capture sediment and water before leaving the site. The solubility of phosphorus at a construction site is an important consideration. The mechanics of dissolving phosphorus into the water column is limited by the solubility characteristics of the soils or particles that the phosphorus is bound to. The solubility characteristics refer to several factors which include pH (a major driver), redox conditions, cation exchange capacity of the soil, ionic strength of the soil water solution, and temperature. For example, with a decrease in pH, the redox conditions encourage phosphorus to co-precipitate with metal oxyhydroxides (or calcite) in the soil matrix. That is because the metal oxyhydroxides are more soluble in a reduced state.

The remaining source of phosphorus on a construction site may be from land treatment practices employed by the construction site personnel, such as fertilizers, tackifiers, hydroseed, wood mulch, or other types of applications may contain phosphorus. These products could be evaluated for their phosphorus content, as this is currently unknown.

Organophosphates are commonly used as construction materials, flame retardant, and plasticizers. Fertilizers generally contain phosphorus in the form of orthophosphate. Phosphate is not very mobile in soil; it tends to remain attached to solid particles rather than dissolving in water. However, if too much fertilizer is applied, the phosphates are carried into surface waters with storm runoff and also with melting snow. Soil erosion of fertilized fields and lawns can also carry a considerable amount of particulate phosphate to streams.

Groundwater

A source of phosphorus on the construction site may be the water on-site. Phosphorus behavior in the groundwater environment is not a sediment issue as it is on the surface. In some locations, there may be a high water table at the construction site that already has a moderately high phosphorus content. Reasons may include “upgradient” factors such as septic leach fields, high fertilizer use, or animal farms.

Groundwater is commonly believed to contain a low concentration of dissolved phosphorus, due to its affinity for binding with soils. However, some research has indicated that in some locations phosphorus is not binding to the soil matrix and is remaining dissolved under certain redox conditions. This is primarily due to low dissolved oxygen (< 1 mg/L) causing a highly reduced environment. This allows the iron and manganese (that phosphorus tends to bind to in the soil) to mobilize in an anoxic condition. When the dissolved oxygen turns oxic (>2 mg/L), the oxyhydroxides precipitate and phosphorus rapidly bonds to them and co-precipitates from the groundwater, becoming immobile (Charles Pitz, personal communication, 1-8-07).

Urban Environments – Source Studies

According to a soil scientists with Ecology and with Washington State University Extension (Shiou Kuo), phosphorus content in soils vary along a time gradient as well as the geological make up of the local soils. Kuo’s impression is that Washington soils have the capacity to bind anthropogenic (human-caused) sources of phosphorus in the upper horizons, but with increasing storage of phosphorus, the binding capacity is only temporary (personal communication 1-25-07). Native soil concentrations of phosphorus, at least on the western side of the state, are expected to be higher than in the dryer eastern side of the state with less vegetative matter; total phosphorus concentrations were speculated at 1000 ppm and several 100 ppm, respectively. In Kuo’s opinion, the backyard gardener is more likely to over fertilize than is the agricultural community; therefore, on a cumulative scale, the urban environment may be a significant source of phosphorus to the watershed. An abundance of phosphorus is relatively common in urban environments, typically due to the use of fertilizers for landscape propagation.

Soil phosphorus concentrations for agricultural areas that are being developed as urban areas are expected to be higher than for native soils due to years of fertilizer use. Also, from recent work Ecology has done in the Walla Walla region, we have learned the native Blue Mountain soils have a higher native phosphorus content than expected (Joe Joy, personal communication, 3/28/07).

Source studies to estimate the sediment and phosphorus loads are beginning to indicate residential landscapes as high source areas. A Wisconsin study of two small residential drainage basins collected stormwater phosphorus data from streets, lawns, roofs, driveways, and parking lots (Waschbush, 1995). Data from a Source Loading And Management Model (SLAMM), combined with other monitoring points, were used to determine the loads for each source area. The largest total and dissolved phosphorus, and suspended solids loads, were from streets and lawns in the urban residential basin. Lawns were the predominant source of phosphorus, and streets were the main source of suspended solids (Waschbush, 1995).

An innovative method to estimate erosion from construction sites was developed in Dane County, Wisconsin, by adapting the Universal Soil Loss Equation (USLE). The USLE was developed to estimate sheet and rill erosion from agricultural field by the United States Department of Agriculture (Wischmeier and Smith, 1978). Predicting the soil loss from construction sites was calculated by adapting each factor in the USLE to construction sites conditions. Implementation of the USLE erosion control plans is required of construction planners for projects that will disturb 0.5 acres or more since 1995. Dane County planners, engineers, and consultants have been able to locate areas with the highest erosion rates and target erosion control to protect water quality. The timing of construction site activities has been one of the most valuable elements in erosion control (Balousek et al., 2000).

The USGS and state of Wisconsin monitored soil erosion rates from small construction sites (less than 5 acres) during each of the main construction phases (Owens, 2000). Federal and state regulations pertaining to construction sites recognize the potential impacts from individual sites and groups of sites within a stream basin. This study collected total and suspended solids data for one year from two typical small construction sites, one residential and one commercial. Results indicate that small sites are a large source of sediment erosion, yielding 10 times the typical loads from rural and urban land uses. The active construction phase produced the largest (by orders of magnitudes) sediment loads when compared to pre- and post- construction phases. Once seeded or mulched, the loads were dramatically reduced (Owens, 2000).

Relationships between surrogate measurements

The following is a review of several studies that tested surrogate relationships either between types of sediment measurements or between sediment and phosphorus measurements.

Lubliner, 2005

In a stormwater study by Ecology, stormwater runoff quality data were evaluated for total suspended solids (TSS), turbidity, and transparency from construction sites in western Washington (Lubliner, 2005). This study found that 24% (44 of 183) of construction sites were discharging stormwater offsite when visited. From these stormwater samples collected, no relationship was found between TSS and turbidity ($r^2 = 0.38$), or TSS and transparency ($r^2 = 0.32$). However a significant relationship was developed between turbidity and transparency ($r^2 = 0.925$). The 44 discharging sites showed turbidities ranging from 2.3 to >1000 NTU. Most of these sites (80%) showed turbidities in the range of 2.3 to 200 NTU. This study was not developed to evaluate the impacts of construction site characteristics or the implementation of best management practices on discharge water quality.

Corsi, 1997

The USGS, together with the state of Wisconsin, has developed a unit-area load based on monitoring data to estimate the mass of suspended solid and total phosphorus from small watersheds throughout the state (Corsi, 1997). Land use, drainage area, eco-region, and other watershed characteristics such as slope, soil type, and climate affect the magnitude and variability of the unit-area loads. The unit-area loads of TSS and total phosphorus within the watersheds were found to vary greatly from year to year, depending upon climatic conditions. Watersheds in steeper areas, more prone to erosion, greater runoff, and stream velocities, resulted in larger sediment and phosphorus loads. No relationship was apparent between unit-area loads and percent agriculture, percent forest, or drainage area.

Storm-runoff loads were separated from the total annual loads for a select few watersheds. The median annual storm-runoff load as a percentage of the annual suspended sediment load ranged from 59-95%. The median storm-runoff phosphorus load ranged from 36-87% of the total annual-runoff load for the same watersheds.

Center for Streamside Studies, 2001

The Center for Streamside Studies at the University of Washington studied the Puget Sound lowland water quality during storm events to correlate TSS, turbidity, and phosphorus (Center for Streamside Studies, 2001). The suspended sediment was characterized in eight streams over the winter storm events and was found to vary up to 3 orders of magnitude during storm events. Turbidity and TSS can be correlated, but this relationship may depend on the shape, size, and composition of sediment in the stream or watershed. Each drainage in this study had a single primary land use of forest, agriculture, or urbanized. Urban streams had the highest sediment concentrations; however, during storm flows, the forest and agricultural streams had the largest fraction of silts.

Stream nutrient data collected by King County at the same locations were correlated to the sediment parameters. A strong correlation between TSS and total phosphorus, as well as TSS and turbidity, were found under storm conditions, which indicates that the dominant fraction of total phosphorus moved through the stream systems in particulate form (Center for Streamside Studies, 2001). The authors did note that this relationship was not found under normal baseflow conditions. The extent phosphorus varied between three varied density sub-watersheds was also examined. Nutrient, sediment, and flow data collected daily revealed that the high and medium density watersheds had strong positive correlations between total phosphorus and TSS. The low density watershed had a poor correlation between these parameters.

Conclusions of the source studies

- Urban lawns were a predominant source of phosphorus, and streets were the main source of suspended solids (Waschbush, 1995).

- A strong correlation between TSS and total phosphorus was found under storm conditions, for medium-density and high-density watersheds in King County. This indicates that the dominant fraction of total phosphorus moved through the stream systems in particulate form (Center for Streamside Studies, 2001).

- Within the same Wisconsin watersheds, Corsi (1997) found the percentage of phosphorus load from storm runoff compared to the total annual-runoff load (36-87%) fell below the percentages of suspended sediment loads (59-95%). This suggests that controlling sediment will aid in controlling particulate-bound phosphorus.

Special Cases – Washington's 303(d) Waterbodies

Waterbodies that do not meet Washington State water quality standards are placed on the federal Clean Water Act Section 303(d) list and designated as impaired (polluted) by the state and federal government. If a construction site discharges to a waterway on the 303(d) list for turbidity, fine sediment, phosphorus, or high pH, additional sampling requirements may apply to the construction site. A list of these impaired waterbodies is at the following web site: www.ecy.wa.gov/programs/wq/stormwater/construction/impaired.html

The runoff from the construction site must comply with turbidity water quality standards found in the general permit. Directions on how to sample and how permit requirements are applied can be found in an Ecology manual entitled, *How to do Stormwater Monitoring: A Guide for Construction Sites* (Ecology, 2006). Turbidity criteria are summarized below:

- If background water turbidity is 50 NTU or less, discharge turbidity cannot be greater than 5 NTU over background turbidity.
- If background water turbidity is greater than 50 NTU, discharge turbidity cannot cause more than a 10 percent increase in turbidity, over the background turbidity.
- If discharge is less than 5 NTU as it leaves the site, there is no need to sample the receiving water to determine background turbidity.

Impaired waters with a Total Maximum Daily Load (TMDL) may have set allocations on discharges in the watershed that establish limits on the amount of pollution a waterway with a TMDL can receive. This process of establishing a loading capacity is explained in Figure 2.

Establishing the TMDL Loading Capacity:

$$TMDL = WLA + LA + MOS$$

Wasteload Allocation (WLA): This represents the contribution of discrete "point" sources of pollutants (e.g., municipal, industrial, and construction stormwater discharges);

Load Allocation (LA): This represents "nonpoint" sources of a pollutant, (natural sources, most agricultural activities, and other sources that are not regulated by an Ecology permit); and

Margin of Safety (MOS): This allows for uncertainty in the estimation of, and ability to achieve, the previous two allocations.

The sum of these three components is also called the *Loading Capacity*.

Figure 2. Elements of the TMDL Loading Capacity.

Wasteload allocations (WLAs) are typically set for point sources of pollutants. The Ecology definition of a *point* source is:

Point sources includes sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

The following excerpts are summarized from the Construction General Permit, pages 20-21:

<u>Sampling and Limitations For Sites Discharging to Applicable TMDLs</u>

1. Discharges to a waterbody subject to an applicable Total Maximum Daily Load (TMDL) for turbidity, fine sediment, high pH, or phosphorus, shall be consistent with the assumptions and requirements of the TMDL.

a Where an *applicable TMDL sets specific waste load allocations* or requirements for discharges covered by this permit, discharges shall be consistent with any specific waste load allocations or requirements established by the applicable TMDL.

b Where an applicable TMDL has established a general waste load allocation for construction stormwater discharges, but no specific requirements have been identified, compliance with Conditions S4 (Monitoring) and S9 (SWPPPs) will be assumed to be consistent with the approved TMDL.

c Where an applicable TMDL has not specified a waste load allocation for construction stormwater discharges, but has not excluded these discharges, compliance with Conditions S4 (Monitoring) and S9 (SWPPPs) will be assumed to be consistent with the approved TMDL.

d Where an applicable TMDL specifically precludes or prohibits discharges from construction activity, the operator is not eligible for coverage under this permit.

One example in Washington State (*Cottage Lake* below) was found where a TMDL Implementation Plan recommended that construction discharges draining to a phosphorus-impaired waterbody be monitored for phosphorus. This may occur more in the future if construction sites are found to be a quantifiable source of the pollutant for which a TMDL study is initiated.

Cottage Lake Total Phosphorus TMDL

The Cottage Lake Total Phosphorus Total Maximum Daily Load Water Quality Implementation Plan (Shoblom, 2006) makes several direct recommendations concerning the phosphorus content of construction stormwater discharges. The TMDL did not make any explicit wasteload allocations for General Construction Permit holders.

Shoblom’s solution has been to recommend that all construction sites that could discharge stormwater within the Cottage Lake watershed use the following BMPs. Shoblom also recommends that the responsibility to promote voluntary implementation of these BMPs during permit review meetings and onsite inspections lies with Ecology, King County, and Snohomish County.

Suggested best management practices (BMPs):

- Schedule grading and clearing activities to avoid, or minimize, the possibility of generating stormwater during construction activities.
- Infiltrate construction stormwater (e.g., ponds, bioswales)
- Monitor stormwater discharges weekly during discharge periods to ensure phosphorus removal techniques are effective.
- Cover all exposed soils.
- Install a stabilized (rock) construction entrance and/or wheel wash.
- Conduct aggressive street sweeping to pick up sediment tracked off-site.
- Restrict/prohibit the use of nonorganic fertilizers, or use nonorganic fertilizers that do not contain phosphorous.

In addition to the BMPs, the author lists a series of recommended actions to be taken under the authority of the NPDES program and the King County Department of Development and Environmental Services (DDES). The DDES issues building and land use permits and implements the requirements in the King County Surface Water Design Manual.

Given Cottage Lake is designated a "Sensitive Lake," the DDES manual requires that post-construction stormwater runoff in Sensitive Lake Water Quality Treatment Areas must receive treatment that provides approximately 50 percent phosphorus removal. The assumed phosphorus concentration is unknown.

The Cottage Lake Water Quality Implementation Plan (Shoblom, 2006) recommends the following actions:

- Stormwater permit holders monitor and report phosphorus levels in their NPDES discharges. Construction stormwater permit holders monitor their discharges weekly during wet weather periods.
- Phase I permit holders prioritize their outfall inventories in TMDL areas and look for phosphorus sources in their screening analyses.
- King County staff continue to require removal of phosphorus as provided in Volume V, Section 3.3 of the Western Washington Stormwater Manual (Ecology, 2001).
- King County building permit staff discuss the need for controlling phosphorus from construction sites during pre-application meetings to discuss the goals of the Cottage Lake TMDL.
- King County staff continue to investigate and require new technologies for phosphorus removal as these technologies become available and are practical.

Minnesota Construction Stormwater General Permit

Minnesota's Construction Stormwater General Permit (2003) is comparable to Washington's general permit. However, Minnesota goes further in its requirements for special or impaired waters, requiring sites near specially-protected waters to add the following additional controls or to file for an individual permit:

- Sites that discharge near waters with qualities that warrant extra protection (special waters) must use additional best management practices and enhanced runoff controls.
- Sites that discharge near an "impaired water" for which there is a Total Maximum Daily Load (TMDL) allocation for sediment—and parameters associated with sediment transport—must meet special conditions.
- Sites that discharge to calcareous fens, a rare and unique wetland, may require an individual permit.

A handy feature at the Minnesota webpage is an interactive map called Special Waters Search to help project planners identify those waters near their site that may require extra protections or an individual permit: www.pca.state.mn.us/water/stormwater/stormwater-c.html

Best Management Practice for Phosphorus Removal

EPA

The EPA has requested the input of the National Research Council to improve the permitting of stormwater discharges. A study is underway to evaluate the link between stormwater discharges and water quality, the state of stormwater management, and policy recommendations to improve general permit conditions. Construction stormwater is included in this assessment, and some of the most pertinent questions should be answered. These questions include:

1. What specific parameters should be monitored, and when and where?
2. What effluent limits and benchmarks are needed to ensure that the discharge does not cause or contribute to a water quality standards violation?

This study will produce a report around September 2008. See the report from the following website: www8.nationalacademies.org/cp/projectview.aspx?key=48711.

Ecology's Websites and Resources

Ecology has a list of BMPs to manage sediment from construction sites in the Stormwater Manual for Western Washington Volumes II, IV, and V (Ecology, 2001) and the Stormwater Management Manual for Eastern Washington (Ecology, 2004). There are also Ecology publications to aid in BMP selection for phosphorus management. See website www.ecy.wa.gov/programs/wq/stormwater/newtech/technologies.html#phosphorous.

Other Websites and Resources

CH2M Hill recently produced a Stormwater Best Management Practices Effectiveness Review (CH2M Hill, 2005). This project reviewed 310 effectiveness studies from 17 references, some local and some national. Results are provided in an Access© database group-able by BMP type or by constituent. One can, for example, select total phosphorus and see a list of BMP studies and various measures of effectiveness for each study.

The Minnesota State Construction Stormwater General Permit (2003) requires erosion and sediment management practices from construction sites of one or more acres. The fact sheet was summarized to produce this list: www.pca.state.mn.us/publications/wq-strm2-05.pdf. Regulated parties choose which practices are best for specific sites, but all regulated parties are required to:

1. Identify areas not to be disturbed with flags, stakes, and similar objects.
2. Install prevention practices in an appropriate and functional manner prior to construction.

Possible erosion BMPs include, but are not limited to:

- Construction phasing
- Vegetative buffer strips
- Temporary seeding
- Sod stabilization
- Horizontal slope grading
- Minimizing land disturbance
- Preserving trees and natural vegetation
- Mulch or wood fiber blanket
- Stockpiling covers

Regulated parties must minimize sediment from entering surface waters, curb and gutter systems, and storm sewer inlets. Construction sites are allowed to choose which practices are best for specific sites. BMPs must:

1. Be established downgradient before upgradient land disturbance begins
2. Protect storm drain inlets
3. Control temporary soil stockpiles
4. Control vehicle tracking with stone pads, concrete, steel wash racks or the equivalent
5. Remain until final stabilization

Possible sediment control BMPs include:

- Silt fences
- Inlet protection
- Check dams
- Sedimentation traps and basins
- Stabilized construction entrances

Recommended Discussions for General Permit Writers, TMDL Study Scientists and TMDL Implementation Leads

Information from other states, EPA websites, and nonprofit watershed research groups were searched for this literature review. There appears to be a lack of data on total phosphorus in construction discharges. Certainly the lack of any data weighs heavily in the direction of monitoring. On the other hand, the potential for phosphorus discharge from construction sites may not be a concern for many of the sites in Washington. It seems that Ecology will need to decide whether to require monitoring as part of the Construction Stormwater General Permit.

The following questions should be topics of discussion for groups at Ecology that develop permits, study environmental impacts of permit decisions, and develop solutions to protect water quality. Although each group has individual roles to play, working in concert should produce a clear and successful plan.

1. Have previous studies quantified typical total phosphorus loading from construction?

   Only the pilot work in Bellingham.

   A comprehensive study should be conducted by Ecology, or general permit holders should be asked to collect total phosphorus data.

2. Is turbidity a suitable surrogate for total phosphorus?

   This will require watershed-specific or statewide sampling to develop the relationship between turbidity and total phosphorus. The soils throughout the state are different; therefore, a regression curve might need to be regional or soil-specific.

3. What is the probability that a site will cause or contribute to a violation of total phosphorus criterion in the receiving water, despite compliance with the turbidity criterion (5 NTU over background), or the benchmark (25 NTU).

   Unknown.

4. Construction stormwater discharge as it relates to 303(d) impaired waterbodies in Washington and nationally is not well understood. This topic is not well studied, likely due to the limited temporal scale of construction projects and an overall lack of resources.

   A statewide survey of phosphorus concentrations could be done. How to use the information, once collected, should be part of the study design.

5. If a TMDL is being conducted in a watershed, what are TMDL leads and the general permit holders (industry and construction) to do?

   Contact the general permit managers at Ecology for direction.

6. Even if there is a numeric wasteload allocation given to the general permit holders in the watershed, what BMPs would be recommended as part of the solution?

   Unknown

7. What percent of total phosphorus is removed from construction stormwater if the suspended sediment is removed? Does this depend on soil type? How much dissolved phosphorus remains after solids removal?

   Total and dissolved phosphorus could be directly measured from point sources in an impaired watershed. An intensive case study of fate and transport of phosphorus concentrations from construction sites in a watershed may help to answer the question of fate and transport over distance.

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Appendix A. Glossary and Abbreviations

303(d) list: Section 303(d) of the federal Clean Water Act requires Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality limited estuaries, lakes, and streams that fall short of state surface water quality standards, and are not expected to improve within the next two years.

Best management practices (BMPs): Physical, structural, and/or operational practices that, when used singularly or in combination, prevent or reduce pollutant discharges.

Clean Water Act: A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

Ecology: Washington State Department of Ecology

Inorganic phosphate: This is phosphate that is not associated with organic material. Types of inorganic phosphate include orthophosphate and polyphosphates.

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

Organic phosphate: This is phosphate that is bound to plant or animal tissue. Organic phosphates are formed primarily by biological processes. They are contributed to sewage by body waste and food residues, and also may be formed from orthophosphates in biological treatment processes or by receiving water biota. Organic phosphates may occur as a result of the breakdown of organic pesticides which contain phosphates. They may exist in solution, as loose fragments, or in the bodies of aquatic organisms.

Orthophosphate: This is sometimes referred to as *reactive phosphorus*. Orthophosphate is the most stable kind of phosphate, and is the form used by plants. Orthophosphate is produced by natural processes and is found in sewage.

Polyphosphates (also known as *metaphosphates* or *condensed phosphates*): These are strong complexing agents for some metal ions. Polyphosphates are used for treating boiler waters and in detergents. In water, polyphosphates are unstable and will eventually convert to orthophosphate.

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

Total Maximum Daily Load (TMDL): A distribution of a substance in a waterbody designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Appendix B. Methods of Measurement

Inorganic phosphorus is from rocks and minerals. Plants and algae use mostly the inorganic form (orthophosphate – PO_4^3). Organic phosphorus is from plants and animals. Both forms of phosphorus can be dissolved in the water column.

Phosphorus absorbs readily to soils and combines readily with calcium, aluminum, and iron.

Phosphorus

Phosphorus can be measured as total phosphorus which includes all forms of phosphorus. The polyphosphates and organic forms are converted to orthophosphate by sulfuric acid digestions and UV-catalyzed persulfate digestion, respectively. After digestion, the orthophosphate ion is quantified.

Orthophosphate can be directly measured in the water column and is the form of phosphorus that is bio-available to plants and algae. Orthophosphate ion is measured colorimetrically by the molybdate-blue/ascorbic acid method. Orthophosphate reacts with ammonium molybdate and potassium antimonyl tartrate to form phosphomolybdic acid. This complex is reduced by ascorbic acid to yield an intense blue color that is quantified by a colorimetric meter.

The reporting limits from Ecology's Manchester Laboratory is 0.01 mg/L for total phosphorus and 0.003 mg/L for orthophosphate.

Turbidity

Turbidity is a unit of measurement quantifying the degree to which light traveling through a water column is scattered by the suspended organic and inorganic particles. Organic particles include plant or animal material or algae, and inorganic particles refer to sediments including clay. The scattering of light increases with a greater suspended load. Turbidity is commonly measured in nephelometric turbidity units (NTU). (NCSU, 2007.)

Turbidity is often due to suspended sediment in the water column; however, in some situations turbidity can result from algal populations. A waterbody's suspended load is a component of the total turbidity. Suspended sediment concentration is often monitored with a turbidity meter. A turbidity meter either measures the amount of light that is transmitted through the sample, or measures the light that is scattered by the sample. Although turbidity can be influenced by other factors such as size distribution, shape, and absorptivity of the sediment, and the color of the water, turbidity meters give satisfactory estimates (Gordon et al., 1992).

The Nephelometric Method is a comparison of the light scattered by the sample and the light scattered by a reference solution.

- Detection limits: Should be able to detect turbidity differences of 0.02 NTU with a range of 0 to 40 NTU.

- Interferences: Rapidly settling coarse debris, dirty glassware, presence of air bubbles, and surface vibrations.
- Minimum volume is 100 mL.
- Holding time is 48 hours at 4°C.

Total Suspended Solids (TSS)

Sediment introduced into surface water is either deposited on the bed of the stream or lake or suspended in the water column (suspended load). The measurements for total suspended solids refer to the weight of the sediment in the volume of water. Several methods are available for sampling suspended sediment in streams. If the stream is small and well-mixed, a sample can be obtained using a grab sample. However, for the most accurate measurements from receiving water, a suspended sediment sampler is recommended (NCSU, 2007).

Total suspended solids refers to the portion of the total solids in a sample container that is retained on a filter.

- Detection limits: 1 mg/ L using a 1 liter sample.
- Holding time is 7 days at 4°C.