Stormwater Quality Survey of Western Washington Construction Sites, 2003-2005

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Stormwater Quality Survey of Western Washington Construction Sites, 2003-2005

by
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Abstract

Stormwater discharges from construction sites have been regulated since 1992 by the Washington State Department of Ecology, under the NPDES and the State Waste Discharge General Permit programs. This survey in western Washington was initiated to obtain representative data to characterize stormwater discharged from construction sites.

Data were collected during the two winter, wet seasons of 2003-04 and 2004-05. Data were on general site characteristics and water quality parameters, including turbidity, transparency, and total suspended solids (TSS).

Of 183 eligible construction sites visited in four counties, 44 sites were discharging runoff and were sampled. The low incidence of sites discharging stormwater offsite (24%) during field sampling visits is attributed, in part, to lower than normal rainfall, permeable soils, and the use of water quality best management practices. It can also be attributed to the variable and intermittent nature of stormwater discharges, which makes it difficult to time sampling visits to coincide with stormwater discharge events.

During this snapshot study, only six of 44 sites (14%) discharged stormwater directly to receiving waters during field sampling visits. Two of the six caused an increase in measured turbidity downstream of the discharge point.

Stormwater from construction sites showed a wide range of water quality. Approximately 80% of sites had turbidity from 2.3 to 200 NTU, transparency tube depths from 10 to 60 cm, and TSS from 1 to 46 mg/L. None of these parameters correlated to site characteristic data (stage of construction, type of construction, size of site, disturbed acreage, or site slope).

Transparency was found to be a good surrogate for turbidity values below 250 NTU, which corresponds to 5.5 cm in transparency tube depth. TSS correlated poorly with turbidity.

Acknowledgements

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Introduction

Under the National Pollution Discharge Elimination System (NPDES) and State Waste Discharge General Permit program, the Washington State Department of Ecology (Ecology) has regulated discharges associated with construction activity since 1992. During this time, stormwater sampling and analysis has been conducted only on certain sites when it was necessary to address specific water quality issues. Data representative of a wider range of construction stormwater quality in Washington have not been available.

This project was limited to a survey of construction sites in western Washington, where much of the state's construction activity is taking place. Western Washington has wet winters with saturated soils and a high potential for erosion problems; therefore, discharged stormwater has a great potential for impacting receiving waters. Also, logistical limitations favored limiting this study to the western portion of the state. Figure 1 shows the study area which includes Thurston, Pierce, King, and Snohomish counties.

The primary objective of the study was to obtain representative data to characterize the quality of stormwater discharged from construction sites. Turbidity and transparency were measured in the field and total suspended solids (TSS) were sampled and analyzed in the laboratory. This study was a "snap-shot" survey, each site being evaluated only a single time. A series of descriptive qualities about each sampled construction site were recorded and potential relationships between stormwater quality and site conditions were evaluated. Sites were not revisited through the course of the wet season.

A secondary objective was to evaluate the relationship between turbidity and transparency measurement methods. Turbidity is a measure of light scatter from materials in the water sample. A transparency tube is a simple device for visually assessing light transmission and is commonly used in limnological studies. This simple device may serve as a simpler and more inexpensive method to monitor stormwater discharge quality, if a relationship between the two measurements can be found. The task of developing a correlation curve involved taking measurements for each parameter from the same stormwater discharge sample. Potential correlations between turbidity measurements, transparency tube readings, and TSS were evaluated.

Each construction site was visited once, at which a single stormwater discharge grab sample was collected. Eleven discharge samples were collected in Year 1, 2003 – 2004, far below the study goal of 45 samples (Golding, 2004). Therefore the study was extended another winter season, Year 2, 2004 – 2005. During Year 2 of the study, 36 additional samples were collected to satisfy the study goal.

The survey-level data developed in this study will be useful to state and local government agencies involved in the permitting and inspection of construction activities, as well as to construction operators and their consultants who develop Stormwater Pollution Prevention Plans.

Figure 1: Study Area

Shaded areas are the four counties included in the study.

Methods

Site Selection

The aim of the study was to sample stormwater discharges from 45 construction sites in four western Washington counties: King, Snohomish, Pierce, and Thurston. These counties were selected to (1) represent a variety of geographic areas from Puget Sound to the Cascade Crest, and (2) include construction sites from urban, suburban, and rural areas.

A list of eligible constructions sites for the study was developed from Ecology's Water Quality Permit Life Cycle System (WPLCS) database. Site visits were conducted on eligible construction sites and sampled only if stormwater was discharging off-site. The numbers of eligible and sampled sites are shown in Table 1. Sites were considered eligible if they were under active construction as determined by the estimated project end date of the project reported on the permit application. An active site was defined as in a stage between initial ground clearing and final site stabilization.

Table 1: Construction Site and Samples by Year

	Year 1	Year 2	Total
	Winter 2003-2004	Winter 2004-2005	
Number of sites considered eligible for study from WPLCS	(69 Eligible) *Pierce = 62* *Thurston = 7*	(249 Eligible*) *King = 156* *Snohomish = 93*	318
Visited construction sites	64	119	183
Collected discharge samples	12	36	48
Sites discharging directly to receiving water	3	3	6

* Eligible = Year 2 sites were eligible if the "estimated end of date" was after October 2004.

Year 1 construction sites were in Thurston and Pierce counties, and Year 2 sites were in King and Snohomish counties. The method to select sampling sites differed from Year 1 to Year 2. The Year 1 site selection strategy was to stratify the number of sites in each county to be proportional to the number of permits in the county (Golding, 2003 and 2004). In addition, sites were stratified by size, with equal numbers (22) selected in each evaluated size range to provide for sufficient data to characterize each size category. Within each county and size range, sites were selected at random from those with active construction permits listed in the Ecology WPLCS database. No preference was given to sites that discharge to surface water. Due to these selection criteria, extensive drive time between the selected sites was required. Of the 64 sites visited the first year, only 12 (19%) were discharging and sampled. The Year 1 sampling strategy is explained in detail in the study Quality Assurance Project Plan and the Interim Report, (Golding, 2003 and 2004).

The sampling strategy was changed from a random site selection design in Year 1 to a geographically targeted approach for Year 2 of the study. This targeted approach improved the number of samples collected, and allowed the study goal of 45 samples to be reached. Of the 119 sites visited during the second year in King and Snohomish counties, 33 were discharging stormwater off site via surface flow or to a regional treatment system. The percentage of discharging sites improved to 28% under the more targeted scheme. Figure 2 illustrates the differences in the study design for the two years of study.

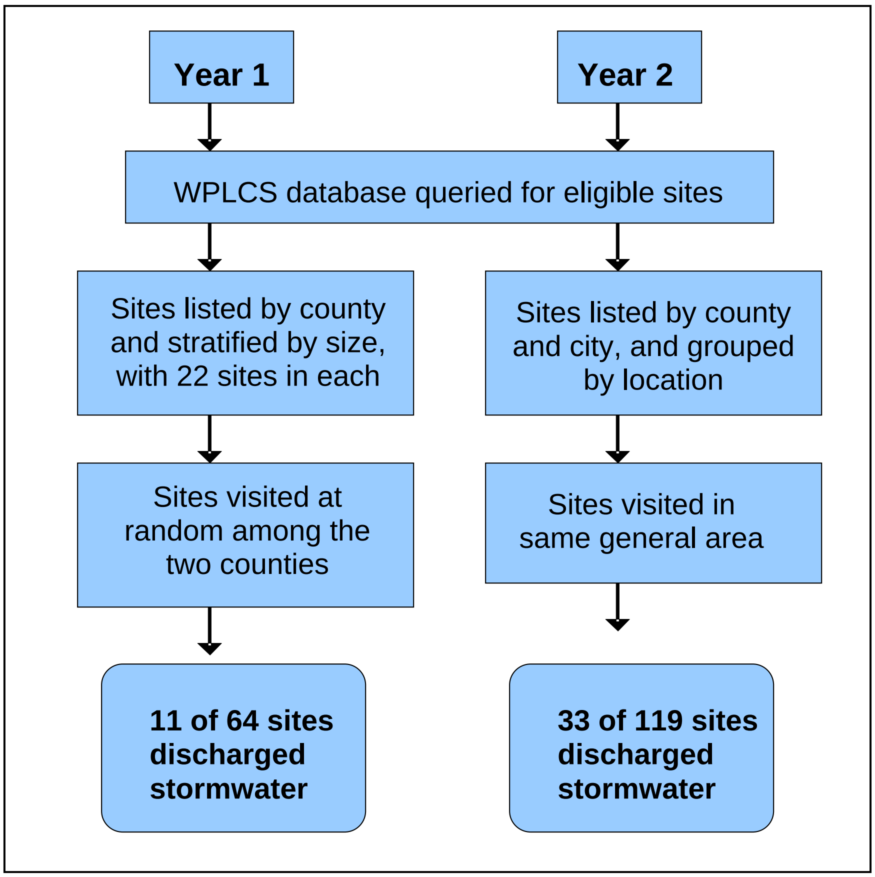

Figure 2: Study Year Conceptual Design

Over the two-year study, 183 construction sites considered eligible were visited in the four-county study area. From those visited sites, 48 samples were collected from 44 unique sites. Figure 3 summarizes the outcome of the site visits.

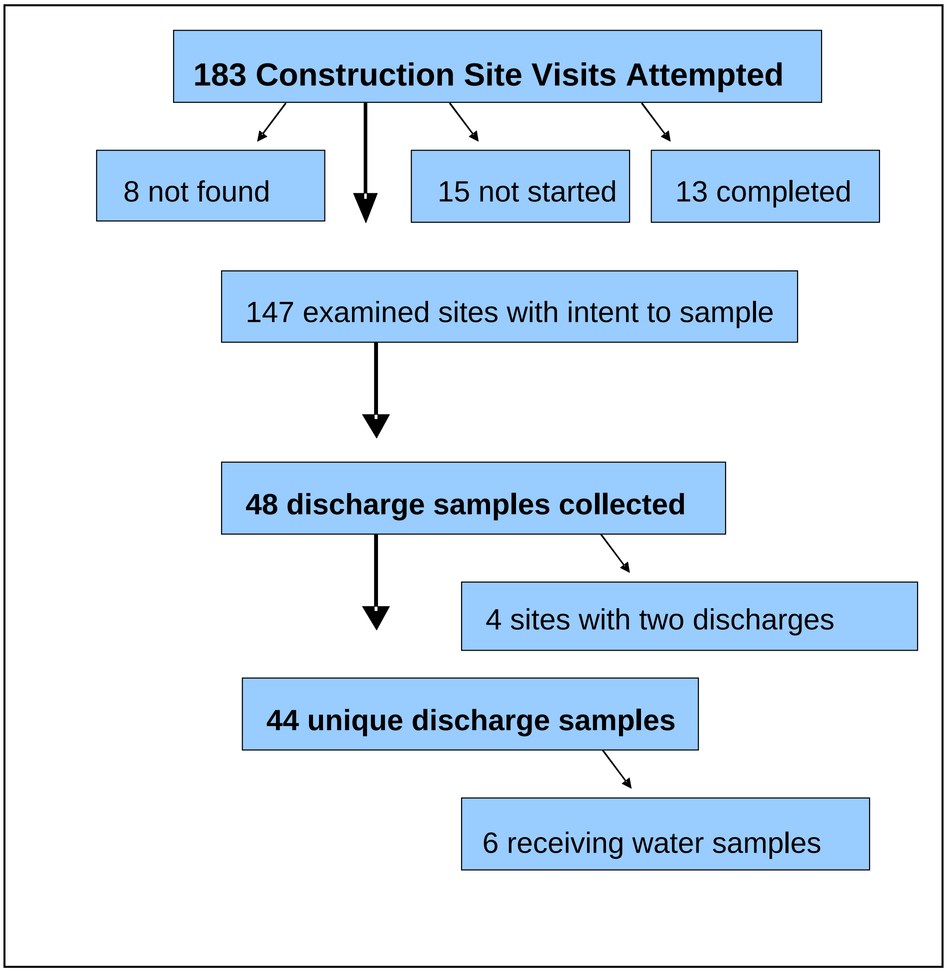

Figure 3: Outcomes of the 183 Construction Sites Selected to Visit

Sampling Criterion

Sampling took place during the winter, wet seasons of 2003-04 and 2004-05 in western Washington. The winter, wet season was defined for this study as November 1 through April 30. The criterion for stormwater discharge collection was the occurrence of an accessible discharge leaving the construction site. Stormwater samples were not collected from sites with no active discharge leaving the site, sites that relied on infiltration only, or sites that had complete removal of all stormwater via vactor trucks.

For construction sites, erosion is the principal cause of high solids concentrations. Thus storm duration and intensity are the greatest factors in pollutant generation. The typical precipitation pattern in western Washington is characterized by overlapping winter storm fronts that yield long periods of precipitation, for days and even weeks at a time. For this reason, the sampling design allowed stormwater discharge samples to be taken at any point during the winter.

This study was designed to sample during rain events regardless of the time intervals between or the length of the storms. Weather forecasts, radar information, and verified precipitation from online Washington State Department of Transportation live traffic cameras formed the basis for deployment of the sampling team.

Sampling Procedures

Field measurements were made for turbidity and transparency on site. Total suspended solids (TSS) samples were collected as grab samples in a plastic container and sent to the Ecology's Manchester Environmental Laboratory. During Year 1, turbidity was also determined at Manchester Laboratory. Table 2 lists sample sizes, containers, preservation, and holding times for the study parameters. Table 3 lists the analytical methods used in the study.

Table 2: Analysis, Containers, Preservation, and Holding Times for Study Samples

Parameter (Analyte)	Sample size	Container	Preservation	Holding time
Lab Turbidity	500 mL	500 mL w/m poly	cool to 4º C	48 hours
Field Turbidity	1000 mL	15 mL borosilicate glass	none	~15 minutes
Transparency	1000 mL	60 cm deep tube*	none	none
TSS	1000 mL	1000 mL w/m poly	cool to 4º C	7 days

* Manufacturer's specifications and in the July 2005 Draft Construction Stormwater General Permit.

Table 3: Analytical Methods

Analyte	Analytical method	Reference
Lab Turbidity	Standard Method 2130	APHA, 1995
Field Turbidity	Hach Model 2100P Manufacturer Instructions	Hach, 2001
TSS	Standard Method 2540D	APHA, 1995

Calibration of the portable nephelometer was performed prior to the field season with known formazin standards. Additionally, the meter was verified at each use by measuring the turbidity of know portable Gel-ex secondary standards. Turbidity measurements in the field were made according to the manufacturer's directions using a Hach 2100P ratio-type portable turbidimeter. The Hach 2100P measures the ratio of scattered light to transmitted light from a 90º signal in nephelometric turbidity units (NTU). The accuracy is ± 2% of the reading plus stray light (<0.02NTU). Repeatability is ± 1% or 0.01 NTU, whichever is greater. The Year 1 turbidity samples were also sent to the laboratory and measured with a bench top Hach ratio-type instrument, such that the results could be paired and differences between field and laboratory readings assessed. All field measurements were made in replicate. The first year of the study found that the field turbidimeter was as accurate as the laboratory turbidimeter. For this reason, laboratory turbidity analyses were dropped for the second year study design.

Transparency was measured using a portable, easy to use, clear plastic transparency tube (Figure 4). The tube is commercially available and is made of 1¾-inch diameter, clear polycarbonate, marked in centimeters. The tube is 60 cm. long with a drain tube and valve so the sample can be drained off. The depth (cm) of the water column at which a black-and-white secchi disk affixed to the bottom of the clear tube becomes visible is recorded. All field measurements were made in duplicate.

Figure 4: A Transparency Tube

Grab samples for TSS were collected at the point of discharge from the property using a 1-liter polyethylene bottle. Samples were transported to Manchester Laboratory according to protocol, at 4°C, and processed within 48 hours. The chain-of-custody procedure was followed.

Transparency measurements were paired with turbidity measurements so that a comparison could be made between the two. A correlation between Year 1 and Year 2 data was evaluated.

When the discharge from a construction site flowed into receiving waters, the impacts were assessed. Turbidity, transparency, and TSS were measured upstream and downstream of the point where the discharge entered the receiving water. Measurements were made where the receiving water was free-flowing, sufficiently distant from the discharging bank to avoid any eddies. Measurements were taken at two locations downstream from the discharge point: at 100 feet from the discharge point, and also at a distance three times the width of the receiving water from the discharge. The upstream sample was taken 100 feet upstream from the discharge point. Two distances below the point of discharge were analyzed for comparison on impact distance. All distances were measured by pacing.

Data Quality

Field replicates and laboratory duplicates allow for a determination of sampling and analytical precision. Field replicates are two independently collected samples from the same sample source. Laboratory duplicates are a split and analyzed as separate samples. Table 4 contains the results of replicates and duplicates and relative percent differences (RPDs) for the study. RPD is calculated as the difference between samples, divided by the mean, and expressed as a percent.

Table 4: Relative Percent Difference by Parameter

Measured Parameter	RPD Range	Mean RPD	% Below 20% RPD
Transparency[1]	0% to 76%	8.5	89%
Field Turbidity	0% to 27%	5.7	94%
Total Suspended Solids	0% to 35%	14.1	75%
Lab Turbidity	0% to 7%	2.4	100%

[1] - only one transparency RPD was at 75.9%, and the rest were below 29%

An RPD of less than 20% was taken as an indication of adequate precision (Golding, 2003). Overall, laboratory and field turbidity replicates and duplicates showed good precision. Laboratory RPD represents only the analytical variability within the study and is expected to be very low. Laboratory duplicates for turbidity RPD values resulted in the smallest range of RPDs.

Field replicates are expected to have higher variability because they incorporate environmental and sampling variabilities. High RPDs for results near method detection limits do not necessarily indicate low precision. For example, the RPD between measured turbidity of 1 and 2 NTU is 66.7%, whereas the RPD between 99 and 100 NTU is 1%. Two of the three RPD values above 20% RPD were from field turbidities that were below 6 NTU and within 1 mg/L of each other.

The majority of the samples taken for each parameter were below a RPD of 20%. The highest RPDs occurred with transparency tube results of 6 cm or below. The two transparency replicate readings that led to the sole high transparency RPD value of 76% were 0.9 cm and 2 cm. Laboratory duplicates for total suspended solids (TSS) resulted in good precision, with all but three duplicate sample results within 2 mg/L.

Data for the measured water quality parameters are presented in Appendix A. Appendix B contains the RPD Tables A-1, A-2, and A-3 for turbidity, transparency, and TSS.

Results and Discussion

Stormwater Quality

Over the two-year study, 183 construction sites with active general stormwater permits issued by the Department of Ecology were visited. Of the 183 sites, 44 (24%) were discharging runoff, four of which had multiple discharges. A total of 48 discharge samples were collected from the 44 sites. Figure 5 shows the locations of the construction sites sampled during the two-year study. Six of the 44 sites (14%) discharged directly to receiving waters. The remainder of the sites either allowed the water to infiltrate into the ground or the sites were connected to a city stormwater collection system.

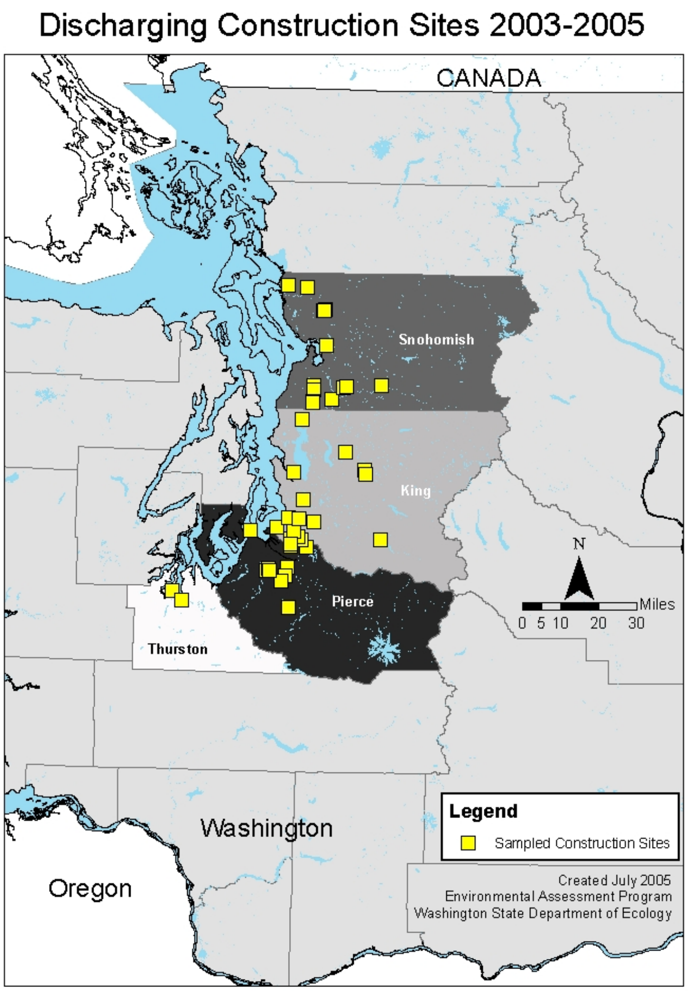

Figure 5: Map of Sampled Construction Sites

Turbidity and transparency were measured, and TSS was analyzed for each of the 48 discharges sampled. Turbidity was the principal parameter used to characterize runoff quality. Turbidity ranged considerably, from 2.3 to >1000 NTU. The readings from five discharges caused the meter to error, usually due to the upper detection limit of the field turbidimeter at 1000 NTU. Transparency readings ranged from 0.7 to over 60 centimeters in depth. Twelve samples filled the transparency tube with the secchi disk remaining visible. These samples were reported as > 60 cm. TSS also varied considerably, from 1 to 7470 mg/L.

The majority of the sampled construction sites made efforts to retard or treat stormwater with best management practices (BMPs) before it was allowed to flow beyond the site boundary. Approximately 80% of construction sites had turbidities in the range of 2.3 to 200 NTU, TSS from 1 to 46 mg/L, and transparency tube depths from 10 to 60 cm. Water quality data are presented in Appendix A.

Comparisons of Turbidity Indicators

Correlation between field turbidity and laboratory turbidity

During Year 1, in addition to field measurements of turbidity, study samples were sent to Manchester Laboratory for a laboratory analysis of turbidity. Both instruments were ratio-type and of the same manufacturer, thus a high degree of correlation was anticipated. Figure 6 shows the comparison between Year 1 turbidity measurements made both in the field and at Manchester Laboratory.

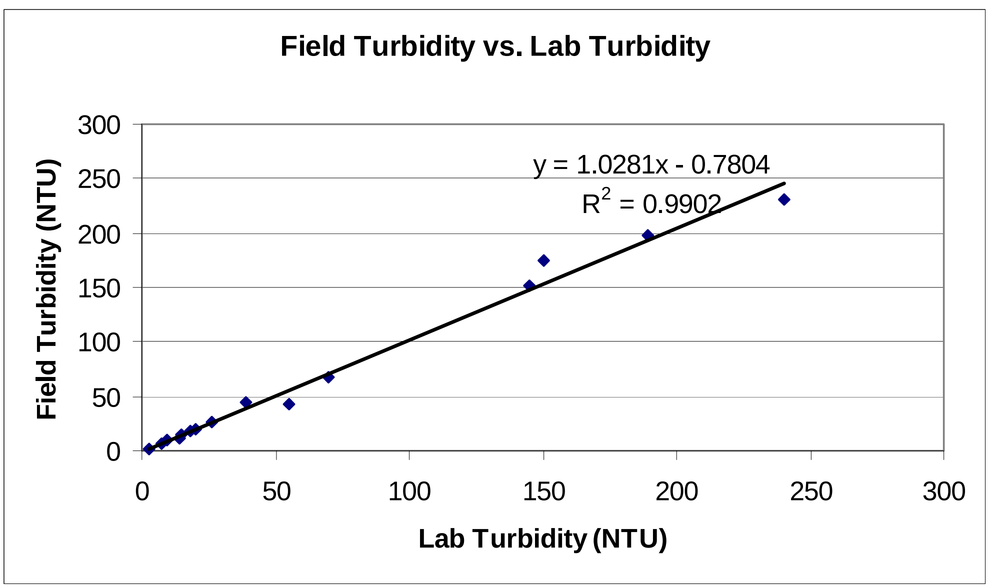

Figure 6: Comparison of Field and Laboratory Turbidity Results, 2003-2004

The statistical parameter, r^2, represents the variation in the dependent variable (y axis) that can be explained by the independent variable (x axis). For the linear relationship in Figure 6, r^2 is high (0.99). These results, in their closeness to 1.0, show that the correlation between, and the precision of, the field and laboratory turbidity measurements is excellent. The slope of the line in Figure 6 is close to 1, and the y intercept close to zero, indicating that the accuracy of the field turbidimeter relative to that of the laboratory is very good.

The calculated statistic, Student's t, given by Equation 2 (Zar, 1996), was found to be larger than the tabulated t-value for an alpha of 0.001, a significant correlation at the 99.9% confidence level. Based on these results, laboratory turbidity determinations were dropped in Year 2 of the study.

Correlation between turbidity and transparency

A secondary goal of the study was to develop a curve to correlate the transparency tube readings in centimeters (cm) to field turbidimeter measurements in NTU. Turbidity was compared with transparency tube results for each year of the study (Figure 7). The combined data define the overall correlation curve (Figure 8). The high degree of correlation shown in Figure 7 indicates that turbidity measurements for each year had good agreement with the transparency tube depths.

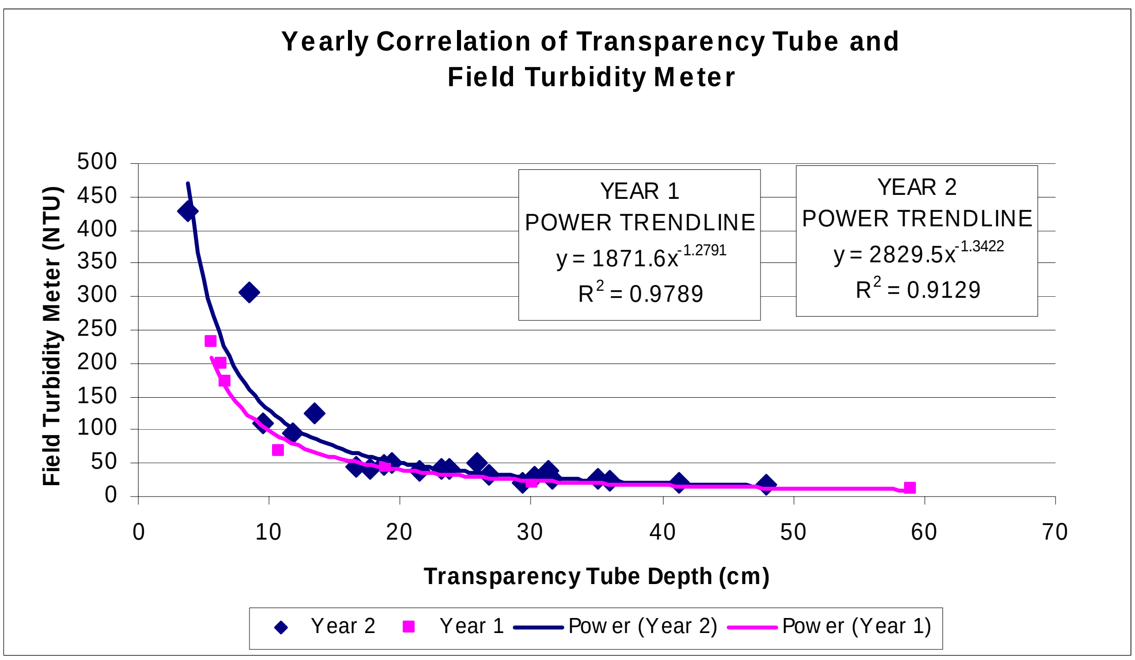

Figure 7: Comparison of Yearly Turbidity and Transparency Correlation Curves

Each year's regression curve was compared using a simple linear regression comparison in SYSTAT. The Year 1 curve was not found to be significantly different from the Year 2 curve in an ANOVA two-tailed test, $p>0.05$. Therefore, the data for both years of the study were combined to create the overall study correlation curve, shown in Figure 8.

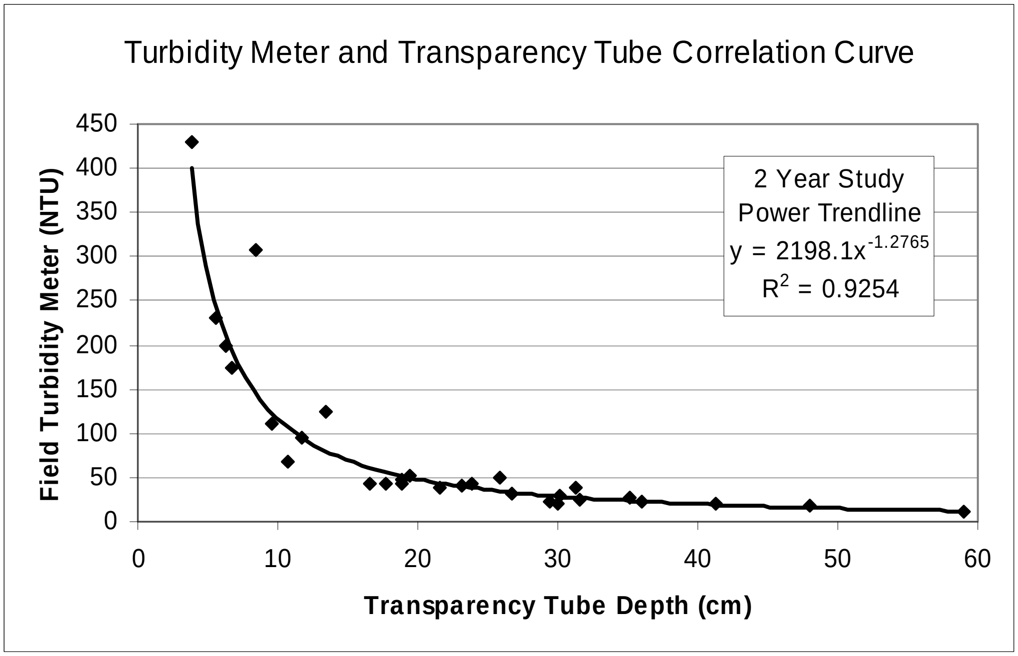

Figure 8: Turbidity and Transparency Correlation Curve

Using a power series, transparency tube results were found to correlate well with turbidity results. The $r^2 = 0.9254$ indicates a good correlation between the transparency tube and field turbidimeter turbidity measurements for the study. Ambient light conditions and differing operator techniques may increase variability in tube depth results. In this study, different operator results were within 1 cm of each other.

As was noted in the *Data Quality* section of this report, transparency tube results became imprecise for water column depths of 6 cm or less. This, combined with the small degree of slope of the transparency-turbidity curve for 250 NTU or higher, leads to the conclusion that transparency results less than 6 cm, which correspond to 250 NTU and higher, should not be translated directly as turbidity but instead interpreted as
>250 NTU. Transparency was found to be a good surrogate for turbidity, for estimated turbidity values below 250 NTU and transparency tube depths of 5.5 cm and greater. The calculated standard deviation for the turbidity readings is 2.5. Thus the readings made for a tube depth of 60 cm would be translated as 12 ± 2.5 NTU.

Turbidity can be estimated using the transparency depth as X and trendline equations shown in Figures 7 and 8. Using the regression equations in both Figures 7 and 8 for the correlation curves, the following table of corresponding turbidity and transparency tube calculations are presented. Table 5 illustrates the differences in turbidity (Y values) given specific transparency depths (X values).

Table 5: Calculated Turbidities from Transparency Depths

	If X=	then Y=	If X=	then Y=
Year 1	5	250 ± 2.5	29	25 ± 2.5
Year 2	6	250 ± 2.5	34	25 ± 2.5
2 Year Study*	5.5	250 ± 2.5	33	25 ± 2.5

* Two-year study is the combined data from the two individual years of data.

A complete table of transparency tube depths and calculated turbidities is provided in Appendix D.

Correlation between turbidity and TSS

The possibility of a correlation between total suspended solids (TSS) and turbidity was also explored. TSS may be anticipated to relate to turbidity. Figure 9 shows the relationship between TSS concentrations and turbidity found in the study results.

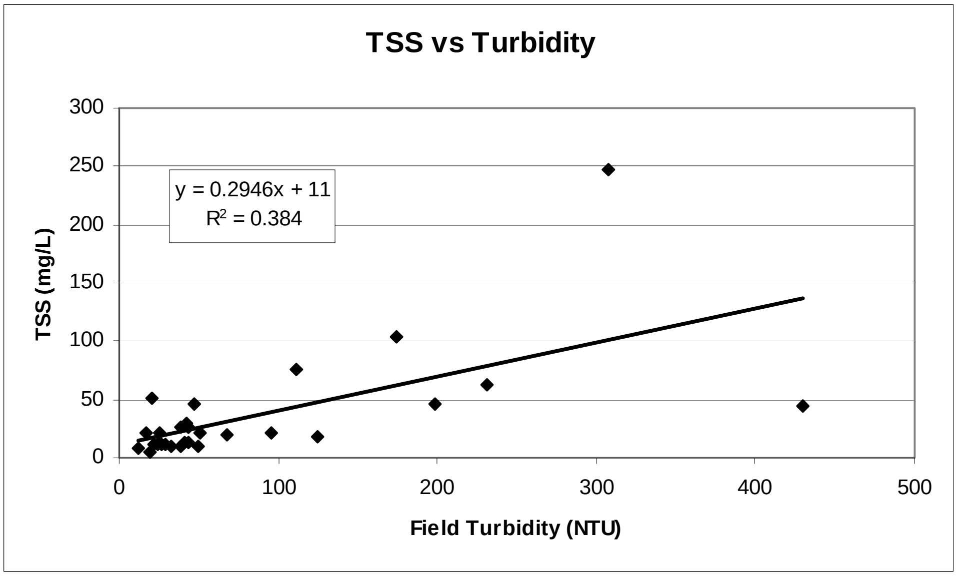

Figure 9: TSS vs Turbidity

Poor correlation between TSS and turbidity ($r^2 = 0.38$) was found. The relationship between TSS and transparency was also evaluated. A power series correlation coefficient between TSS and transparency (not shown) was 0.572 ($r^2 = 0.33$), indicating a poor of correlation between TSS and transparency.

The poor correlations between TSS and turbidity or transparency may be explained in terms of soil particle size. TSS is a measure of the mass of solids (other than dissolved solids) in a sample. For two samples, one with large solids (e.g., sand) and the other with small solids (e.g., silt), the total weight of solids and the corresponding value for TSS may be identical. Turbidity and transparency, on the other hand, are somewhat dependent on particle size. A sandy sample, high in TSS, could be expected to score low for turbidity and high for transparency, because sand-sized particles settle rapidly and do not scatter light in the way that silt does.

Descriptive Site Characteristics

Descriptive characteristics of the 44 construction sites visited were noted on the field forms and are summarized below. The following sections present the descriptive aspects of the construction sites sampled, and examine the relationships of a number of factors with site characteristics. The site characteristics were not well recorded for Year 1 of the study, but were used where possible.

Weather

The Year 1 2003-2004 sampling season experienced lighter than average rainfall. The Year 2 2004-2005 sampling season also experienced lighter rainfall for much of the winter. At the SEATAC WSCMO AP (457473) weather station from 1973 to 2003, the average November through March rainfall was 24.3 inches. In comparison, Year 1 and Year 2 experienced 21.6 and 16.8 inches of rainfall, respectively. When rain did fall, the storm patterns were characterized by localized storm systems of varying intensity, rather than widespread rain.

A total of 20 sites were experiencing rain at the time of sampling, 14 of which had experienced rain during the two previous days, representing 32% of sites visited. The weather conditions at each site are summarized in Table 6.

Table 6: Weather Conditions at the Construction Sites when Visited

Site Weather Conditions	Number of Sites	
	Preceding Visit	During Visit
Dry	2	0
Fog	0	1
Overcast*	2	22
Raining	30	20
Sunny	4	1
No Data	3	0
Raining overnight	3	0

*Overcast does not imply dry; it may have been raining prior to the visit.

Of the sites with a discharge sample collected, 68% had experienced rain two days prior to the visit, whereas 45% of the sites with discharge samples collected were visited during a rain event. It appears that rain for two days prior to sampling is preferred to produce runoff from western Washington construction sites. There were no predictive relationships with precipitation event type, and the three measured water quality parameters (turbidity, transparency, nor TSS).

Type of site and stage of construction

During the course of the two-year study, the type of construction underway and the stage of each construction site was recorded. These data are summarized in Tables 7 and 8, respectively.

Table 7: Types of Construction Sites

Type of Site	Number of Sites
Commercial	6
Residential	25
Industrial	1
Transportation	4
Utility	2
School	5
Other	1

Table 8: Stages of the Construction Sites

Stage of Project	Description	Number of Sites
NF	Project not found	8
0	Not started	13
1	Initial ground clearing	7
2	Initial installation of erosion BMPs	7
3	Rough grading	16
4	Final grading	24
5	Temporary shutdown (winter shutdown)	19
6	Working on buildings	11
7	Project finished	15
4 & 6	Final grading and working on buildings	19
5 & 6	Soils covered, no grading, and working on buildings	12

NF = not found
BMPs = best management practices

Residential sites were, by far, the most common type of site visited. Only a few construction sites were scattered throughout the other categories, with the sole "Other" site type referring to the Point Defiance Zoo that was not easily placed in the other categories.

Of the 183 construction sites visited, 13 sites had not started any work. The construction project at 15 sites was finished; therefore, and a site examination was not performed. Eight construction sites could not be found, usually due to an incomplete address. There are no results for stage 1 (initial ground clearing) because stormwater was not running off these sites.

Many of the construction sites were found in multiple stages at the same time, particularly residential sites. At one end of a typical residential site, the foundations were being excavated (stage 4); at the middle of the site, activities such as framing and installing utilities were predominant; and at the other end of the project, landscaping and painting were the main activities.

"Working on buildings" (stage 6) was added in Year 2 to cover framing through painting. The reasoning is that drywall, sawdust, shavings, wash water, concrete, paint, landscape soils, and other building materials could influence the transparency, turbidity, and TSS content of the water sample.

The construction site stages most commonly found over the course of the study were final grading (stage 4), temporary winter shut down (stage 5), and a combination stage of final grading and working on the structure (stage 4 & 6).

These descriptive characteristic data were insufficient to investigate a relationship with the three water quality parameters measured.

Size

Information on the three size classifications (small, medium, and large) are summarized in Table 9. Small refers to an area of less than 5 acres, medium is between 5 and 20 acres, and large is any size greater than 20 acres. When possible, the size and disturbed acreage were verified with personnel; otherwise, the size and/or disturbed acres were visually estimated. The actual size of the project was not expected to correlate well with stormwater discharge quality.

Table 9: Estimated Size of the Construction Sites

Size	Number of Sites	Percentage of Sites	Mean		
			Transparency (cm)	Turbidity (NTU)	TSS mg/L)
Large	16	36%	10.9	90.1	628.7
Medium	21	48%	26.3	49.5	33.7
Small	6	14%	22.9	40.8	131.2
No Data	1	2%	-	-	-

Visual estimation is prone to bias and error, and is a rough qualitative measurement made for a cursory analysis with the measured parameters. The relationship of disturbed acreage at each construction site and the water quality parameters were examined (data not shown).

The linear regression analysis was performed on the estimated disturbed acreage and the measured water quality parameters. The results were turbidity (r^2=0.45), transparency (r^2=0.08), and TSS (r^2=9E^{-05}) (data not shown). These r^2 values indicate that no meaningful predictive trend was found between estimated disturbed acreage and the water quality parameters.

Slope

The slope of the site was visually estimated for each of the visited sites, and was not tested for a relationship with the discharged water quality parameters. Table 10 presents the descriptive statistics of the construction sites related to slope.

Table 10: Estimated Slope of Construction Sites

Slope	Number of Sites	% of Sites Sampled
Sloped	20	45%
Slightly sloped	22	50%
Flat	2	5%

Almost all the construction sites were somewhat sloped. The study area elevations vary considerably, and valley floor areas that would be expected to be flat are already built out. The only two sites visited that had no visual slope were in Pierce County.

Best Management Practices

Best management practices (BMPs) are widely used as either preventive (i.e., source control) measures or treatment measures to improve the quality of stormwater that may leave a construction site. Typical and accepted BMPs are listed in the Stormwater Management Manual for Western Washington, Vol. II, Chapter 4 (Ecology, 2005).

In this study, the use of three BMPs at each construction site was noted:

1. Storm drain inlets protected from sediment.
2. Stormwater routed to a stormwater pond or basin.
3. Disturbed soil protected from erosion, where protection may include mulch, plastic, vegetation, or erosion-control blankets.

Descriptions and uses of the three BMPs are listed in Tables 11 and 12, respectively.

Every site visited within the two-year study had at least one of the three BMPs in use. No correlations were found between the types of BMPs used and the water quality parameters measured. The study was not designed to produce a sufficient number of sample points for this purpose. The most common BMP among the three surveyed was to route stormwater to a stormwater pond for treatment (BMP #2).

Table 11: Description of Best Management Practices

BMP	Description
1	Storm drain Inlet Protected
2	Stormwater Routed to Pond/Basin
3	Disturbed Soil Protected by Cover
None	None of the above BMPs employed
All 3 *	Inlets Protected AND Routed to Ponds AND Soils Covered
1 & 2 *	Inlets Protected AND Routed to Ponds
1 & 3 *	Inlet Protected AND Soils Covered
2 & 3 *	Routed to Pond AND Soils Covered

*AND – denotes a Boolean concept where each statement must be true.
This is not just a sum of the two types of BMPs.

Table 12: Use of Best Management Practices

BMP	Number of Sites	Mean		
		Transparency (cm)	Turbidity (NTU)	TSS (mg/L)
1	23	20.8	47.6	453.0
2	38	19.7	61.0	230.1
3	27	22.1	48.6	303.9
1&2	21	23.1	47.6	348.9
1&3	14	24.4	35.8	559.5
2&3	24	21.8	50.2	316.0
All 3	13	26.7	35.8	548.0

Soil Permeability and Expected Runoff

With only 24% of the 183 active sites discharging when visited, soil permeability was considered as a causal factor in the low incidence of surface runoff. Soil permeability for western Washington was mapped using ArcView and data from the State Soil Survey (STATSGO).

Figure 10 shows soil permeability for western Washington. The study area has a maximum permeability almost entirely above 0.6 inches per hour, high enough to account for much of the low incidence of surface runoff.

Other than in the Olympic Mountains and portion of the northwestern Olympic Peninsula, soils with low permeability (mostly exposed unweathered bedrock) occur only in the Cascade Mountains where the soils are interspersed with coarse material with high permeability.

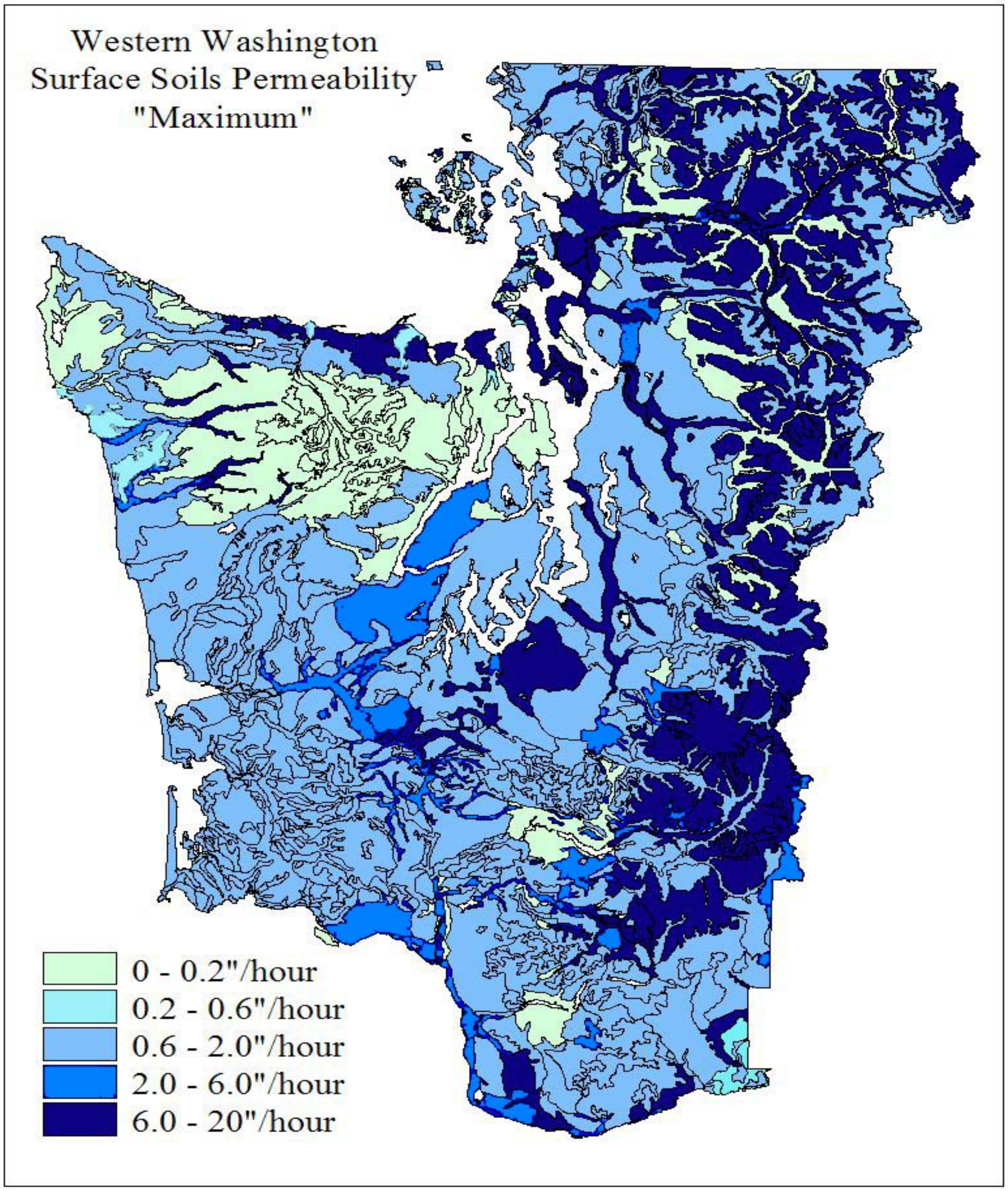

Figure 10: Soil Permeability for Western Washington

Infiltration rates are affected by groundwater elevation as well as soil permeability. High water tables, often associated with precipitation, prevent infiltration. For this reason, even in cases where soils are permeable, stormwater runoff may occur. The lower than average precipitation during the sampling seasons for this two-year study may have resulted in lower water tables and a lower frequency of discharge. Actual permeability at construction sites could be altered for the better or worse due to many activities (e.g., vegetation removal, grading, digging for foundations and utilities).

Receiving Water Evaluation

Six of the 44 sites sampled discharged directly to receiving waters when the site was sampled. The receiving waterbodies were all small streams, with widths ranging from 2 to 5 feet. Receiving waters were sampled both upstream and at two points downstream of the discharge for turbidity, transparency, and total suspended solids (TSS). The two distances downstream were at three times the width at the point of discharge and at 100 feet, determined by pacing. These two points were compared to test the differences in the measured water quality parameters at the two distances. Receiving water turbidity readings are presented in Table 13.

Table 13: Turbidity Readings Upstream and Downstream (Units = NTU)

Site	Mean Turbidity					Difference in Turbidity	
	Stream Width (ft)	100ft Up-stream	Stormwater Discharge	3xW Down-stream	100ft Down-stream	Upstream to 3xW Downstream	Upstream to 100ft Downstream
SBI Development	3.0	2.2	8.9	--	2.2	--	0.0
Tristate Copart Malcolm Drilling	3.0	5.2	38.9	--	6.4	--	1.2
Magnolia Meadows	5.0	5.5	95.5	5.5	5.2	0.0	-0.3
Pelzel Village Development	5.0	6.4	43.7	23.1	25.7	**16.7**	**19.3**
Bethel Kapowski Elementary School	2.5	9.8	174.0	64.7	45.0	**54.9**	**35.2**
TriWay Cooper Crest	2.0	17.6	145.0	18.5	12.0	0.9	-5.7

Bold = distance downstream located three times the width (3xW) of the stream

Two of the six sites, Pelzel Village Development and Bethel Kapowski Elementary School, showed higher turbidities at both (3xW and 100 feet downstream) locations. See Appendix C for photographs of these two sites. Because these streams were small, the distance representing three times the width (3xW) was within 15 feet.

The four other receiving waters were not adversely impacted by turbidity from the construction site stormwater discharge. SBI Development, Tristate Copart Malcolm Drilling and Magnolia Meadows were unchanged by the discharge, and TriWay Cooper Crest turbidity improved at 100 feet downstream of the discharge.

At two of the locations, Tristate Copart Malcolm Drilling and SBI Development, downstream turbidity was measured 100 feet downstream of the discharge but was mistakenly not recorded 3xW downstream.

The six construction sites were located in all four counties: one in Snohomish, two in King, two in Pierce, and one in Thurston. Although not specifically measured, the flow rates of the discharges into the streams were also quite small. Overall, the low incidence of receiving water impacts may be related to the lack of wet weather precipitation and/or may reflect the efforts of the construction community to not route site stormwater to area streams.

Conclusions

General Findings

During the two winter, rainy seasons of 2003-04 and 2004-05, a total of 183 active construction sites in western Washington were visited. This study found that 24% (44 of 183) of construction sites were discharging stormwater offsite when visited. This may be the result of study design, lighter than average precipitation, the presence of stormwater retention facilities at the sites, and/or the high permeability of soils where construction was taking place. Managers at most of the sites visited appeared to have made concerted efforts to protect water quality and not direct stormwater discharge into area streams. Only six of the 44 sites visited discharged directly into a receiving water, and two of those caused a measurable impact.

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.

All 44 sites had at least one of the three surveyed best management practices (BMPs) in place:

1. Storm drain inlets protected from sediment.
2. Stormwater routed to a stormwater pond or basin.
3. Disturbed soil protected from erosion, where protection may include mulch, plastic, vegetation, or erosion-control blankets.

This study was not developed to evaluate the impacts of construction site characteristics or BMP implementation on discharge water quality.

Comparisons of Turbidity Indicators

The field turbidimeter and the Manchester Laboratory turbidimeter had a near-perfect, one-to-one relationship ($r^2 = 0.99$) to each other, indicating that a field meter, when properly calibrated, is as precise as the laboratory meter. Total suspended solids (TSS) was not found to be a valid surrogate for turbidity determinations.

Transparency and field turbidity measurements were highly correlated ($r^2 = 0.92$). Transparency was a good surrogate for turbidity below 250 NTU or transparency tube depths of 5.5 cm or greater. The correlation between transparency tube and turbidity measurements may or may not be specific to the soils in the four counties of the study area. Because the transparency tube and turbidimeter measure different properties (light transmission versus light scatter), it cannot be assumed that the above correlation applies to all soil types. Regional variations in soil properties may affect the readings of each instrument differently.

Site Characteristics and Turbidity

Both the 2003-2004 and 2004-2005 winter seasons experienced lighter than average rainfall. Precipitation in 2004-2005 came to western Washington early in the winter, and not again until late spring.

Whether a site would be discharging was better predicted by the two days of rain preceding a visit, than by rain during the visit. Antecedent soil moisture conditions and the use of some BMPs on construction sites are likely factors in the number of rainy days necessary to cause a discharge. BMPs with a potential effect on discharge timing include underground vaults, large chemical treatment ponds, and small crude ponds that were periodically re-dug.

Data were tallied on the number of sites characterized by stage of project, type of project, disturbed acreage, and slope of a site. These data were insufficient to warrant further analysis. Residential sites were the most visited type of site, representing 57% of the 44 sites where a discharge sample was collected.

The size of the construction site was evaluated separately for correlations with the three water quality parameters measured: turbidity, transparency, and TSS. No correlations were found. Stormwater solids content could theoretically be independent of project size. The potential for loading is ultimately dependent on the amount of soil available, not the outline of the project area. Completely denuded small sites with no protective measures could yield the same stormwater sediment load as large sites with protected soils and BMP implementation. However, in a heavy rain storm, a large disturbed area of unprotected soils is more likely to lose more sediment than a small site.

The significance of the three BMPs implemented independently, in some combination, or as all three together, on the water quality parameters is not yet known.

Receiving Water Turbidity

Of the six sites discharging directly to receiving waters, two caused an increase in downstream turbidity. The sample size was too small to allow for a meaningful evaluation of the extent that construction sites discharging to receiving waters were responsible for increases in turbidity.

Recommendations

Recommendations made as a result of this study are as follows:

- A properly calibrated field ratio-type turbidimeter can be assumed to be as accurate as laboratory analysis for use in future studies.
- Transparency tube readings are a valid surrogate for turbidity measurements in the field between 5.5 cm in depth to the top of the turbidity tube (60 cm). Below 5.5 cm transparency, turbidity should be estimated as 250 NTU or greater. When transparency readings are equal to 60 cm, turbidity should be estimated as 12 NTU ± 2.5 NTU or less. This inexpensive transparency tube should be considered as an alternative to a laboratory or portable ratio-type turbidimeter when faced with financial or logistical limitations.
- A separate study should be conducted to sample stormwater discharge from construction sites in other areas of Washington State.
- The finding that 24% of the 183 construction sites discharged stormwater, and only 3% discharged directly to receiving waters, suggests that there are real benefits to active on-site stormwater management at construction sites.

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Appendix A: Sampled Construction Sites Information

Table A-1: List of Sampled Sites and Water Quality Analysis

Date Taken	Sample Name	Site Name	Transparency Tube Depth (cm)	Transparency Tube Replicate	Field Turbidimeter (NTU)	Field Turbidimeter Replicate	TSS (Lab) mg/L	TSS Lab Replicate	Lab Turbidity (NTU)	Lab Turbidity Replicate
YEAR 1										
1/15/04	CAPSTONE	Capstone Homes	5.5	5.6	231		62		240	240
1/15/04	SLAVIC	Slavic Church	10.8	10.6	68.1	67.7	20		70	
1/28/04	PELZEL	Pelzel Village Development (discharge)	18.8	18.9	45.3	42	14	15	55	
1/28/04	BELEM	Bethel Kapowski Elementary School	6.4	7	174		104	114	150	
1/27/04	PDZOO#1	Point Defiance Zoo (main discharge)	4	3.2	error		876		900	
1/27/04	PDZOO#2	Point Defiance Zoo (discharge 2)			160					
1/27/04	PDZOO#3	Point Defiance Zoo (discharge 3)			316					
1/28/04	CHAFFY#1	Chaffy the Ridge at Glacier Creek	6.4	6.2	198		46		189	
1/28/04	CHAFFY#2	Chaffy the Ridge at Glacier Creek (discharge 2)			168					
1/28/04	CHAFFY#3	Chaffy the Ridge at Glacier Creek (discharge 3)			193					
2/25/04	COOPER#1	TriWay Cooper Crest	0.8	0.6	error		28	26	140	
2/25/04	COOPER#2	TriWay Cooper Crest (discharge 2)			24.6					
3/3/04	WHITTENBRG#1	Wittenburg Estates (pond)	59	59	12.4	12.2	9		14	
3/3/04	WHITTENBRG#2	Wittenburg Estates (leaky silt fence)			85					
4/6/04	BOWLIN	Bowlin Plat	29.9	30.2	20.5	20.2	51		20	

Date Taken	Sample Name	Site Name	Transparency Tube Depth (cm)	Transparency Tube Replicate	Field Turbidimeter (NTU)	Field Turbidimeter Replicate	TSS (Lab) mg/L	TSS Lab Replicate	Lab Turbidity (NTU)	Lab Turbidity Replicate
4/20/04	PTLDBUS	Portland Avenue Business Park	>60	>60	2.37	2.23	2		2.6	
4/20/04	PTLDBUSFD	Portland Avenue Business Park Field Duplicate			2.45		1		2.6	2.5
4/21/04	HENDER	Henderson Ave/ I-5 Exchange	>60	>60	14.3		5		15	
4/21/04	HENDERREP	Henderson Ave/ I-5 Exchange Field Duplicate			14.2		6		15	
YEAR 2										
12/6/04	LAKELAND	Lakeland	5.2	5.1	--		7			
12/6/04	AUBHS4	Auburn High School #4	13	12.5	--		36			
12/9/04	SFEDISTCTR	Safeway Distribution Facility	26.4	27	31.9	32.4	10			
12/9/04	KBINVEST#1	KB Investment Center Discharge 1	16.2	17	44	43.7	27			
12/9/04	KBINVEST#2	KB Investment Center Discharge 2	17.6	17.8	42.8	42	30			
12/9/04	NEWMIDDLE	New Middle School Federal Way	35	35.2	43.4	42.9	27	25		
12/9/04	QUADNORTH	Quadrant NorthLake	24	23.6	26.3	26.4	11			
12/15/04	ENCHANTED	Enchanted Meadows	21.2	25	41.5	40.7	13			
12/21/04	PARCBLKN	Parcel K North Quadrant	3.6	4	424	435	45			
12/21/04	SNOQELEM	Elementary School Snoqualmie Valley	32.6	30.6	24.9	26.4	21	19		
12/29/04	LKTACRKB	SBI Development	>60	>60	8.85	8.85	4	5		
1/18/05	PENNONCON	Pennon Constr - Federal Way	19.4	19.4	53.3	49.2	22	24		
1/18/05	KINGDOT	King Co. Dept of Transportation	35	37	23	24.3	12			
1/21/05	TRIMALC	Tristate Copart Malcolm Drilling	21	22	39.9	37.8	26	27		
1/27/05	HANSONDAM	Traylor Howard Hanson Dam	>60	>60	23.5	23.6	1	1		

Date Taken	Sample Name	Site Name	Transparency Tube Depth (cm)	Transparency Tube Replicate	Field Turbidimeter (NTU)	Field Turbidimeter Replicate	TSS (Lab) mg/L	TSS Lab Replicate	Lab Turbidity (NTU)	Lab Turbidity Replicate
3/1/05	INCLINE	Highground Incline	>60	>60	3.85	3.78	2	4		
3/1/05	MAMEADOWS	Magnolia Meadows	11.5	12	94.8	96.1	21	21		
3/1/05	MEADESTAT	Magnolia Estates	>60	>60	20.5	21.6	11			
3/16/05	ECHORIVER	WSDOT SR522 Paradise Lake Rd	>60	>60	4.14	3.92	3			
3/16/05	ECHOPOND	WSDOT SR522 Paradise Lake Rd	>60	>60	13	12.2	15			
3/16/05	FRYELANDS	Monroe School Fryelands Elem	1.6	1.7	error		720			
3/16/05	SKGEBLDG	Sky River Building	19	18.6	14.4	13.3	10	8		
3/16/05	SKYHARBOR	Sky Harbor	>60	>60	48.6	44.8	46			
3/17/05	BRYANT	Bryant Estates	>60	>60	8.02	7.24	4			
3/17/05	SUMMERSET	Summerset	>60	>60	2.59	3.17	1 [J]			
3/29/05	CAMPUSP1	Campus Park (pond1)	>60	>60	6.83	6.67	3			
3/29/05	CAMPUSP2	Campus Park (pond2)	>60	>60	20.5	21.1	10			
3/29/05	LUNDEEN	Snoho Co. Lundeen Pkway	29.2	29.6	19.1	25.1	12			
3/29/05	AVIARA	Aviara	9	7.8	309	307	247			
4/1/05	WEBSTERP	DR Horton - Webster Pond (pump)	0.9	2			7470			
4/1/05	WEBSTERV	DR Horton - Webster Pond (vault)	14.6	12.2	123	127	18	16		
4/1/05	SUNSETEST	McNaughton Sunset Meadows Estate	30.4	30	28.6	29.2	11			
4/1/05	HAWTHORN	Hawthorn Station	25	26.8	47.4	50.9	10			
4/1/05	CREEKWALK	Creekwalk at Bellemont Crossings	41	41.5	18.6	20.4	5			
4/6/05	CONNER	Conner Clifton	32.6	30	35.6	41.7	10	7		
4/6/05	SAMMPIPE#2	Sammamish Water Pipe 36 Sample 2	48	48	17.3	17.58	22			
4/12/05	OTHELLO	Seattle Housing Auth-Holly Park-Othello Station	0.6	0.8	error		2580	2700		

1 [J] - an estimated value, due to the sample being below the detection limit.

Appendix B: RPDs for Turbidity, Transparency, and Total Suspended Solids

Table B-1: Field Turbidity Relative Percent Difference (RPD)

$$\text{RPD} = \left(\frac{\text{difference of 2 results}}{\text{mean}}\right) \times 100$$

Field Turbidity (NTU)	Replicate (NTU)	Mean (NTU)	RPD (%)
31.9	32.4	32.15	1.6
44	43.7	43.85	0.7
42.8	42	42.4	1.9
43.4	42.9	43.15	1.2
26.3	26.4	26.35	0.4
41.5	40.7	41.1	1.9
424	435	429.5	2.6
24.9	26.4	25.65	5.8
8.85	8.85	8.85	0.0
2	2.3	2.15	14.0
2.04	2.34	2.19	13.7
53.3	49.2	51.25	8.0
23	24.3	23.65	5.5
39.9	37.8	38.85	5.4
4.6	5.82	5.21	23.4
6.69	6.11	6.4	9.1
23.5	23.6	23.55	0.4
3.85	3.78	3.815	1.8
20.5	21.6	21.05	5.2
94.8	96.1	95.45	1.4
5.12	5.35	5.235	4.4
5.43	5.54	5.485	2.0
5.04	4.89	4.965	3.0
5.09	5.9	5.495	14.7
13	12.2	12.6	6.3
4.14	3.92	4.03	5.5
14.4	13.3	13.85	7.9
48.6	44.8	46.7	8.1
8.02	7.24	7.63	10.2
2.59	3.17	2.88	20.1
112	110	111	1.8
6.83	6.67	6.75	2.4
20.5	21.1	20.8	2.9
21.5	21.6	21.55	0.5
19.1	25.1	22.1	27.1
309	307	308	0.6
123	127	125	3.2

Field Turbidity (NTU)	Replicate (NTU)	Mean (NTU)	RPD (%)
28.6	29.2	28.9	2.1
47.4	50.9	49.15	7.1
18.6	20.4	19.5	9.2
35.6	41.7	38.65	15.8
17.3	17.58	17.44	1.6
68.1	67.7	67.9	0.6
45.3	42	43.65	7.6
6.46	6.3	6.38	2.5
25.6	25.7	25.65	0.4
11.8	12.1	11.95	2.5
12.4	12.2	12.3	1.6
20.5	20.2	20.35	1.5
2.37	2.23	2.3	6.1

Table B-2: Lab Turbidity Relative Percent Difference (RPD)

Lab Turbidity (NTU)	Replicate (NTU)	Mean (NTU)	RPD (%)
240	240	240	0.0
7.5	7.4	7.45	1.3
140	150	145	6.9
14	14	14	0.0
2.6	2.5	2.55	3.9

Table B-3: Total Suspended Solids (TSS) Relative Percent Difference (RPD)

TSS (mg/L)	Replicate (mg/L)	Mean (mg/L)	RPD (%)
27	25	26	7.7
21	19	20	10.0
4	5	4.5	22.2
22	24	23	8.7
26	27	26.5	3.8
1	1	1	0.0
21	21	21	0.0
4	5	4.5	22.2
10	8	9	22.2
76	75	75.5	1.3
18	16	17	11.8
10	7	8.5	35.3
2580	2700	2640	4.5
14	15	14.5	6.9
104	114	109	9.2
28	26	27	7.4

Table B-4: Transparency Relative Percent Difference (RPD)

Transparency Tube (cm)	Replicate (cm)	Mean (cm)	RPD (%)
5.2	5.1	5.15	1.9
13	12.5	12.75	3.9
26.4	27	26.7	2.2
16.2	17	16.6	4.8
17.6	17.8	17.7	1.1
24	23.6	23.8	1.7
35	35.2	35.1	0.6
21.2	25	23.1	16.5
3.6	4	3.8	10.5
32.6	30.6	31.6	6.3
19.4	19.4	19.4	0.0
35	37	36	5.6
21	22	21.5	4.7
11.5	12	11.5	4.3
1.6	1.7	1.65	6.1
19	18.6	18.8	2.1
9.2	10	9.6	8.3
29.2	29.6	29.4	1.4
9	7.8	8.4	14.3
0.9	2	1.45	75.9
14.6	12.2	13.4	17.9
30.4	30	30.2	1.3
25	26.8	25.9	6.9
41	41.5	41.25	1.2
32.6	30	31.3	8.3
48	48	48	0.0
0.6	0.8	0.7	28.6
5.5	5.6	5.55	1.8
10.8	10.6	10.7	1.9
18.8	18.9	18.85	0.5
6.4	7	6.7	9.0
4	3.2	3.6	22.2
6.4	6.2	6.3	3.2
0.8	0.6	0.7	28.6
59	59	59	0.0
29.9	30.2	30.05	1.0

Appendix C: Photos

Figure C-1: Bethel Kapowski Discharge and Receiving Water

The Bethel Kapowski Elementary School discharge site was an overtopping silt fence with a large pool of water behind the fence. This discharge was found to cause an increase in the receiving water downstream of the overtopping silt fence.

Figure C-2: Tristate Copart Malcolm Drilling Discharge and Receiving Water

Tristate Copart was a virtually finished construction site alongside a small urban stream. A small pool of the discharge water slowly mixes with the creek. This discharge was not found to cause an increase in the receiving water.

Appendix D: Transparency Results

Table D-1: Calculated Turbidity Results from Observed Transparency Tube Depths

Transparency Tube Depth (cm)	Calculated Turbidity[1] (NTU)	(±) Standard Deviation for Turbidity Values[2]
5.5	249	2.5
6	223	2.5
7	183	2.5
8	155	2.5
9	133	2.5
10	116	2.5
11	103	2.5
12	92	2.5
13	83	2.5
14	76	2.5
15	69	2.5
16	64	2.5
17	59	2.5
18	55	2.5
19	51	2.5
20	48	2.5
21	45	2.5
22	43	2.5
23	40	2.5
24	38	2.5
25	36	2.5
26	34	2.5
27	33	2.5
28	31	2.5
29	30	2.5
30	29	2.5
31	27	2.5
32	26	2.5
33	25	2.5
34	24	2.5
35	23	2.5
36	23	2.5
37	22	2.5
38	21	2.5
39	20	2.5
40	20	2.5
41	19	2.5
42	19	2.5
43	18	2.5
44	18	2.5
45	17	2.5
46	17	2.5
47	16	2.5
48	16	2.5
49	15	2.5

Transparency Tube Depth (cm)	Calculated Turbidity[1] (NTU)	(±) Standard Deviation for Turbidity Values[2]
50	15	2.5
51	15	2.5
52	14	2.5
53	14	2.5
54	14	2.5
55	13	2.5
56	13	2.5
57	13	2.5
58	12	2.5
59	12	2.5
60	12	2.5

1- Turbidity calculated from the correlation equation between the field turbidity (ratio-type) meter and transparency tube depth (cm). The equation used is:

Turbidity (NTU) = 2198.1*(Tube Depth^(-1.2765)).

2- The standard deviation is calculated from the log transformed turbidity data, using Excel. The resultant figure was retransformed to a non-logarithmic number to yield a usable standard deviation of 2.5 NTU.