TECHNOLOGY EVALUATION AND ENGINEERING REPORT

WSDOT Ecology Embankment

Prepared for

Washington State Department of Transportation

July 2006

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TECHNOLOGY EVALUATION AND ENGINEERING REPORT

WSDOT Ecology Embankments

Prepared for

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Executive Summary

The Ecology Embankment is an innovative stormwater best management practice (BMP) that was developed by the Washington State Department of Transportation (WSDOT) for treatment of highway runoff. It functions as a flow-through water quality treatment device that can be utilized where available right-of-way is limited.

WSDOT has conducted hydrologic and water quality monitoring at an Ecology Embankment installation located on State Route (SR) 167 in south King County (Figure 1) between 2001 and 2005. The purpose of this monitoring was to obtain data on system performance that would support the issuance of a General Use Level Designation (GULD) for the Ecology Embankment from the Washington Department of Ecology (Ecology). This monitoring was performed in accordance with procedures described in *Guidance for Evaluating Emerging Stormwater Treatment Technologies; Technology Assessment Protocol – Ecology (TAPE)* (Ecology 2004).

This document presents the technology evaluation and engineering report (TEER) that was prepared for the Ecology Embankment based on the monitoring data described above. The specific goal of this TEER is to demonstrate satisfactory performance of the Ecology Embankment for issuance of a GULD in relation to the following treatment goals:

- Basic Treatment
- Phosphorus Treatment
- Enhanced Treatment for Dissolved Metals Removal
- Oil Treatment

Technology Description

The Ecology Embankment is a linear flow-through stormwater runoff treatment device that can be sited along highway side-slopes (conventional design) and medians (dual Ecology Embankment), borrow ditches, or other linear depressions. The Ecology Embankment can be used where available right-of-way is limited, sheet flow from the highway surface is feasible, lateral gradients are generally less than 25 percent (4H:1V), and longitudinal gradients are less than 5 percent.

The Ecology Embankment has four basic components: a gravel no-vegetation zone, a vegetated filter strip, the ecology-mix bed, and a gravel-filled underdrain trench. The Ecology Embankment removes suspended solids, oil, phosphorus, and metals from highway runoff through physical straining, ion exchange, carbonate precipitation, and biofiltration. Physical straining occurs in the no-vegetation zone and vegetated filter strip, and biofiltration may occur in the vegetated filter strip. The ecology-mix bed, which contains crushed rock, dolomite, gypsum, and perlite, treats stormwater through several processes:

- Physical filtration
- Chemical precipitation
- Sorption and cation exchange
- Biological uptake and metabolism

In addition, to the extent that infiltration occurs into the soil underlying any portion of the ecology embankment, discharge pollutant loading is reduced.

Procedures for Obtaining Data

In order to facilitate performance monitoring pursuant to the procedures described in Ecology (2004), an Ecology Embankment test system was specifically designed and constructed on the shoulder of northbound SR 167 in Auburn at milepost 16.4 (see Figure 1). This test system collected runoff from a 500-foot length of Ecology Embankment.

Automated monitoring equipment was installed in this test system to characterize influent and effluent flow volumes during discreet storm events. In association with this hydrologic monitoring, automated samplers were employed to collect flow-weighted composite samples of the influent and effluent for subsequent water quality analyses. Based on the data obtained from this monitoring, removal efficiency estimates were computed for targeted monitoring parameters.

Water quality monitoring was conducted at the Ecology Embankment test system in three phases (Taylor study, WSDOT study, and Tetra Tech study) over a five period from 2001 through 2005. During these studies, a total of 25 separate storm events were sampled (9 during the Taylor study, 3 during the WSDOT study, and 13 during the Tetra Tech study). Water quality samples were analyzed for the following parameters during the indicated number of storm events: total suspended solids (TSS), 25 events; total phosphorus, 25 events; soluble reactive phosphorus (SRP), 9 events; total and dissolved zinc, 25 events; total and dissolved copper, 13 events; hardness, 25 events; turbidity, 12 events; pH, 12 events; and particle size distribution (PSD), 8 events. Influent and effluent flow monitoring data are also available for 9 of the storm events. These data were subsequently evaluated in the following ways:

- Computation of pollutant removal efficiencies using three methods:

  - ☐ Method #1 - Individual Storm Reduction in Pollutant Concentration

  - ☐ Method #2 - Aggregate Pollutant Loading Reduction

  - ☐ Method #3 - Individual Storm Reduction in Pollutant Loading

- Statistical comparisons of influent and effluent concentrations and loads

- Temporal trend analysis

- Correlation analysis to examine influence of storm characteristics on system performance.

Data Summaries

Individual storm events during which water quality samples were collected must meet specific requirement for all of the following criteria to be considered valid pursuant to the TAPE (Ecology 2004):

- Minimum precipitation depth
- Minimum antecedent dry period
- Minimum storm duration
- Minimum number of sample aliquots
- Minimum portion of storm volume covered by sampling.

Monitoring results show that the criteria for minimum antecedent dry period and minimum storm duration were met for all 25 storm events. The criterion for minimum precipitation depth (0.15 inch) was met during all storm events except one. The criterion for minimum number of sample aliquots (10) was met for 68 percent of the sampled storm events. This criterion could not be assessed for four of the storms because this information was not recorded.

The criterion for minimum portion of storm volume covered by sampling (75 percent) was only met for 32 percent of the sampled storm events. This criterion could not be assessed for three of the storms because this information was not recorded. Sampling during the Tetra Tech study (i.e., the last study period) targeted only the rising limb of the storm hydrograph for both the influent and effluent samples; thus, the minimum coverage of the storm hydrograph, as specified by the TAPE, was typically not achieved. This could potentially cause system performance to be overestimated for the associated storm events if the influent sample concentrations have a high bias from capturing only the initial wash off or “first flush” of pollutants. However, analyses performed on the compiled water quality data do not show a consistent pattern of higher influent pollutant concentrations for the Tetra Tech study relative to the two earlier studies. Therefore, the lack of adequate storm volume coverage during the Tetra Tech study should not substantially diminish the overall validity of the associated data for assessing the performance of the Ecology Embankment.

The water balance of the Ecology Embankment was evaluated based on influent and effluent flow volumes from 20 storm events that occurred during the Taylor study. No flow monitoring data were collected during the WSDOT study and the flow data from the Tetra Tech study were determined to be unreliable. The data from the Taylor study indicated that the percentage of influent that was accounted for in the effluent ranged from 0 to 120 percent, with a median value of 36 percent. Taylor Associates (2002) concluded that these water losses in the Ecology

Embankment were likely not caused by water bypassing the system; rather, they probably stemmed from the storage and subsequent evaporation of water from within the ecology mix bed. In additional, water losses likely occurred through absorption and infiltration within the strip of pervious area between the paved shoulder and the Ecology Embankment.

Because flow volumes were only calculated for the samples collected during the Taylor study, pollutant removal estimates based on loading (Method #2 and Method #3) were only calculated for these storms. Pollutant removal estimates based on concentrations (Method #1) were calculated for all storms.

Conclusions Based on Data

Study conclusions derived from the monitoring data are summarized below for each of the treatment goals that are addressed in this TEER.

Basic Treatment

TAPE guidelines (Ecology 2004; Hoppin 2006 personal communication) indicate that the goal for basic treatment is 80 percent removal for influent total suspended solids (TSS) concentrations from 100 to 200 milligrams per liter (mg/L), inclusive. For influent concentrations that are greater than 200 mg/L, a higher treatment goal may be appropriate. For influent concentrations less than 100 mg/L, the effluent TSS concentration goal is less than 20 mg/L.

Out of twelve storms with influent concentrations less than 100 mg/L, the 20 mg/L goal established in the TAPE was only exceeded during one storm (effluent TSS concentration = 26 mg/L). Effluent concentrations during the remaining eleven storms were all 10 mg/L or less, and the median across all twelve storms was 3.9 mg/L. For the thirteen storms with influent TSS concentrations equal to or greater than 100 mg/L, the Method #1 removal efficiency estimates indicated the 80 percent goal established in the TAPE was met or exceeded during every storm event except one. It should be noted the calculated removal efficiency for this one storm (i.e., 79.3 percent) came very close to meeting the goal. The median value for the Method #1 removal efficiency estimates was 96.0 percent across all thirteen of these storm events. Similarly, the removal efficiencies calculated using Method #3 for these storms were all greater than the 80 percent goal and had a median value of 94.8 percent. Finally, the aggregate TSS removal efficiency calculated using Method #2 was 95.3 percent for these same storms. These data indicate the SR 167 Ecology Embankment consistently met the basic treatment goal for influent concentrations that are both less than 100 mg/L and greater than 100 mg/L. Furthermore, the coefficient of variation (COV) for the influent concentrations indicates there are an adequate number of storm events for assessing this treatment goal with a confidence level of 95 percent and a power of 80 percent.

Phosphorus Treatment

TAPE guidelines (Ecology 2004) indicate the goal for phosphorus treatment is 50 percent removal for influent total phosphorus concentrations that are within the range of 0.1 to 0.5 mg/L. Based on Method #1 removal efficiency estimates, the 50 percent removal goal established in the TAPE was met during all but two storms. The median removal efficiency for total phosphorus from these data was 86.3 percent. Method #3 removal efficiency estimates showed the 50 percent removal goal was met during all storms. The median removal efficiency estimate from these data was 74.3 percent. Finally, the aggregate total phosphorus removal efficiency estimate as calculated using Method #2 was 81.1 percent. These data indicate the SR 167 Ecology Embankment consistently met the treatment goal for phosphorus. Furthermore, the coefficient of variation (COV) for the influent concentrations indicates there are an adequate number of storm events for assessing this treatment goal with a confidence level of 95 percent and a power of 80 percent.

While total phosphorus decreased, an increase in effluent SRP concentrations relative to influent was observed in the monitoring data from the Taylor study. This increase was likely caused by the transformation of removed particulate phosphorus into the dissolved phase as evidenced by the percentages of SRP that made up the total phosphorus concentration of influent and effluent samples, respectively. However, it is not uncommon for soluble phosphorus to be exported from stormwater BMPs that trap sediment (CASQA 2003, Koon 1995). Speciation notwithstanding, the overall reduction in total phosphorus meets the goal identified in the TAPE for phosphorus treatment. Phosphorus can readily transform between particulate and dissolved phases in different environments. By reducing the overall source of phosphorus to receiving waters, less phosphorus is available for cycling through the system and potential biological uptake. This, in turn, will lead to an overall reduction in phosphorus related water quality problems.

Enhanced Treatment

TAPE guidelines (Ecology 2004) indicate that the data collected for an “enhanced” BMP should demonstrate significantly higher removal rates for dissolved metals than basic treatment facilities. To evaluate the monitoring results relative to this goal, dissolved zinc and copper performance data from the Ecology Embankment were compared to performance data for several types of basic treatment facilities that were obtained from other data sources.

With regard to dissolved zinc, the performance goal for enhanced treatment from the TAPE assumes that the facility is treating stormwater with concentrations ranging from 20 to 300 μg/L. Only one of the sampled storm events for the SR 167 Ecology Embankment had an influent concentration that was not within this range. Excluding this data point, dissolved zinc removal efficiency estimates calculated using Method #1 ranged from 34.4 to 91.9 percent, with a median value of 78.7 percent. (The one outlier influent concentration, 493 μg/L, had an effluent concentration of 14 μg/L, which represents 97.2% removal.) Removal efficiency estimates calculated using Method #3 for these storms ranged from 77.3 to 96.4 percent, with a median value of 90.7 percent. Finally, the aggregate removal efficiency for dissolved zinc based on Method #2 was 89.4 percent. Statistical analyses showed that the median removal efficiency for dissolved zinc in the Ecology Embankment was significantly higher ($p < 0.0001$) than the median values reported for basic treatment facilities from other data compilations (ASCE 2006, WSDOT 2006a). Therefore, these results indicate that the Ecology Embankment meets the goal identified in the TAPE guidelines for enhanced treatment in relation to dissolved zinc. Furthermore, the coefficient of variation (COV) for the influent concentrations indicates there are an adequate number of storm events for assessing this treatment goal with a confidence level of 95 percent and a power of 80 percent.

With regard to dissolved copper, the performance goal for enhanced treatment from the TAPE assumes that the facility is treating stormwater with concentrations ranging from 3 to 20 μg/L. Three of the sampled storm events for the SR 167 Ecology Embankment had influent concentrations that were not within this range. Excluding these values and considering only the remaining ten storm events with dissolved copper data, the calculated removal efficiency estimates for this parameter from Method #1 ranged from 17.6 to 65.5 percent, with a median value of 39.2 percent. (Method #2 and Method #3 removal efficiency estimates cannot be calculated for these storms due to a lack of flow data for the associated samples.) Statistical analyses showed that the median removal efficiency for dissolved copper in the Ecology Embankment was significantly higher ($p < 0.0001$ and $p = 0.0164$ in separate data analyses) than the median values reported for basic treatment facilities from other data compilations (ASCE 2006, WSDOT 2006a). Therefore, these results indicate that the Ecology Embankment meets the goal identified in the TAPE guidelines for enhanced treatment in relation to dissolved copper. Furthermore, the coefficient of variation (COV) for the influent concentrations indicates there are an adequate number of storm events for assessing this treatment goal with a confidence level of 95 percent and a power of 80 percent.

Oil Treatment

Current TAPE guidelines (Ecology 2004) for oil treatment require the effluent to have no visible sheen, and total petroleum hydrocarbon concentrations must be no greater than 10 mg/L (daily average) and 15 mg/L (discrete sample). Petroleum products are hydrophobic and tend to separate from water and bind to solid materials including suspended particulates, soil, exposed vegetation and roots, as well as filter media. Treatment for petroleum products within the Ecology Embankment is expected to occur in several system components (i.e., vegetated filter strip, ecology-mix bed) that all rely on filtration. In addition, biodegradation of petroleum hydrocarbons is also expected to occur with exposure to indigenous soil microorganisms (Wisconsin DNR 1994; Zheng and Obbard 2003) and the biofilm present within the ecology mix (Wolverton, B.C. and McDonald-McCaleb 1986). While no water quality monitoring was conducted at the SR 167 Ecology Embankment site for petroleum products, treatment performance can be inferred based on data from other systems that use similar pollutant removal mechanisms. Specifically, vegetated swales and media filters have been shown to provide good treatment performance for petroleum products. Furthermore, effluent total petroleum hydrocarbon (TPH) concentrations reported for media filters are substantially below the effluent goal identified in the TAPE guidelines for oil treatment. Based on these data, it is expected that the Ecology Embankment will also provide adequate treatment in relation to this goal.

Introduction

The Ecology Embankment is an innovative stormwater best management practice (BMP) that was developed by the Washington State Department of Transportation (WSDOT) for treatment of highway runoff. It functions as a flow-through water quality treatment device that can be utilized where available right-of-way is limited. The Ecology Embankment, which can be sited on both highway side slopes and medians, collects runoff as sheet flow and uses infiltration through a pervious, alkalinity-generating media called the ecology-mix to remove suspended solids and soluble metals from highway runoff through physical straining, ion exchange, carbonate precipitation, and biofiltration.

WSDOT has conducted hydrologic and water quality monitoring at an Ecology Embankment installation located on State Route (SR) 167 in south King County (Figure 1) between 2001 and 2005. The purpose of this monitoring was to obtain data on system performance that would support the issuance of a General Use Level Designation (GULD) for the Ecology Embankment from the Washington Department of Ecology (Ecology). This monitoring was performed in accordance with procedures described in *Guidance for Evaluating Emerging Stormwater Treatment Technologies; Technology Assessment Protocol – Ecology (TAPE)* (Ecology 2004). Pursuant to guidance presented in this same document, a technology evaluation and engineering report (TEER) must be completed for any stormwater treatment system that is under consideration for a GULD. The specific objectives of the TEER are as follows:

- Document treatment performance of a technology under consideration for a GULD to show that it will achieve Ecology's performance goals for target pollutants as demonstrated by field testing performed in accordance with the TAPE.

- Demonstrate the technology is satisfactory with respect to factors other than treatment performance (e.g., maintenance).

This document presents the TEER that was prepared for the Ecology Embankment based on the monitoring data described above. The specific goal of this TEER is to demonstrate satisfactory performance of the Ecology Embankment for issuance of a GULD in relation to the following treatment goals:

- Basic Treatment
- Phosphorus Treatment
- Enhanced Treatment for Dissolved Metals Removal
- Oil Treatment

In accordance with these goals, monitoring data from the Ecology Embankment installation on SR 167 have shown the system achieves 96.0 percent removal for TSS, 86.3 percent removal for total phosphorus, 78.7 percent removal for dissolved zinc, and 39.2 percent removal for dissolved copper. (Values reported here represent the median removal efficiency for each parameter as calculated using Method #1). To date, no specific sampling has been performed to assess the performance of the Ecology Embankment with regard to oil treatment; however, removal efficiency should be similar to those reported for the other parameters given the treatment mechanisms that are employed within the system. Specifically, oil treatment should be achieved through hydrophobic adsorption as the runoff passes through the Ecology Embankment and comes into contact with associated gravel, soil, vegetation, and the ecology-mix treatment media. Additional treatment may also occur through metabolism by soil and epilithic microorganisms. Treatment performance for oil can be inferred based on data from other systems that use similar pollutant removal mechanisms. Specifically, vegetated swales and media filters have been shown to provide good treatment performance for petroleum products (ACWA 2006). Furthermore, monitoring data indicate effluent total petroleum hydrocarbon (TPH) concentrations reported for media filters are substantially below the effluent goal identified in the TAPE guidelines for oil treatment.

The data and analyses used to derive these performance claims are described within this TEER. Pursuant to the guidelines in Ecology (2006), this information is presented under the following major headings:

- Technology Description
- Procedures for Obtaining Data
- Data Summaries
- Conclusions Based on Data

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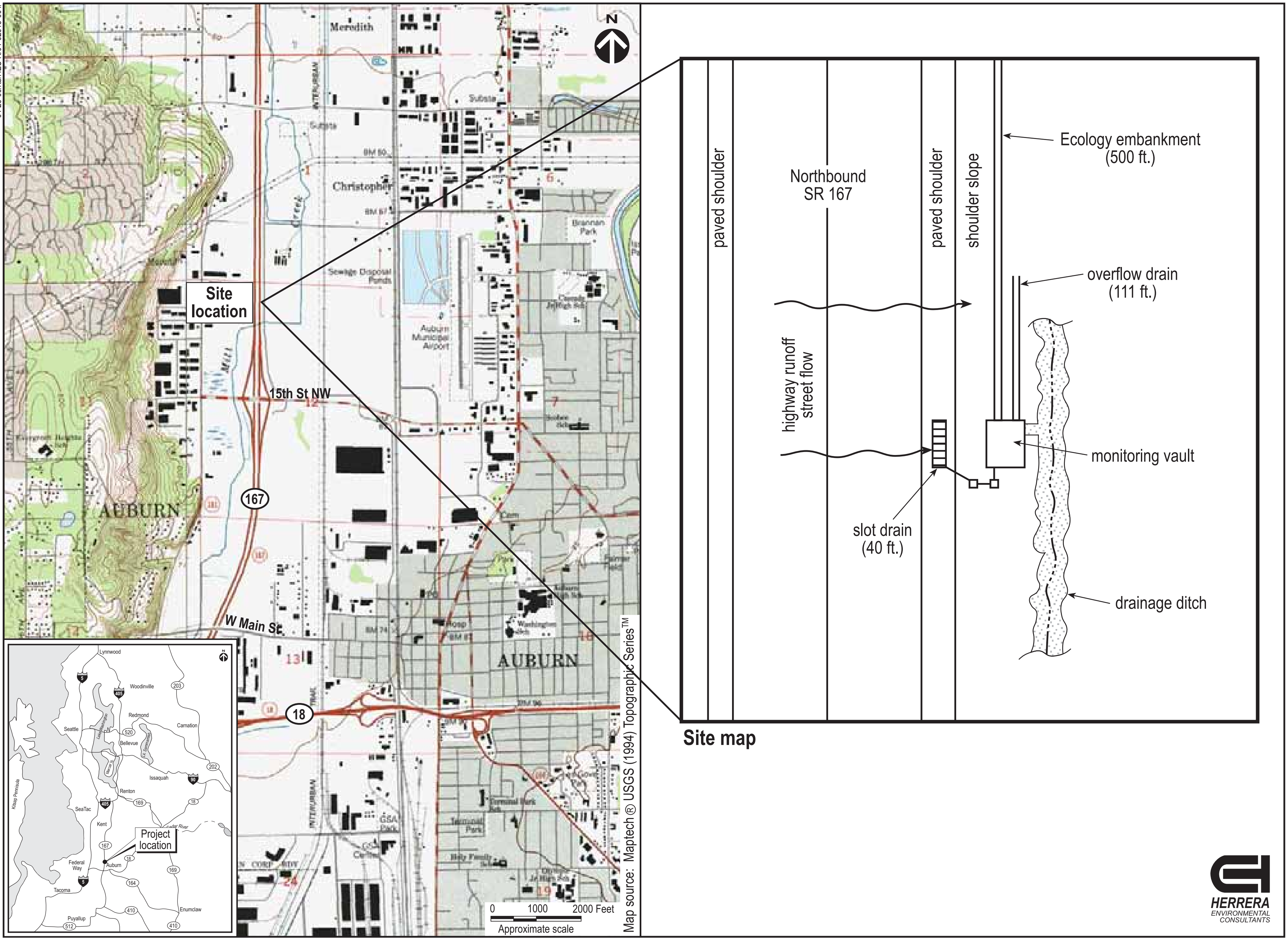


Figure 1. Vicinity and site map for the SR 167 Ecology Embankment, Auburn, Washington.

Technology Description

This section provides a description of the Ecology Embankment including the physical dimensions and functions of its various components, sizing methodology, expected treatment capabilities, applicability and limitations, and related operations and maintenance requirements.

Physical Description

The Ecology Embankment is a linear flow-through stormwater runoff treatment device that can be sited along highway side-slopes (conventional design) and medians (dual Ecology Embankment), borrow ditches, or other linear depressions. Cut-slope applications may also be considered. The Ecology Embankment can be used where available right-of-way is limited, sheet flow from the highway surface is feasible, lateral gradients are generally less than 25 percent (4H:1V), and longitudinal gradients are less than 5 percent. Lateral gradients as steep as 3H:1V are allowed with protection and stabilization considerations. Complete design guidance for Ecology Embankments is included in the *Highway Runoff Manual* (WSDOT 2006b).

The Ecology Embankment has four basic components: a gravel no-vegetation zone, a vegetated filter strip, the ecology-mix bed, and a gravel-filled underdrain trench. See Figures 2 and 3 for typical Ecology Embankment configurations.

Stormwater runoff is conveyed to the Ecology Embankment over a vegetation-free gravel zone to ensure sheet dispersion. It is critical for runoff to remain dispersed (sheet flow) across the Ecology Embankment. Channelized flows or ditch flows running down the middle of the Dual Ecology Embankment (i.e., continuous off-site inflow) should be minimized. The gravel zone also provides some pollutant trapping. Next, a vegetated filter strip, which may be amended with compost, is incorporated into the top of the fill-slope to provide pretreatment, further enhancing pollutant removal and extending the life of the system. The runoff is then filtered through a bed of porous, alkalinity-generating granular medium – the ecology-mix. Ecology-mix is a fill material composed of crushed rock, dolomite, gypsum, and perlite. Treated water drains from the ecology-mix bed into the gravel underdrain trench for hydraulic conveyance; an underdrain pipe may be required in the trench. Geotextile lines the underside of the ecology-mix bed and the infiltration trench.

Designs for the four components of the Ecology Embankment are described in more detail below.

No-Vegetation Zone

The no-vegetation zone (i.e., vegetation-free zone) is a shallow gravel trench located directly adjacent to the highway pavement. It should be between 1 foot and 3 feet wide. Depth will be a function of how the roadway section is built from subgrade to finish grade; the resultant cross

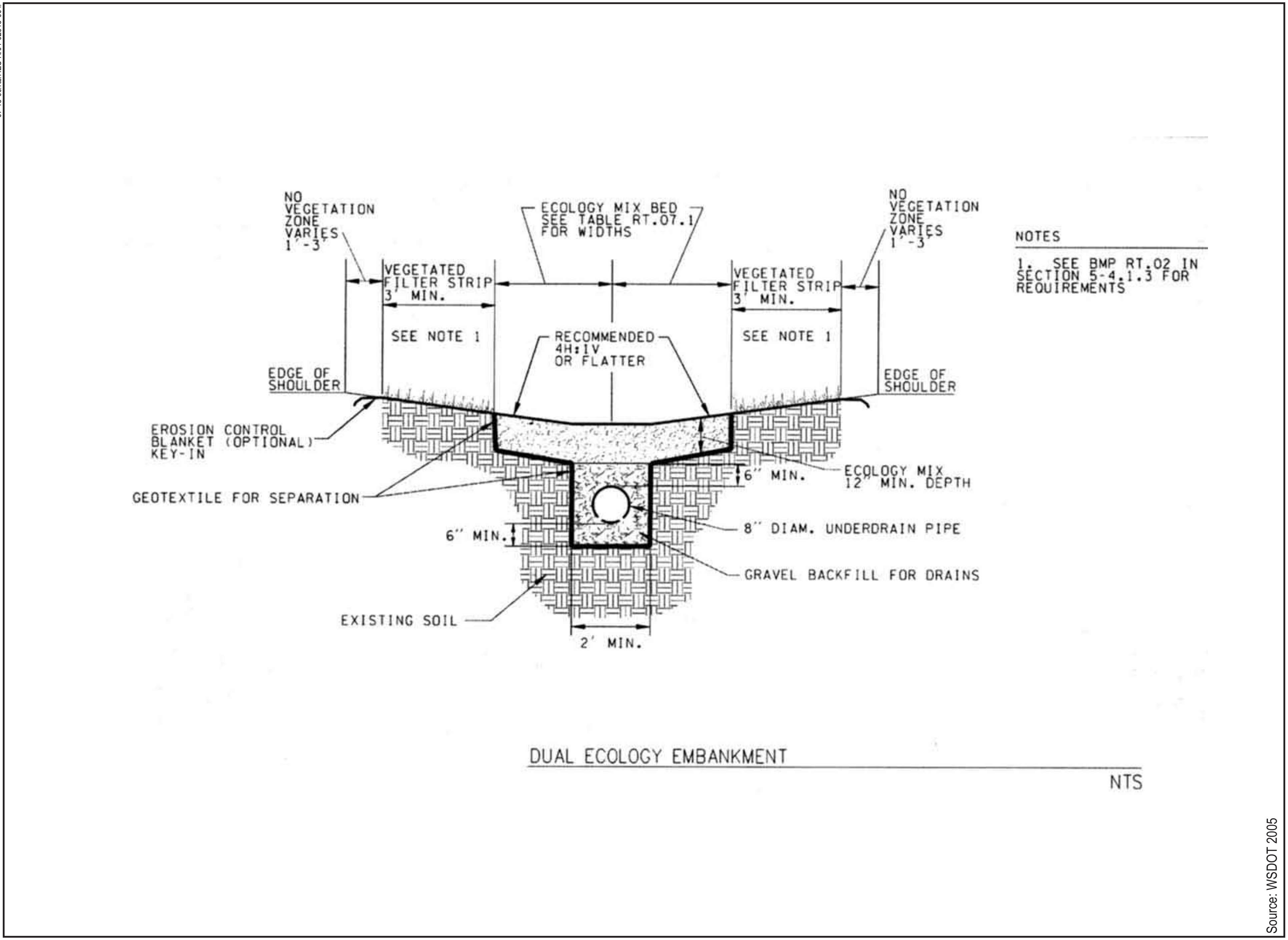


Figure 2. Typical cross-section of Ecology Embankment.

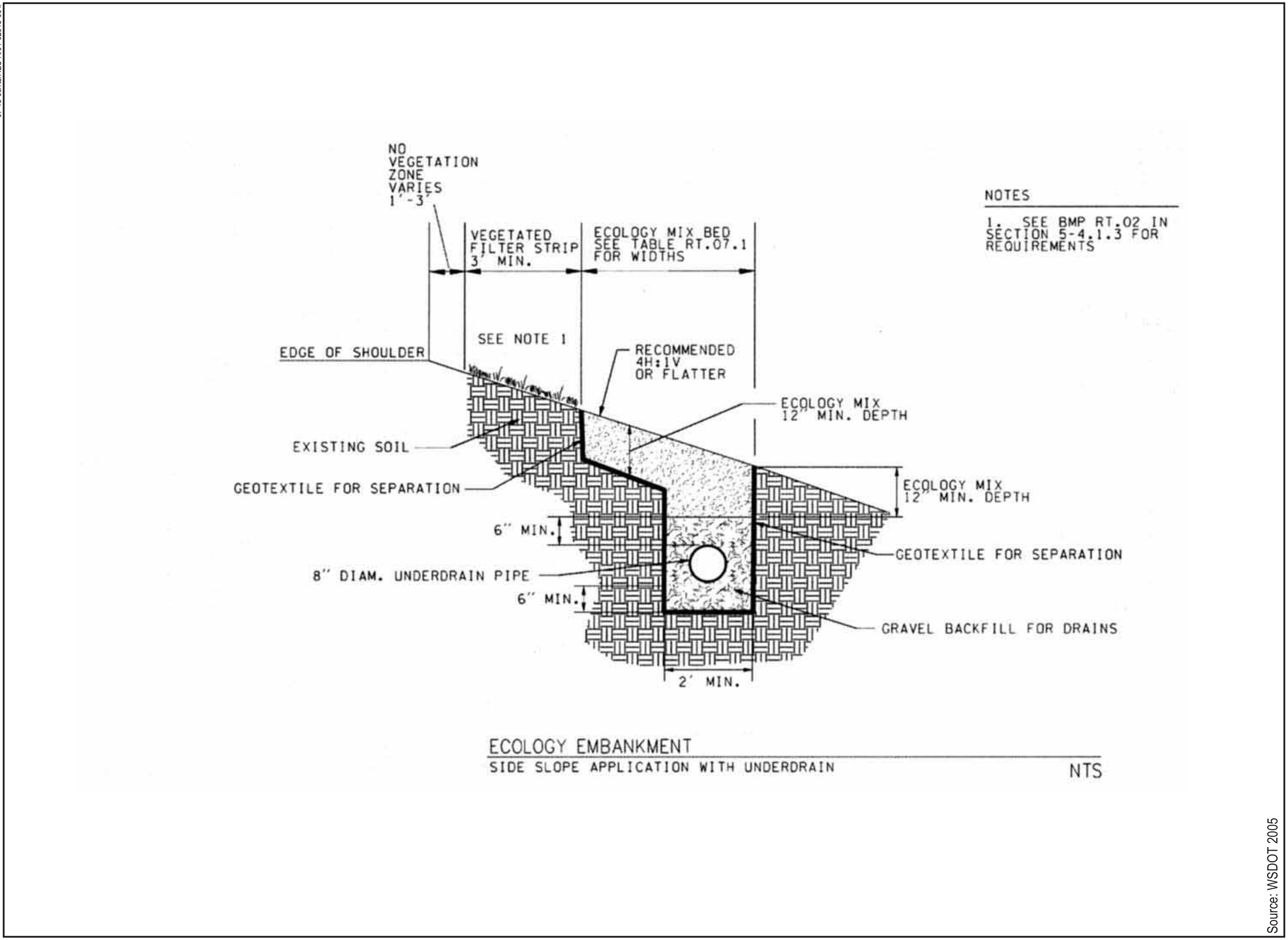


Figure 3. Typical cross-section of dual Ecology Embankment.

section will typically be triangular to trapezoidal. Within these bounds, width varies depending on WSDOT maintenance spraying practices.

Vegetated Filter Strip

The width of the vegetated filter strip is dependent on the availability of space within the highway side slope. The baseline design criterion for the vegetated filter strip within the Ecology Embankment is a 3-foot minimum width, but wider vegetated filter strips are recommended if the additional space is available. In addition, use of compost amendments within the strips is recommended to maximize treatment efficiency (see BMP RT.02, *Vegetated Filter Strip*, in WSDOT 2006b).

Ecology-Mix Bed

The ecology-mix is a mixture of crushed rock (screened between 3/8-inch and #10 sieve) and three amendments: dolomite, gypsum, and perlite (Table 1). The crushed rock provides the support matrix of the medium; the rock and amendments provide physical filtration of solids;, and the amendments provide chemicals and the environment needed for pollutant removal by precipitation, ion-exchange, and sorption.

Gravel Underdrain

The gravel underdrain trench provides hydraulic conveyance when required, and should be evaluated for infiltration loss. In Group C and D soils, a perforated 8-inch PVC pipe may be required in the underdrain trench to ensure free flow of the treated runoff through the ecology-mix bed. In some Group A and B soils, the underdrain pipe may be unnecessary if most water draining from the ecology-mix percolates into subsoil from the underdrain trench, or if trench flow alone is adequate to ensure free drainage from the ecology-mix bed, and if an underdrain pipe is not required to route runoff to a flow control BMP or stormwater outfall. In all cases, the underdrain should be modeled as an infiltration trench (see BMP IN.03 in WSDOT 2006b).

The MGSFlood model has been enhanced (Version 3.0) to model the hydraulic response of gravel-filled trenches. Gravel-filled infiltration trenches have some advantages over other flow control facilities: they generally fit within existing highway rights-of-way; they tend to cut through several soil types, which improves the likelihood that they will encounter areas of high infiltration capacity; and they can maintain clear zone safety requirements without installation of guardrails or fences.

The underdrain trench may daylight laterally via pipe or gravel hydraulic connection to a downslope open trench or swale, as long as flow-control requirements are met, the ecology-mix bed integrity is maintained, and free-flow of runoff through the ecology mix is maintained. Ecology has approved this design at SR-518.

Table 1. Specifications for ecology-mix components.

Amendment	Quantity
Mineral aggregate Crushed screenings 3/8 inch to #10 sieve Crushed screenings shall be manufactured from ledge rock, talus, or gravel, in accordance with Section 3-01 of *Standard Specifications for Road, Bridge, and Municipal Construction* (WSDOT 2002), which meets the following test requirements: Los Angeles Wear, 500 Revolutions — 35% max. Degradation Factor — 30 min. Crushed screenings shall conform to the following requirements for grading and quality: Sieve Size — Percent Passing (by weight) 1/2" square — 100 3/8" square — 90-100 U.S. No. 4 — 30-56 U.S. No. 10 — 0-10 U.S. No. 200 — 0-1.5 % fracture, by weight, min. — 75 Static stripping test — Pass The fracture requirement shall be at least one fractured face and will apply to material retained on the U.S. No. 10 if that sieve retains more than 5 percent of the total sample. The finished product shall be clean, uniform in quality, and free from wood, bark, roots, and other deleterious materials. Crushed screenings shall be substantially free from adherent coatings. The presence of a thin, firmly adhering film of weathered rock shall not be considered as coating unless it exists on more than 50 percent of the surface area of any size between successive laboratory sieves.	3 cubic yards
Perlite (Horticultural grade, free of any toxic materials): >70% larger than 18 mesh <10% smaller than 120 mesh	1 cubic yard per 3 cubic yards of mineral aggregate
Dolomite: $CaMg(CO_3)_2$ (calcium magnesium carbonate) #0, gradation #16 sieve	10 pounds per cubic yard of perlite
Gypsum:Non-calcined, agricultural gypsum $CaSO_4{\bullet}2H_2O$ (hydrated calcium sulfate) #0, gradation #8 to #16 sieve	1.5 pounds per cubic yard of perlite

Signing

Non-reflective guide posts will delineate the Ecology Embankment. This practice allows WSDOT personnel to identify where the system is installed and to make appropriate repairs should damage occur to the system. If the ecology embankment is in a critical aquifer recharge area for drinking water supplies, signage prohibiting the use of pesticides must be provided.

Where required, the underdrain trench should be a minimum of 2 feet wide for either the conventional or dual Ecology Embankment. Widening or deepening the underdrain trench may provide additional infiltration and storage capacity. Void space may be used in the calculations to help reduce the size of downstream detention facilities, depending on conditions. If orifices are incorporated into the discharge riser design, the water storage capacity within the underdrain trench below the underdrain pipe can be used as live storage. Therefore, this live storage volume can be subtracted from the required detention volume of the detention pond used for flow control following the Ecology Embankment. However, the design must ensure that this does not cause backflows out of the transmission trench that impede free flow through the ecology-mix bed.

Materials

Ecology-Mix

The ecology-mix used in the construction of Ecology Embankments consists of the materials listed in Table 1. Mixing and transportation must be done in a manner that ensures the materials are thoroughly mixed prior to pouring into the ground, and that separation does not occur during transportation or pouring.

Gravel Backfill

Gravel backfill for pipe bedding should conform to Section 9-03.12(3) of *Standard Specifications for Road, Bridge, and Municipal Construction* (WSDOT 2002).

Underdrain Pipe

Where pipe is required, it should be 8-inch diameter PVC perforated pipe, per the standard listed in Section 9-05.2(6) (Underdrain Pipe) of *Standard Specifications for Road, Bridge, and Municipal Construction* (WSDOT 2002). The perforation holes should be situated 30 to 45 circumference-degrees from the top and bottom of the pipe. The underdrain pipe can be elevated above the bottom of the underdrain trench to provide additional water storage.

Landscaping (Planting Considerations)

Landscaping is the same as for biofiltration swales (see BMP RT.04 in WSDOT 2006b), unless otherwise specified in the special provisions for the project's construction documents.

Treatment Processes

The Ecology Embankment removes suspended solids, phosphorus, metals, and oil from highway runoff through physical straining, ion exchange, carbonate precipitation, and biofiltration. Treatment processes associated with each of the components of the Ecology Embankment are described below.

No-Vegetation Zone

Stormwater runoff is conveyed to the Ecology Embankment via sheet flow over a vegetation-free gravel zone to ensure sheet dispersion, and provide some pollutant trapping.

The primary function of this zone is to ensure sheet flow conveyance to the adjacent vegetated filter strip. It is critical for runoff to remain dispersed (sheet flow) across the Ecology Embankment. Channelized flows or ditch flows running down the middle of the Dual Ecology Embankment (i.e., continuous off-site inflow) should be minimized.

This zone also provides some treatment through sediment filtration and limited infiltration. Pollutants attached to the filtered solids will also be removed from the runoff. The range of particle sizes captured in the no-vegetation zone will depend on flow. Most sediment may be trapped during low intensity and/or very brief storms, and some of this flow may infiltrate to underlying soils, reducing pollutant loads to the following portions of the Ecology Embankment. Higher intensity storms will result in primarily coarse sediment trapping.

Vegetated Filter Strip

After the no-vegetation zone, a vegetated filter strip, which may be amended with compost, is incorporated into the top of the fill-slope to provide pretreatment, further enhancing pollutant removal and extending the life of the system.

While the vegetated filter strip treats runoff prior to filtration through the ecology-mix, it is important to note that the Ecology Embankment is designed to fully treat highway runoff in the ecology-mix bed. The vegetated filter strip is considered additional treatment in the system, and will extend the life of the ecology-mix bed reducing long-term operations and maintenance needs. Incorporation of compost amendment in vegetated filter strips is encouraged. Properly designed compost amended vegetated filter strips (CAVFS) are approved for basic and enhanced metals treatment (WSDOT 2006b; Ecology 2005). Because vegetated filter strips upslope of Ecology Embankments may not meet the width requirements of standalone filter strips, these lesser-width CAVFS will not have the same treatment effectiveness. However, they will still provide a degree of solids and dissolved metals treatment capability.

The vegetated filter strip physically filters sediments and pollutants associated with sediments from runoff. The soil matrix can remove phosphorus through sorption and precipitation with iron oxides, aluminum oxides, calcium, and ferric iron. Vegetative uptake is also a process of phosphorus removal in the vegetated filter strip. Dissolved metals can be removed by sorption to iron, aluminum, and manganese oxides, precipitation with carbonates and sulfides, and sorption to exchanges sites in clay and organic matter. Where filter strips are amended with compost, additional metals removal can be achieved through chelation and complexation with organic matter. An advantage of the compost-amended vegetated filter strip is improved removal of soluble cationic contaminants through sorption; further, metals are also removed through uptake by plants, biofilms, and soil organisms, and these populations are enhanced by compost amendment. To the extent that infiltration occurs into the soil underlying the vegetated filter strip, discharge pollutant loading is reduced.

Ecology-Mix

Dolomite and gypsum add alkalinity and ion exchange capacity to promote the precipitation and exchange of heavy metals for light metals, and precipitation of phosphorus. Perlite improves moisture retention, which is critical for the formation of a biomass of epilithic biofilm within the ecology-mix. In addition, the perlite increases tortuosity of the matrix, enhancing retention for treatment chemical reactions. The combination of physical filtering, precipitation, ion exchange, and biofiltration provides the water treatment capacity of the mix. These processes are described in more detail below:

- Physical filtration: The granular filter media provides filtration of particulate materials and the pollutants associated with them.
- Chemical precipitation: Carbonate from dolomite increases the buffer-capacity and alkalinity of runoff. This leads to precipitation through the formation of metal carbonates and hydroxides. Calcium from dolomite and gypsum, and magnesium from gypsum combine with phosphate to form relatively insoluble metal-phosphate precipitates.
- Sorption by cation exchange: A matrix containing gypsum and dolomite adsorbs metals from runoff by exchanging calcium and magnesium ions with heavier metals including copper and zinc.
- Biological uptake: Epilithic biofilm in the matrix can remove phosphorus, precipitate and sequester metals, and metabolize petroleum hydrocarbons.
- Infiltration below the ecology-mix: Runoff that infiltrates to underlying soils will reduce pollutant loading to the downstream surface discharge point.

Gravel Underdrain

The gravel underdrain trench provides hydraulic conveyance when required, and should be evaluated for infiltration loss. Runoff that infiltrates to underlying soils will reduce pollutant loading to the downstream surface discharge point.

BMP Sizing Methods

Flows to Be Treated

The basic design concept behind the Ecology Embankment and dual Ecology Embankment is to fully filter all runoff through the ecology-mix. Therefore, the infiltration capacity of the medium and drainage below needs to match or exceed the hydraulic loading rate.

Width

The width of the ecology-mix bed is determined by the amount of contributing pavement routed to the embankment. The surface area of the ecology–mix bed needs to be sufficiently large to fully infiltrate the runoff treatment design flow rate using the long-term filtration rate of the ecology-mix. An initial infiltration rate of 50 inches per hour is estimated for ecology mix based on media gradation using permeability values in FHWA (1980). A long-term infiltration rate of 28 inches per hour is used to account for siltation. For design purposes, a 50 percent safety factor is incorporated into the long-term ecology-mix infiltration rate to accommodate variations in slope, resulting in a design infiltration rate of 14 inches per hour. The ecology-mix bed should have a bottom width of at least 2 feet in contact with the underdrain trench (i.e., the contact area should be no less than the underdrain width).

Length

In general, the length of an ecology embankment or dual ecology embankment is the same as the contributing pavement. Any length is acceptable as long as the surface area of the ecology–mix bed is sufficient to fully infiltrate the runoff treatment design flow rate.

Cross Section

In profile, the surface of the ecology embankment should preferably have a lateral slope less than 4H:1V (less than 25 percent). On steeper terrain, it may be possible to construct terraces to create a 4H:1V slopes, or other engineering may be employed to ensure slope stability up to 3H:1V. If sloughing is a concern on steeper slopes, consideration should be given to incorporating permeable soil reinforcements, such as geotextiles, open-graded/ permeable pavements, or commercially available ring and grid reinforcement structures, as top layer components to the ecology-mix bed. Consultation with a geotechnical engineer is required. Ecology has approved one 3H:1V design (SR-202) where the Ecology Embankment is protected at the top by a guardrail, and stabilized at its base by a pervious rock wall. To accommodate additional storage, the underdrain trench can be over-excavated and filled with drainage gravel, and the perforated pipe elevated above the bottom of the trench. The void space within the drainage gravel (35 percent of total volume) can be used to reduce the live storage requirements for downstream flow control facilities.

Inflow

Runoff is always conveyed to an Ecology Embankment using sheet flow from the pavement area (separated by the no-vegetation zone/gravel zone). The side slopes can be designed using the criteria and design methodology for the Vegetated Filter Strip (BMP RT.02 in WSDOT 2006b). If not enough lateral space is available for a full-sized conventional vegetated filter strip, a narrower strip down to a minimum of 3 feet still provides some pretreatment to enhance the runoff treatment function of the Ecology Embankment. This partial strip is acceptable since the ecology-mix is designed to provide full runoff treatment for both suspended solids and dissolved metals; although reducing the width of the vegetated filter strip may shorten the life of the ecology-mix.

Ecology-Mix Bed Sizing Procedure

The ecology-mix should be a minimum of 12 inches deep, including the section on top of the underdrain trench.

For runoff treatment, sizing the ecology-mix bed is based on the requirement that the runoff treatment flow rate from the pavement area $Q_{Highway}$ cannot exceed the long-term infiltration capacity of the Ecology Embankment, $Q_{Infiltration}$:

$$Q_{Highway} \leq Q_{Infiltration}$$

For western Washington, $Q_{Highway}$ is the flow rate at or below which 91 percent of the runoff volume for the developed threshold drainage area (TDA) will be treated, based on a 15-minute time step, and can be determined using the water quality data feature in MGSFlood. For eastern Washington, $Q_{Highway}$ is the peak flow rate predicted for the 6-month, short duration storm under post-developed conditions for each TDA, and can be determined by selecting the short duration storm option in StormSHED.

The long-term infiltration capacity of the Ecology Embankment is based on the following equation:

$$\frac{LTIR_{EM} * L_{EE} * W_{EE}}{C * SF} = Q_{Infiltration}$$

where:

- $LTIR_{EM}$ = Long-term infiltration rate of the ecology-mix (use 14 inches per hour for design) (in/hr)
- L_{EE} = Length of Ecology Embankment (parallel to roadway) (ft)
- W_{EE} = Width of the Ecology Embankment ecology-mix bed (ft)
- C = Conversion factor of 43200 ((in/hr)/(ft/sec))
- SF = Safety factor (equal to 1.0 unless unusually heavy sediment loading is expected).

Assuming that the length of Ecology Embankment is the same as the length of the contributing pavement, solve for the width of the Ecology Embankment:

$$W_{EE} \geq \frac{Q_{Highway} * C * SF}{LTIR_{EM} * L_{EE}}$$

Project applications of this design procedure have shown that in almost every case the calculated width of the Ecology Embankment does not exceed 1.0 foot. Therefore, Table 2 was developed to simplify the design steps and should be used to establish an appropriate width.

Table 2 Design widths for Ecology Embankments.

Pavement width that contributes runoff to the Ecology Embankment	Minimum Ecology Embankment width[a]
≤ 20 feet	2 feet
≥ 20 and ≤ 35 feet	3 feet
> 35 feet	4 feet

[a] Width does not include the required 3-foot filter strip width (see Figures 2 and 3).

Expected Treatment Capabilities

The Ecology Embankment removes suspended solids, oil, phosphorus, and metals from highway runoff through physical straining, ion exchange, carbonate precipitation, and biofiltration. The combination of treatment processes is expected to achieve 96.0 percent removal for TSS, 86.3 percent removal for total phosphorus, 78.7 percent removal for dissolved zinc, and 39.2 percent removal for dissolved copper. (Values reported here represent the median removal efficiency for each parameter as calculated using Method #1). Because all elements of the Ecology Embankment involve treatment within soil, vegetation, gravel, or treatment media, oil removal through hydrophobic adsorption is also expected to be high.

Applicability and Limitations

In many instances, conventional runoff treatment is not feasible due to right-of-way constraints (e.g. adjoining wetlands, geotechnical considerations, etc.). The Ecology Embankment and the dual Ecology Embankment are runoff treatment options that can be situated in most right-of-way confined situations. In many cases, an Ecology Embankment or a dual Ecology Embankment can be sited without the acquisition of additional right-of-way needed for conventional stormwater facilities or capital-intensive expenditures for underground wet vaults.

Applications

Ecology Embankments

The Ecology Embankment can achieve basic, oil, phosphorus, and enhanced water quality treatment. Since maintaining sheet flow across the Ecology Embankment is required for its proper function, the ideal locations for Ecology Embankments in highway settings are highway side slopes or other long, linear grades with lateral slopes less than 4H:1V, and longitudinal slopes no steeper than 5 percent. As slopes approach 3H:1V, without design modifications, sloughing may become a problem due to friction limitations between the separation geotextile and underlying soils. The longest flow path from the contributing area delivering sheet flow to the Ecology Embankment should not exceed 75 feet for impervious surfaces and 150 feet for pervious surfaces.

Dual Ecology Embankment for Highway Medians

The dual Ecology Embankment is fundamentally the same as the side-slope version. It differs in siting and is more constrained with regard to drainage options. Prime locations for dual Ecology Embankments in a highway setting are medians, roadside drainage or borrow ditches, or other linear depressions. It is especially critical for water to sheet flow across the dual Ecology Embankment. Channelized flows or ditch flows running down the middle of the dual Ecology Embankment (i.e., continuous off-site inflow) should be minimized.

Limitations

Ecology Embankments

The following limitations apply to ecology embankments:

- Steep slopes – Avoid construction on longitudinal slopes steeper than 5 percent. Avoid construction on 3H:1V lateral slopes, and preferably use less than 4H:1V slopes. In areas where lateral slopes exceed 4H:1V, it may be possible to construct terraces to create a 4H:1V slopes, or to otherwise stabilize up to 3H:1V slopes. See *Cross Section* above in the *BMP Sizing Methods* section for details

- Wetlands – Do not construct in wetlands and wetland buffers. In many cases, an Ecology Embankment (due to its small lateral footprint) can fit within the highway fill slopes adjacent to a wetland buffer. In those situations where the highway fill prism is located adjacent to wetlands, an interception trench/ underdrain will need to be incorporated as a design element in the Ecology Embankment.

- Shallow groundwater – Mean high water table levels in the project area need to be determined to ensure that the ecology-mix bed and the underdrain (if needed) will not become saturated by shallow groundwater.

- Unstable slopes – In areas where slope stability may be problematic, consult a geotechnical engineer.

Dual Ecology Embankments for Highway Medians

In addition to the limitations on the Ecology Embankment (above), the following limitations apply to dual Ecology Embankments:

- Wetlands – Do not construct in wetlands and wetland buffers.
- Areas of seasonal groundwater inundations or basement flooding – The hydraulic and runoff treatment performance of the dual Ecology Embankment may be compromised due to backwater effects and lack of sufficient hydraulic gradient.

Operations and Maintenance Procedures

Maintenance will consist of routine roadside management. While herbicides will not be applied directly over the Ecology Embankment, it may be necessary to periodically control noxious weeds with herbicides in areas around the Ecology Embankment as part of WSDOT's roadside management program. The use of pesticides is prohibited if the Ecology Embankment is in a critical aquifer recharge area for drinking water supplies. Areas of the Ecology Embankment that show signs of physical damage will be repaired or replaced by local maintenance staff in consultation with regional hydraulics/water quality staff. Potential defects or problems that may occur at a typical Ecology Embankment installation are summarized in Table 3 with recommended maintenance or corrective actions.

It is anticipated that the infiltration capacity of the ecology-mix may decrease over time due to progressive siltation. Therefore, the infiltration capacity of the ecology-mix bed will be checked on a cycle coinciding with highway repaving activities. However, it should be noted that the sizing procedure for the Ecology Embankment is extremely conservative with regard to the infiltration capacity. Specifically, the design widths shown in Table 2 for the Ecology Embankment range from 2 to 4 feet even though the design procedure indicates a width of 1.0 foot is adequate in almost every case. To put this information into perspective, the runoff treatment flow rate ($Q_{Highway}$) for an Ecology Embankment that is 500 feet in length and treating runoff from two lanes of traffic is approximately 0.13 cubic feet per second (cfs) based on calculations performed using MGSFlood. Using the sizing formulas provided above, the required width of this Ecology Embankment is only 0.8 feet assuming the design long-term infiltration rate ($LTIR_{EM}$) of 14-inches per hour. If a width of 4 feet is used for the Ecology Embankment per the guidance in Table 2, the minimum long-term infiltration rate that is required to treat $Q_{Highway}$ is only 2.8 inches per hour. Data compiled by WSDOT indicate that infiltration rates this low are unlikely even after long periods of operation. For example, WSDOT recently conducted testing to evaluate infiltration rates in two Ecology Embankments that have been in operation for a period of approximately 9-years. Results from this testing indicate the average infiltration rate for the ecology mix in these systems was 9.78 inches per hour (Johnson and Palmerson 2005 personal communication). Given these considerations, progressive siltation is not expected to limit the capacity of the Ecology Embankment for treating the required runoff flow rate over the system's design life.

Table 3. Maintenance requirements for the Ecology Embankment.

Maintenance Component	Defect or Problem	Condition When Maintenance is Needed	Recommended Maintenance to Correct Problem
General	Sediment accumulation on grass filter strip	Sediment depth exceeds 2 inches or creates uneven grading that interferes with sheet flow.	Remove sediment deposits on grass treatment area of the embankment. When finished, embankment should be level from side to side and drain freely toward the toe of the embankment slope. There should be no areas of standing water once inflow has ceased.
	No-vegetation zone/flow spreader	Flow spreader is uneven or clogged so that flows are not uniformly distributed over entire embankment width.	Level the spreader and clean so that flows are spread evenly over entire embankment width.
	Poor vegetation coverage	Grass is sparse or bare, or eroded patches are observed in more than 10% of the vegetated filter strip surface area.	Consult with roadside vegetation specialists to determine why grass growth is poor and correct the offending condition. Replant with plugs of grass from the upper slope or reseed into loosened, fertile soil or compost.
	Vegetation	Grass becomes excessively tall (greater than 10 inches); nuisance weeds and other vegetation start to take over.	Mow vegetation or remove nuisance vegetation so that flow is not impeded. Grass should be mowed to a height of 3 to 4 inches. Remove grass clippings.
	Ecology mix replacement	Water is seen on the surface of the ecology mix from storms that are less than a 6-month, 24-hour precipitation event. Maintenance also needed on a 10-year cycle and during a preservation project.	Excavate and replace all of the ecology mix contained within the ecology embankment.
	Excessive shading	Grass growth is poor because sunlight does not reach embankment.	If possible, trim back overhanging limbs and remove brushy vegetation on adjacent slopes.
	Trash and debris	Trash and debris have accumulated on embankment.	Remove trash and debris from embankment.

Source: WSDOT 2006b

Reduction of available carbonate material for precipitation, and reduction of available calcium and magnesium for heavy metal ion exchange may also decrease the pollutant removal efficiency of the Ecology Embankment after long periods of operation. To date, long term monitoring data for the Ecology Embankment have not shown any significant decreases in pollutant removal efficiencies that would indicate the treatment capacity may be waning (see Data Summaries section). To evaluate this potential, WSDOT will periodically monitor representative Ecology

Embankment systems through its National Pollution Discharge Elimination System (NPDES) monitoring program.

Signing

Non-reflective guide posts will delineate the Ecology Embankment. This practice allows WSDOT personnel to identify where the system is installed and to make appropriate repairs should damage occur to the system. If the ecology embankment is in a critical aquifer recharge area for drinking water supplies, signage prohibiting the use of pesticides must be provided.

Cost

The cost of constructing an ecology embankment will vary based on material and transport costs and facility size, but is expected to be approximately $1.21 per square foot of pavement. Therefore, an Ecology Embankment with a width of 3 feet would cost between $24.2 and $42.4 per linear foot, based on the design guidance in Table 2. The cost of routine operation and maintenance of the facility (vegetation management) is incidental to highway maintenance procedures.

Differences Between Current and Original Design Criteria

The following describe differences between the original (WSDOT 1995) and current Ecology Embankment design guidelines (WSDOT 2006b):

- The original design guidelines specify synthetic matting over the ecology-bed mix for slope stability. It has been found that the matting is not needed for slope stability, and can cause maintenance problems when vehicles run off onto the Ecology Embankment. Consequently, it is no longer required.

- Experience has shown that seeding new ecology-mix does not result in grass growth, presumably because there's no soil for root-holds and to retain moisture for roots. Over time a layer of soil accumulates naturally, and vegetation establishes naturally. Therefore, seeding of the ecology-mix bed is no longer a requirement.

- Lateral slope up to 3H:1V has been approved by Ecology for the SR-202 installation, with conditions for protection at the top, and ecology-mix slope stabilization. The original design guidelines do not specify a maximum slope, but note that a 2H:1V slope will lead to downslope migration of gravel. Appendix E in WSDOT's 2002 petition to Ecology for approval of the ecology embankment contains a drawing with notation allowing lateral slope up to 3H:1V. The current design guidelines also state that slopes steeper than 4H:1V up to 3H:1V may be acceptable if approved by Ecology, and may require engineered slope stability measures. This is strictly a stability issue, not a performance issue, and it has been demonstrated to be acceptable.

- The original design specifies the installation of a perforated pipe in the underdrain trench. However, this pipe may be unnecessary if most water draining from the ecology-mix percolates into subsoil from the underdrain trench, or if trench flow alone is adequate to ensure free drainage from the ecology-mix bed, and if underdrain pipe is not required to route runoff to a flow control BMP or stormwater outfall. In all cases, the underdrain should be modeled as an infiltration trench (see BMP IN.03 in WSDOT 2006b).

- Where underdrain pipe is required, cleanouts and/or inspection ports are no more necessary than any other drainage installation, therefore, the requirement is only subject to the same considerations as other drainage installations, and is not uniquely required for the ecology embankment. i.e., there is no inherent requirement for cleanouts or inspection ports unique to ecology embankment for an underdrain pipe.

Pending Changes in Design Criteria

The following design elements have not been incorporated into the current Ecology Embankment design guidelines (WSDOT 2006b), but may be appropriate in some cases:

- Under some conditions, the Ecology Embankment can be installed with wall at its base. This design with a pervious rock wall has been approved by Ecology for SR-202. Functionally, an impervious wall should also be allowed as long as appropriate drainage is provided.

- Under some conditions, the underdrain trench may daylight laterally via pipe or gravel hydraulic connection to a lower open trench or swale. As long as flow-control requirements are met, the ecology-mix bed integrity is maintained, and free-flow of runoff through the ecology mix is maintained, this should be acceptable. Ecology has approved this design on SR-518.

Procedures for Obtaining Data

The procedures used to obtain performance monitoring data for the SR 167 Ecology Embankment are described herein. This section begins with a general overview of the monitoring design and describes the specific goals Ecology has established for the types of treatment that are being sought under the GULD. Separate sections then describe in more detail the site location, test system, monitoring schedule, and the specific procedures used to obtain the hydrologic and water quality data, respectively.

Monitoring Design Overview

In order to facilitate performance monitoring pursuant to the procedures described in Ecology (2004), an Ecology Embankment test system was specifically designed and constructed at a location on SR 167 in south King County (Figure 1). Automated monitoring equipment was installed in this test system to characterize influent and effluent flow volumes during discreet storm events. In association with this hydrologic monitoring, automated samplers were employed to collect flow-weighted composite samples of the influent and effluent for subsequent water quality analyses. Based on the data obtained from this monitoring, removal efficiency estimates were computed for targeted monitoring parameters. These removal efficiency estimates were subsequently compared to goals identified in Ecology (2004) in order to support the issuance of a GULD for the Ecology Embankment. These treatment goals are described below for the four types of treatment that are under consideration for inclusion in the GULD:

- **Basic Treatment -** 80 percent removal of TSS for influent concentrations that are greater than 100 mg/L, but less than 200 mg/L. For influent concentrations greater than 200 mg/L, a higher treatment goal may be appropriate. For influent concentrations less than 100 mg/L, the facilities are intended to achieve an effluent goal of 20 mg/L TSS.

- **Enhanced Treatment -** Provide a higher rate of removal of dissolved metals than most basic treatment facilities. The performance goal assumes that the facility is treating stormwater with dissolved copper typically ranging from 0.003 to 0.02 mg/L, and dissolved zinc ranging from 0.02 to 0.3 mg/L. Data collected for an "enhanced" BMP should demonstrate significantly higher removal rates than basic treatment facilities.

- **Phosphorus Treatment -** 50 percent total phosphorus removal for a range of influent total phosphorus of 0.1 to 0.5 mg/L. The phosphorus menu facility choices are intended to achieve Basic Treatment in addition to phosphorus removal.

- **Oil Treatment** - No ongoing or recurring visible sheen, a daily average total petroleum hydrocarbon concentration no greater than 10 mg/L, and a maximum of 15 mg/L for a discrete (grab) sample.

Site Location

The Ecology Embankment test system was constructed on the shoulder of northbound SR 167 in Auburn at milepost 16.4 (see Figure 1). (In conjunction with the test system installation, several miles of Ecology Embankments were constructed along northbound and southbound shoulders of SR 167 in 1996.) Average annual daily traffic (AADT) volumes at the test site range from 105,000 in 2001 to 119,000 in 2004 (WSDOT 2004). Average annual precipitation at the test site is approximately 39.06 inches (WRCC Undated), and soils in the site area are mapped as Renton silt loam, Oridia silt loam, and Norma sandy loam (USDA Undated).

Test System Description

The description of the Ecology Embankment test system is divided into separate subsections for the following information: 1) physical dimensions and basis of design; and 2) system layout in relation to monitoring.

Physical Dimensions and Basis of Design

The Ecology Embankment test system is 500 feet long and receives untreated runoff as sheet flow from two lanes of traffic on SR 167 (see Figure 1). The total contributing drainage area for the test system is approximately 0.5 acres. This installation was constructed in accordance to an earlier version of Ecology Embankment design guidelines (WSDOT 1995) which varies slightly from the description provided in the Technology Description section. Following is a summary of design parameters and a discussion regarding consistency with current design standards (WSDOT 2006).

Due to incomplete documentation of as-built conditions at the SR 167 Ecology Embankment test system, the site description below is based on a combination of site plans labeled "as-built" (Batts 2006a) that are provided in Appendix A, the Taylor Study monitoring report (Taylor 2002), design calculations (WSDOT 1997), and field observations.

The width of the roadway contributing flow to the Ecology Embankment test system includes two traffic lanes and both shoulders was 56 feet. The ecology-mix bed was constructed with a width of 5 feet, a minimum depth of 12 inches, and a side slope of 6H:1V (17 percent). The underdrain trench was constructed with a width of 2 feet and an 8-inch perforated PVC underdrain pipe.

The Ecology Embankment test site design meets all of the design guidelines described in the Technology Description section above except that no vegetated filter strip was installed upslope of the ecology-mix bed. The current design calls for a minimum 3-foot wide vegetated filter strip. The available as-built drawings show approximately 4 feet between the edge of the roadway and the surface of the ecology-mix bed, including an approximately 1.5 foot wide gravel section (both plan view dimensions). Because of uncertainty regarding the presence and width of a vegetated filter strip, the test site was visited on May 4, 2006. Reconnaissance performed on this date indicated that grassy vegetation is present in a zone approximately 5.9 feet wide from the edge of the shoulder to where the ecology-mix bed starts. The grassy vegetation present in this zone is expected to perform the treatment function of the vegetated filter strip as specified in the current design guidelines.

System Layout in Relation to Monitoring

As noted in the Monitoring Design Overview section, automated monitoring equipment was installed in association with the test system to characterize influent and effluent flow volumes and quality during discreet storm events. Figures 1 and 4 provide simplified schematic diagrams showing the layout of the test system in relation to this monitoring equipment.

Because stormwater enters the Ecology Embankment test system as highly diffuse sheet flow, direct measurement of influent flow volumes and water quality were not practical. Therefore, a separate slot drain (see Figure 1) was installed parallel to the highway in association with the test system. This slot drain collected sheet flow from 40 feet of the impervious roadway and conveyed it to a monitoring vault (Figure 4) where its volume and quality were measured by automated equipment. This runoff volume was then scaled in proportion to the contributing basin areas for the slot drain versus the test system in order to estimate the influent flow volume for the test system.

Effluent from the Ecology Embankment test system was collected in a perforated underdrain that extends the full 500 foot length of the system (see Figure 1). This water was then conveyed to the monitoring vault described above (see Figure 4) where its volume and quality were also measured using automated equipment. In addition, a 111 foot-long overflow drain was also located downslope of the Ecology Embankment to collect any runoff that bypassed the facility (see Figure 1). This drain conveyed any overflow to the monitoring vault (see Figure 4) where its volume, but not quality, was measured.

Monitoring Schedule

Water quality monitoring was conducted at the Ecology Embankment test system over a five year period from 2001 through 2005. This monitoring was implemented in three separate phases as follows:

- August 2001 through April 2002 – Monitoring conducted by Taylor Associates (Taylor study)

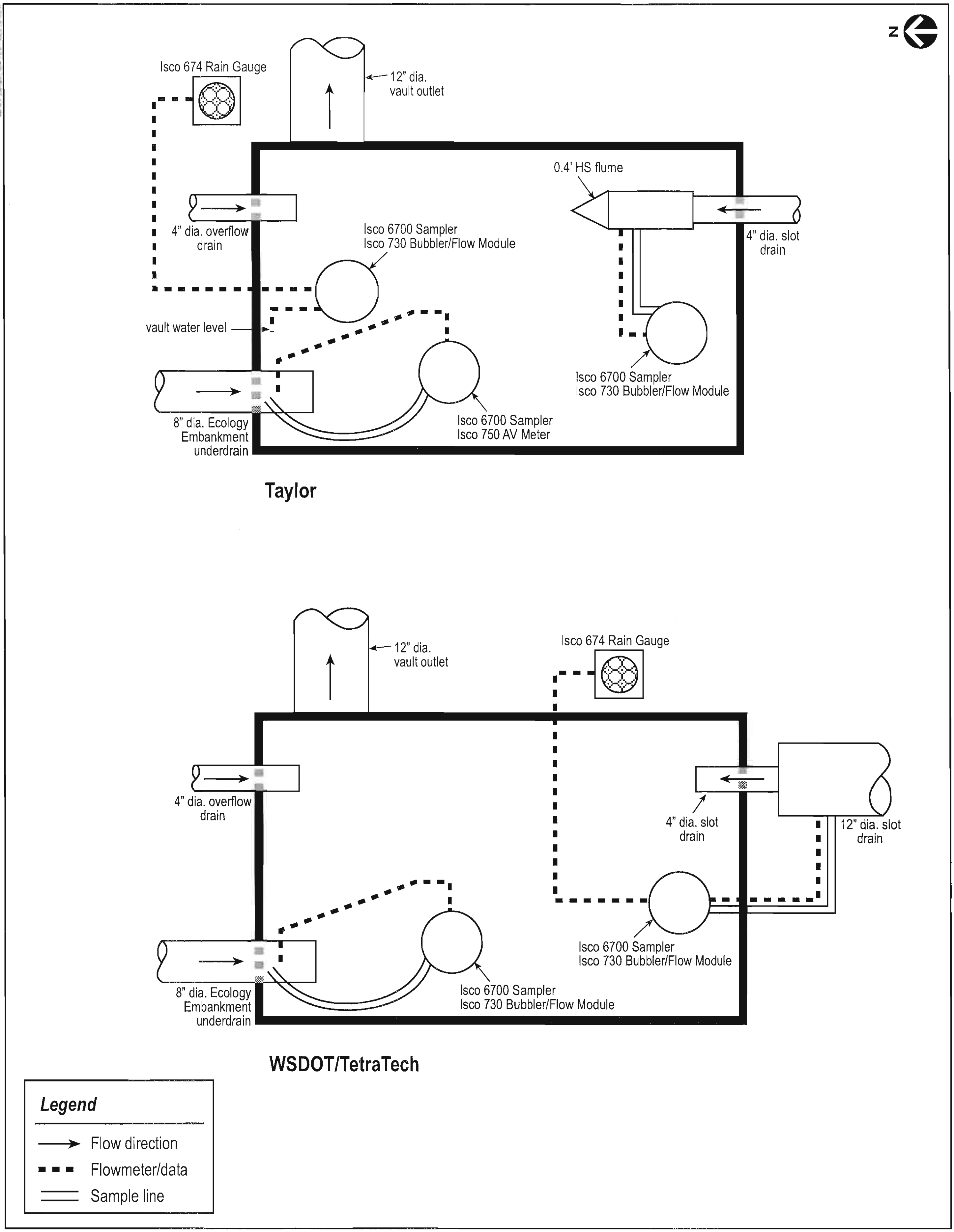


Figure 4. **Schematic for SR 167 Ecology Embankment monitoring vault during Taylor and WSDOT/TetraTech studies.**

- November through December 2003 – Monitoring conducted by WSDOT Environmental Services Office (WSDOT study)
- November 2004 through April 2005 – Monitoring conducted by Tetra Tech, Inc. (Tetra Tech study).

During these studies, a total of 25 separate storm events were sampled (9 during the Taylor study, 3 during the WSDOT study, and 13 during the Tetra Tech study).

Hydrologic Monitoring Procedures

Hydrologic monitoring procedures for the SR 167 Ecology Embankment test system are summarized in separate sections below for the Taylor, WSDOT, and Tetra Tech studies, respectively. These monitoring procedures are also described in greater detail within separate quality assurance project plans (QAPPs) that were prepared for the Taylor and Tetra Tech studies (Taylor Associates 2001; Tetra Tech 2003, 2004). Although no formal QAPP was prepared for the WSDOT study, the associated hydrologic monitoring procedures were essentially identical to those for the Tetra Tech study.

Taylor Study

As described above, hydrologic monitoring was conducted at the following three locations in order to characterize influent and effluent volumes for the SR 167 Ecology Embankment: slot drain, Ecology Embankment underdrain, and overflow drain (Figure 4). Flow volumes from the slot drain were monitored with an ISCO 730 bubbler flow module that was interfaced with an ISCO 6700C autosampler. The bubbler was installed in a 0.4 ft HS-flume and flow was calculated using a standard hydrologic equation. This equation was preprogrammed in the autosampler to facilitate real-time stage to flow conversions. Flume stage data were logged at a 2-minute interval.

Flow volumes from the Ecology Embankment underdrain (Figure 4) were initially measured with an H-flume equipped with an ISCO 730 bubbler flow module, but preliminary flow monitoring indicated that backwater conditions frequently developed through the flume due to high water levels in the downgradient drainage ditch (see Figure 1). To remedy this, the bubbler flow module was removed and replaced with an ISCO 750 area-velocity probe. Water level and velocity data were logged to an ISCO 6700C autosampler on a 5-minute interval. Discharge was calculated using the area-velocity equation based on stage, pipe diameter, and water velocity.

Flow volumes from the overflow drain (Figure 4) were initially measured with a Badger™ propeller-type flow meter. (Note: the overflow drain captures any water that bypasses both the ecology mix bed and gravel underdrain.) During preliminary flow monitoring that was conducted over the period from September through November 2000, the Badger meter did not measure any flow in the overflow drain during 13 monitored storm events with precipitation depths ranging from 0.13 and 1.32 inches. Subsequently, when water quality monitoring began, the meter was replaced with a 5 gallon bucket. The bucket was checked during weekly site visits. Because the bucket was observed to occasionally overfill, the Badger™ meter was reinstalled and was in place for all water quality sampling events discussed within this report.

Water level in the vault was also recorded with an ISCO 730 bubbler module until December 27, 2001, after which the bubbler module was replaced with an ISCO 4230 bubbler flowmeter. This monitoring was performed to evaluate the effect, if any, of backwater conditions on the performance of the Ecology Embankment.

Rainfall was measured with an ISCO 674 tipping bucket rain gauge that was interfaced with the monitoring equipment used to measure water levels in the vault. Rainfall was continuously recorded in 0.01 inch increments for the duration of the study.

WSDOT Study

During the WSDOT study, flow volumes from the slot drain were measured using an ISCO 730 bubbler flow module that was interfaced with an ISCO 6700 autosampler. The autosampler was programmed to log water levels on a 15-minute interval. Unlike the equipment setup described above for the Taylor study, the bubbler flow module measured water levels in a 12 inch pipe within the slot drain as opposed to a 0.4 foot HS-flume within the monitoring vault (see Figure 4). The measured water levels were converted to estimates of flow using the Manning's equation (roughness coefficient [n] = 0.013 and slope = 0.001).

Flow volumes from the Ecology Embankment underdrain were measured at the same location within the monitoring vault as described above for the Taylor study (see Figure 4). However, unlike the Taylor Study which used an AV sensor at this location, the installed monitoring equipment consisted of an ISCO 730 bubbler flow module that was interfaced with an ISCO 6700 autosampler. The autosampler was programmed to log water levels on a 15-minute interval. The measured water levels were converted to estimates of flow using the Manning's equation (roughness coefficient [n] = 0.013 and slope = 0.001). These flow estimates were subsequently determined to be unreliable due to the backwater conditions that frequently persisted in the monitoring vault (see Hydrologic Data Quality Assurance Memorandum in Appendix B).

Rainfall during the WSDOT study was measured with an ISCO 674 tipping bucket rain gauge that was interfaced with the monitoring equipment described above for the slot drain. Rainfall was continuously recorded in 0.01 inch increments for the duration of the study. Flow volumes from the overflow drain (i.e., system bypasses) were not monitored during the WSDOT study.

Tetra Tech Study

Hydrologic monitoring procedures used during the Tetra Tech study were identical to those described above for the WDOT study.

Water Quality Monitoring Procedures

Water quality monitoring procedures for the SR 167 Ecology Embankment test system are summarized in separate sections below for the Taylor, WSDOT, and Tetra Tech studies, respectively. These monitoring procedures are also described in greater detail within separate quality assurance project plans (QAPPs) that were prepared for the Taylor and Tetra Tech studies (Taylor Associates 2001; Tetra Tech 2003, 2004). Although no formal QAPP was prepared for the WSDOT study, the associated water quality monitoring procedures were very similar to those used for the Tetra Tech study.

Taylor Study

Flow-weighted composite samples were collected from the slot drain and Ecology Embankment underdrain using the ISCO Model 6700 automated samplers described above in conjunction with the flow monitoring procedures. The autosampler associated with the slot drain was programmed to initiate sampling at a 0.06 feet increase in stage within the HS flume. Similarly, the autosampler associated with the Ecology Embankment underdrain was programmed to initiate sampling by both a rise in water level and an increase in velocity. (The velocity threshold was required in order to compensate for the backwater conditions that frequently occur in the flow monitoring vault.) Once sampling was initiated, the autosamplers collected 250 milliliter sample aliquots at preset flow increments and composited them within a 10 liter polyethylene sample bottle.

The criteria used to determine if a storm and associated water quality samples were valid are summarized in Table 4. These criteria vary slightly from current TAPE guidelines (Ecology 2004) because the QAPP for the Taylor study was developed based on earlier draft guidelines for the program. Specifically, a minimum rainfall depth value of 0.25 inches was used for the study whereas current TAPE guidelines specify a minimum rainfall depth of 0.15 inches. In addition, the beginning and end of a storm was defined as a 6-hour period with no rain for the study, while current guidelines specify a 6-hour period with less than 0.04 inches of rain. Because these deviations are more restrictive than the current TAPE guidelines, they do not reduce the validity of the data for documenting the treatment performance of the Ecology Embankment.

Once water quality samples were retrieved from the automated samplers at the end of a storm event, they were transported to Aquatic Research, Inc. (Seattle, WA) for analysis. Up to a 1 liter subsample was split off for analysis by shaking and pouring from each original flow-weighted composite sample. The flow-weighted composite samples were then analyzed for the parameters identified in Table 5.

WSDOT Study

During the WSDOT study, flow-weighted composite samples were collected from the slot drain and Ecology Embankment underdrain using the ISCO Model 6700C automated samplers described above in conjunction with the flow monitoring procedures. The autosampler associated with the slot drain was programmed to initiate sampling when the measured precipitation total exceeded 0.04 inches in a 2 hour period. Similarly, the autosampler associated with the Ecology Embankment underdrain was programmed to initiate sampling at a 1 inch rise in stage. Once sampling was initiated, the autosamplers collected 600 milliliter sample aliquots at preset flow increments and composited them within a 9 liter glass sample bottle. Once water quality samples were retrieved from the automated samplers at the end of a storm event, they were transported to Severn Trent Laboratories, Inc. (Seattle, WA) where they were analyzed for the parameters identified in Table 5.

Table 4. Storm validity criteria and sampling goals for SR167 Ecology Embankment performance monitoring studies and for current TAPE guidelines.

Criterion	Taylor Study	WSDOT Study	TetraTech Study	TAPE Guidelines (Ecology 2004)
Minimum Precipitation Depth	0.25 inches	0.25 (0.15) inches[a]	0.25 (0.15) inches[a]	0.15 inches
Storm Start/End (Antecedent Dry Period)	6 hours minimum with no rainfall	24 hours with less than 0.02 inches before a storm, and 6 hours minimum with no rainfall after a storm	24 hours with less than 0.02 inches before a storm, and 6 hours minimum with no rainfall after a storm	6 hours minimum with less than 0.04 inches rainfall
Minimum Storm Duration	1 hour	24 hours	24 hours	1 hour
Minimum Number of Sample Aliquots	10	8	8	10
Minimum Portion of Storm Volume Covered by Sampling	75 percent	75 percent	75 percent	75 percent

[a] 0.15 inches was considered acceptable as long as all other criteria are met.
TAPE: Technology Assessment Protocol – Ecology

Table 5. Water quality parameters and analytical methods for SR 167 Ecology Embankment monitoring studies.

Water Quality Parameter	Analytical Method[a]		
	Taylor Study	WSDOT Study	Tetra Tech Study
Total Suspended Solids (TSS)	EPA 160.2	EPA 160.2	EPA 160.2
Zinc, total and dissolved	EPA 200.7	EPA 200.7; 200.8	EPA 200.8
Copper, total and dissolved	**Not analyzed**	EPA 200.7; 200.8	EPA 200.8
Total Phosphorus	EPA 365.1	EPA 365.2	EPA 365.3
Soluble Reactive Phosphorus (SRP)	EPA 365.1	**Not analyzed**	**Not analyzed**
Turbidity	EPA 180.1	EPA 180.1	**Not analyzed**
Hardness	EPA 130.1	EPA 130.1, 130.2, SM 2340B	EPA 6010B, SM 2340B
pH	EPA 150.1	EPA 150.1	**Not analyzed**
Particle Size Distribution (PSD)	LISST[b]	**Not analyzed**	**Not analyzed**

[a] SM numbers from *Standard Methods for the Evaluation of Water and Wastewater, 18th Edition* (APHA et al 1992) and EPA numbers from *Methods for Chemical Analysis of Water and Wastes* (U.S. EPA 1983).
[b] Sequoia Scientific LISST portable particle size analyzer was used for particle size distribution (PSD) analysis.

Tetra Tech

Water quality monitoring procedures implemented during the TetraTech study were the same as those described above for the WSDOT study with the following exceptions: the parameter list was slightly shorter for the Tetra Tech study (see Table 5), and the analytical procedures were performed by a different laboratory (i.e., OnSite Environmental, Inc.; Seattle, WA).

It should also be noted that the criteria used during the Tetra Tech study to determine if a storm and associated water quality samples were valid (Table 4) varied slightly from current TAPE guidelines (Ecology 2004) because the QAPP was developed based on an earlier version of the guidelines, and because the monitoring program was targeting larger storms. Specifically, the storm start/end criteria were more restrictive for the WSDOT study than the current TAPE guidelines. In addition, the Tetra Tech study was targeting storms with a minimum duration of 24 hours, rather than 1 hour as detailed in the TAPE guidance. Finally, the minimum number of sample aliquots for the Tetra Tech study was 8, slightly less than the 10 specified by the TAPE guidelines.

Analytical Methods

Analytical methods are summarized in Table 5 by monitoring study. The laboratories used for each study (Aquatic Research, Inc.; Severn Trent Laboratories, Inc.; and OnSite Environmental, Inc.) are certified by the Ecology and participate in audits and interlaboratory studies by Ecology and U.S. EPA. These performance and system audits have verified the adequacy of the laboratories' standard operating procedures, which include preventative maintenance and data reduction procedures. The laboratories provided sample and quality control data in standardized reports that are suitable for evaluating the project data.

Quality Assurance and Control Measures

Quality assurance and control measures that were implemented during each of the monitoring studies are described in separate subsections below for hydrologic and water quality monitoring, respectively.

Hydrologic Monitoring

In order to ensure the accuracy of the collected hydrologic data, routine site visits were made during all three performance monitoring studies to address operational problems and perform routine maintenance on the monitoring equipment. Maintenance activities included:

- Inspection of the autosampler batteries
- Recalibration of the bubbler flow modules
- Replacement of desiccant for the bubbler flow modules

- Removal of any accumulated debris within the rain gauge
- Inspection and replacement of the autosampler's pump tubing
- Inspection of the autosampler's suction line
- Removal of any debris that have blocked the suction line intake.

The compiled hydrologic data were subsequently reviewed to identify potential quality assurance issues. The specific procedures and data evaluation criteria that were used during this review are described in the Hydrologic Data Quality Assurance Memorandum that is presented in Appendix B.

Water Quality Monitoring

Additional field samples were collected during both the Taylor and Tetra Tech studies for quality control purposes. During the Taylor study, these samples consisted of field blanks and field duplicates (splits). The field blanks were collected at a rate of 5 percent and were prepared by passing a "sample" of de-ionized water through the automated sampler under field conditions. The vinyl sampler intake lines were flushed prior to the blank sampling by drawing a sufficient volume of deionized water through the strainer and intake line with the automated sampler. Blank samples were submitted for all monitoring parameters identified in Table 5 except for TSS, turbidity, and PSD. Field duplicates (splits) during the Taylor study were collected at a rate of 10 percent of samples submitted for analysis. Field duplicates were collected by splitting the composite sample in the field. Field quality control samples during the Tetra Tech study were limited to field duplicates that were collected at a frequency of one per sample event.

Laboratory quality control samples, include blanks, duplicates, matrix spikes, and control standards, were processed during all three performance monitoring studies. In each case, these samples were analyzed at a minimum frequency of 5 percent for each batch of samples submitted to the laboratory.

In order to ensure the collected monitoring data are of known and acceptable quality, the results from field and laboratory quality control samples described above were subsequently compared to specific Method Quality Objectives (MQOs) for precision, accuracy, representativeness, completeness, and comparability. These MQOs are described in the Water Quality Data Quality Assurance Memorandum that is presented in Appendix C.

Data Management Procedures

For the Taylor and Tetra Tech studies, hydrologic monitoring data, including rainfall, water quality sample collection times, water levels, water velocities, and flow data, were stored in an ISCO Flowlink® database. As necessary, these data were exported to Microsoft® Excel spreadsheets for additional processing and analyses. Note that hydrologic data collected during the WSDOT study were not retained in any format upon completion of the monitoring. Therefore, these data were not available for any subsequent analyses that were performed for this report.

Laboratory data were entered into a Microsoft® Excel spreadsheet for all subsequent data management and archiving tasks. Data for each analytical batch were combined into one spreadsheet with one row for each sample to facilitate sorting and statistical analyses. This spreadsheet was reviewed independently to ensure all data entry was performed without error. Specifically, ten percent of the sample values were randomly selected for rechecking and crosschecking with laboratory reports. If errors were detected, they were corrected, and then an additional 10 percent were selected for validation. This process was repeated until no errors were found in the data.

Data Analysis Procedures

Analysis procedures that were used for the hydrologic and water quality data are summarized in separate sections below.

Hydrologic Data

The compiled hydrologic data were analyzed to obtain the following information for each sampled and unsampled storm during the monitoring studies:

- Storm precipitation depth
- Storm average intensity
- Storm peak intensity
- Storm antecedent dry period
- Storm duration
- Influent discharge volume
- Effluent discharge volume.

This information was subsequently used to develop a water budget for the SR 167 Ecology Embankment to assess potential water losses from the system due to infiltration, evaporation, and/or bypass. In addition, this information was examined in conjunction with sample collection data to determine if individual storm events met the criteria identified in Table 4 for assessing valid storm events under the TAPE (Ecology 2004).

As noted above, hydrologic data were not collected during WSDOT study. Furthermore, flow monitoring data collected during the Tetra Tech study were determined to be unreliable (see Hydrologic Data Quality Memorandum in Appendix B). Therefore, the hydrologic analyses presented in this report were directed mainly at the data collected through the Taylor study.

Water Quality Data

Data analysis procedures are described in separate subsections below for the following water quality related study objectives: 1) computation of pollutant removal efficiencies, 2) statistical comparisons of influent and effluent concentrations and loads, 3) temporal trend analysis, 4) correlation analysis to examine influence of storm characteristics on system performance.

Computation of Removal Efficiencies

Pursuant to guidance from Ecology (2004), pollutant removal efficiencies were estimated using the three methods described below.

Method #1: Individual Storm Reduction in Pollutant Concentration

The reduction (in percent) in pollutant concentration during each individual storm (ΔC) was calculated as:

$$\Delta C = 100 \times \frac{\left(C_{in} - C_{eff}\right)}{C_{in}}$$

Where:

C_{in} = flow-weighted influent pollutant concentration, and
C_{eff} = flow-weighted effluent pollutant concentration.

Method #2: Aggregate Pollutant Loading Reduction

The aggregate reduction (in percent) in pollutant load for all storms (ΔL_{agg}) was calculated as:

$$\Delta L_{agg} = 100 \times \frac{\left(\sum_{i=1}^{n}\left(C_{i,in} * V_i\right) - \sum_{i=1}^{n}\left(C_{i,eff} * V_i\right)\right)}{\sum_{i=1}^{n}\left(C_{i,in} * V_i\right)}$$

Where:

$C_{i,in}$ = influent pollutant concentration for storm i,
V_i = volume of storm i,
$C_{i,eff}$ = flow-weighted effluent pollutant concentration, and
n = number of storms.

Method #3: Individual Storm Reduction in Pollutant Loading

Pollutant load reduction (in percent) in individual storms (ΔL) was calculated as:

$$\Delta L = 100 \times \frac{\left(\left(C_{in} \times V\right) - \left(C_{eff} \times V\right)\right)}{\left(C_{in} \times V\right)}$$

Where:

> C_{in} = flow-weighted influent pollutant concentration, and
> V_i = volume of storm i, and
> C_{eff} = flow-weighted effluent pollutant concentration.

Statistical Comparisons of Influent and Effluent Concentrations and Loads

Pollutant concentrations and loads (where data were available) were compared for paired influent and effluent across all storm events using a sign test (Helsel and Hirsh 1992). The sign test is a nonparametric analogue to the paired *t*-test. Through the use of a paired test, differences in the influent and effluent concentrations and loads could be more efficiently assessed, because the noise (or variance) associated with monitoring over a range of storm sizes was blocked out of the statistical analyses. The sign test was required because the paired differences of the data generally exhibited an asymmetrical distribution as opposed to a normal or symmetrical distribution. One- or two-tailed sign tests were employed for specific sampling parameters, depending on the following criteria:

- A one-tailed test was used to evaluate the specific hypothesis that effluent pollutant concentrations and loads were significantly lower than those in the influent. This test was used to evaluate data for pollutants that should potentially be removed by the Ecology Embankment (e.g., TSS, total phosphorus, zinc, and copper).

- A two-tailed test was used to evaluate the specific hypothesis that effluent pollutant concentrations and loads were significantly different than those in the influent, regardless of whether they were higher or lower. This test was used to evaluate data for pollutants that generally should not be affected by the Ecology Embankment (e.g., hardness, pH).

Table D1 in Appendix D describes in more detail the specific hypotheses that were evaluated for each parameter. In all cases, the statistical significance of these tests was evaluated at an alpha level (α) of 0.05.

Temporal Trend Analysis

A temporal trend analysis was performed using a Mann-Kendall test (Helsel and Hirsch 1992) on the data for the five parameters that were measured in every year of performance monitoring (i.e., 2001 – 2005) at the SR 167 Ecology Embankment. These parameters are identified as follows: TSS, total phosphorus, total zinc, dissolved zinc, and hardness. The Mann-Kendall test uses a Kendall’s tau correlation coefficient to determine if there is a significant correlation between a given variable and time. A significant positive or negative correlation would indicate an increasing or decreasing temporal trend, respectively, in the data for the variable. For each parameter, the Mann-Kendall test was performed on the measured influent and effluent concentrations and the associated pollutant removal efficiency estimates (if applicable). In all cases, the statistical significance of these tests was evaluated at an alpha level (α) of 0.05.

Correlation Analysis to Examine Influence of Storm Characteristics

Kendall's tau correlation coefficients were also used to evaluate whether the following storm event characteristics influenced system performance in anyway: storm precipitation depth, storm average intensity, storm peak intensity, storm antecedent dry period, and storm duration. These tests specifically examined potential relationships between these storm event characteristics and the following variables that either directly measure or indirectly influence system performance: influent concentration and load, effluent concentrations and load, and Method #1 and #2 pollutant removal efficiency estimates. In all cases, the statistical significance of these tests was evaluated at an alpha level (α) of 0.05.

Statistical Comparisons of Removal Rates for the Ecology Embankment relative to Basic Treatment Facilities

As described above, current TAPE guidelines (Ecology 2004) indicate that the data collected for an "enhanced" BMP should demonstrate significantly higher removal rates for dissolved metals than basic treatment facilities. To determine if this goal was met with a specific level of statistical confidence, a one-tailed Mann Whitney U test was used to compare median removal efficiencies for dissolved zinc and copper in the Ecology Embankment to the median values reported for basic treatment facilities (ASCE 2006, WSDOT 2006a). The specific null and alternate hypotheses that were assessed in these tests are as follows:

H_o: Ecology Embankment Removal ≤ Basic Treatment Removal

H_a: Ecology Embankment Removal > Basic Treatment Removal.

Pursuant to TAPE guidelines (Ecology 2006), statistical significance in these tests was evaluated at an alpha (α) level of 0.10.

Data Summaries

This section summarizes the data collected through the Taylor, WSDOT, and Tetra Tech performance monitoring studies that were implemented over the five year period from 2001 through 2005. The presentation of these data is organized under separate subsections for the hydrologic and water quality monitoring results, respectively. Additional supporting information for these analyses can also be found in Appendices A through E.

Hydrologic Data

The hydrologic data collected through the Taylor, WSDOT, and Tetra Tech performance monitoring studies are summarized within this section. The section begins with an evaluation of the water budget for the SR 167 Ecology Embankment. The hydrologic performance of the Ecology Embankment is then assessed relative to design runoff treatment flow rate. Finally, data from sampled storm events are then compared to the criteria identified in Table 4 in order to assess their validity in relation to the TAPE. Appendix B summarizes results from the quality assurance review that was performed on these data prior to their analysis herein.

Water Budget

The water budget for the SR 167 Ecology Embankment was analyzed to determine if losses were occurring within the system due to infiltration, bypass, and/or evaporation. To assess these losses, the percentage of influent volume that was accounted for in the effluent was calculated for individual storm events. As noted previously, no flow monitoring data were collected during the WSDOT study and the flow data from the Tetra Tech study were determined to be unreliable (see Appendix B). Therefore, the data used in this analysis were limited to influent and effluent flow volumes from 20 storm events in 2001 and 2002 that were obtained through monitoring conducted during the Taylor study. Bypass volumes (as measured at the overflow drain) were also available for a subset of these storms that were sampled for water quality. These data are presented in Table 6 along with other summary statistics (e.g., storm precipitation depth, storm duration) for the associated storm events. These data indicate that the percentage of influent that was accounted for in the effluent ranged from 0 to 120 percent, with a median value of 38 percent.

These results suggest there are significant water losses from the Ecology Embankment relative to the total influent volume. However, monitoring data collected during the Taylor study also indicated that discharges from the overflow drain for the SR 167 Ecology Embankment were infrequent. For example, during preliminary flow monitoring that was conducted for the study over the period from September through November 2000, no discharge was measured at the overflow drain during 13 storm events with precipitation totals ranging from 0.13 to 1.32 inches (Taylor Associates 2002). During actual water quality monitoring for the study, discharge from the overflow drain was only observed on one occasion (see Table 6). Based on this observation,

Table 6. Summary statistics for flow and rainfall data collected in 2001 and 2002 from SR 167 Ecology Embankment.

Storm Start Date & Time	Storm Stop Date & Time	Storm depth (inch)	Duration (hours)	Antecedent Dry period (hours)	Influent Peak Q (cfs)	Effluent Peak Q (cfs)	Influent Flow Duration (hours)	Effluent Flow Duration (hours)	Influent Volume (cf)	Effluent Volume (cf)	Bypass Volume (cf)	% Flow Through Ecol. Emb.[a]	QA Flag
6/27/01 9:00	6/28/01 1:00	0.80	16	44	0.198	0.114	26	12	2381	859	nd	36%	
7/15/01 23:00	7/17/01 5:00	0.21	30	430	0.001	0.000	1	0	5	0	nd	0%	
7/28/01 2:00	7/29/01 2:00	0.13	24	147	0.054	0.010	13	3	626	85	nd	14%	
8/3/01 10:00	8/3/01 11:00	0.01	1	38	0.003	0.000	5	0	32	0	nd	0%	
8/21/01 11:00	**8/22/01 23:00**	**1.29**	**35**	**432**	**0.300**	**0.117**	**48**	**27**	**3285**	**1377**	**68**	42%	**J**
9/25/01 16:00	**9/26/01 17:00**	**0.49**	**24**	**144**	**0.150**	**0.042**	**17**	**9**	**959**	**397**	0	41%	**J**
10/10/01 9:00	**10/10/01 19:00**	**0.34**	**10**	**55**	**0.138**	**0.089**	**8**	**7**	**658**	**372**	0	57%	
10/30/01 2:00	**10/31/01 6:00**	**0.49**	**18**	**6**	**0.150**	**0.252**	**26**	**6**	**1088**	**928**	0	85%	**J**
11/28/01 4:00	**11/29/01 9:40**	**1.03**	**29**	**21**	**0.113**	**0.104**	**30**	**29**	**1606**	**1926**	0	120%	
12/27/01 22:00	12/28/01 2:00	0.19	4	684	0.050	0.028	7	3	473	162	nd	34%	
12/30/01 23:00	12/31/01 11:00	0.18	12	69	0.031	0.006	16	7	473	45	nd	10%	
1/1/02 12:00	1/2/02 1:00	0.53	13	25	0.064	0.052	16	12	1364	872	nd	64%	
1/5/02 17:00	1/6/02 0:00	0.10	7	9	0.025	0.000	9	1	194	0.36	nd	0%	
1/6/02 12:00	**1/7/02 11:00**	**1.05**	**22**	**13**	**0.113**	**0.108**	**28**	**18**	**2762**	**2030**	0	74%	
1/23/02 22:00	1/26/02 4:00	2.03	54	395	0.089	0.088	35	30	4185	3198	nd	76%	
2/5/02 11:00	2/5/02 14:00	0.17	3	25	0.053	0.032	10	3	428	175	nd	41%	
2/6/02 6:00	2/7/02 2:00	0.22	20	16	0.018	0.001	21	1	504	2	nd	0%	
3/19/02 9:00	**3/20/02 18:00**	**1.04**	**25**	**16**	**0.159**	**0.088**	**26**	**24**	**2946**	**1449**	0	49%	
4/9/02 6:00	**4/10/02 6:00**	**0.45**	**24**	**72**	**0.163**	**0.067**	**34**	**22**	**1096**	**311**	0	28%	
4/26/02 13:00	**4/27/02 14:00**	**0.34**	**22**	**96**	**0.100**	**0.033**	**23**	**7**	**714**	**92**	0	13%	**J**
	Median	0.395	21	50	0.095	0.047	19	7	836	342	0	38%	
	Minimum	0.010	1	6	0.001	0.000	1	0	5	0	0	0%	
	Maximum	2.03	54	684	0.300	0.252	48	30	4185	3198	68	120%	

[a] Percentage of influent volume that was accounted for in the effluent (i.e., effluent volume divided by influent volume).
Storms in **bold** face were sampled for storm events were sampled for water quality (see Table 7).
J: flow data are estimated values based data quality assurance review (see Appendix B).
Q: flow rate
cfs: cubic feet per second
cf: cubic feet
nd: no data

Taylor Associates concluded the water losses were likely not caused by water bypassing the system; rather, they stemmed from the storage and subsequent evaporation of water within the ecology mix bed. Additional water losses were also believed to occur through absorption and infiltration within the three foot wide strip of pervious area between the paved shoulder and the Ecology Embankment.

Performance in Relation to Design Runoff Treatment Flow Rate

Based on modeling performed using MGSFlood, the $Q_{Highway}$ for the SR 167 Ecology Embankment is 0.13 cfs. To assess performance of the system relative to this design flow requires data on system bypasses. As shown in Table 6, these data are only available for nine storm events that occurred during the Taylor study. Monitoring data from these storms indicate the peak influent discharge rate for the system exceeded the $Q_{Highway}$ on six occasions. However, bypass from the system was only observed on one occasion (i.e., August 21-22, 2002 storm event) when the influent discharge rate (0.30 cfs) was approximately double the $Q_{Highway}$. These data indicate that SR 167 Ecology Embankment provided effective treatment up to the design flow rate during this monitoring phase. As noted in the above, performance of the system relative to the design flow could not be assessed in through the later monitoring phases because data on bypass volumes were not collected.

Comparison to TAPE Storm Event Criteria

Over the five year monitoring period covered by the Taylor, WSDOT, and Tetra Tech studies, a total of 25 storm events were sampled to characterize the water quality treatment performance of the SR 167 Ecology Embankment. Nine of these events occurred during the Taylor study, three occurred during the WSDOT study, and thirteen occurred during the Tetra Tech study. As described in Table 4, these individual storm events must meet specific requirement for all of the following criteria to be considered valid pursuant to the TAPE (Ecology 2004):

- Minimum precipitation depth
- Minimum antecedent dry period
- Minimum storm duration
- Minimum number of sample aliquots
- Minimum portion of storm volume covered by sampling.

Summary data related to these criteria are presented in Table 7 for each of the 25 sampled storm events. Figures showing sample collection times in relation to influent and effluent hydrographs are also presented in Appendix E for all sampled storms except those that occurred during the WSDOT study. (Note: each storm in Table 7 was sequentially numbered in order of occurrence. These numbers will be used to reference each storm event throughout the remainder of this document.) These data show the criteria for minimum precipitation depth (0.15 inch) was met during all storm events except one (storm 21, 0.09 inches). The median and maximum precipitation depths across all 25 sampled storm events were 0.35 and 1.29 inches, respectively. The criteria for minimum antecedent dry period (6 hours) and storm duration (1 hour) were met

Table 7. Comparison of summary data from sampled storm events at the SR 167 Ecology Embankment to storm validity criteria from the TAPE.

Event #	Storm Start Date & Time	Storm Stop Date & Time	Storm Precipitation Depth (in)	Storm Antecedent Dry Period (hours)	Storm Duration (hours)	Influent Sample Aliquots (#)	Effluent Sample Aliquots (#)	Influent Storm Coverage (%)	Effluent Storm Coverage (%)
Taylor Study									
1	8/21/01 11:00	8/22/01 22:00	1.29	432	35	45	38	86	72
2	9/25/01 16:00	9/26/01 16:00	0.49	144	24	14	**8**	98	87
3	10/10/01 9:00	10/10/01 19:00	0.34	55	10	**9**	16	**24**	**65**
4	10/30/01 12:30	10/31/01 6:30	0.49	6	18	16	40	99	95
5	11/28/01 4:00	11/29/01 9:00	1.03	21	29	25	53	89	95
6	1/6/02 12:00	1/7/02 10:00	1.05	13	22	38	80	82	84
7	3/19/02 9:00	3/20/02 10:00	1.04	16	25	**9**	40	91	80
8	4/9/02 6:00	4/10/02 6:00	0.45	72	24	16	15	99	88
9	4/26/02 13:00	4/27/02 11:00	0.34	96	22	10	**5**	99	90
WSDOT Study									
10	11/24/03 0:00	11/24/03 6:00	0.21	20	6	ND	ND	ND	ND
11	11/25/03 8:00	11/25/03 15:00	0.15	26	7	ND	ND	ND	ND
12	12/10/03 11:00	12/11/03 8:00	0.35	17	21	ND	ND	ND	ND
Tetra Tech Study									
13	11/2/04 3:00	11/2/04 14:00	0.73	7	11	ND	15	ND	**2**
14	11/15/04 5:00	11/15/04 19:00	0.24	15	14	15	15	**16**	100
15	12/6/04 23:00	12/9/04 2:00	0.66	13	51	15	15	**2**	**10**
16	12/9/04 13:00	12/10/04 3:00	0.64	12	14	15	15	**2**	**5**
17	12/13/04 17:00	12/13/04 23:00	0.24	7	6	15	12	**19**	**60**
18	12/25/04 9:00	12/25/04 17:00	0.24	138	8	15	15	**18**	**51**
19	12/29/04 4:00	12/29/04 18:00	0.26	42	14	15	15	**15**	**28**
20	1/15/05 14:00	1/16/05 5:00	0.30	149	15	15	15	**10**	**38**
21	2/28/05 7:00	2/28/05 14:00	**0.09**	379	21	15	15	**32**	78
22	3/16/05 9:00	3/16/05 16:00	0.20	164	7	12	15	**13**	**69**
23	3/28/05 5:00	3/29/05 17:00	0.43	12	36	15	15	**9**	80
24	4/7/05 9:00	4/7/05 14:00	0.16	28	5	15	15	**19**	**11**
25	4/10/05 19:00	4/11/05 5:00	0.41	78	10	15	15	**2**	**2**
		Median	0.35	26	15	15	15	19	71
		Minimum	0.09	6	5	9	5	2	2
		Maximum	1.29	432	51	45	80	99	100

Values in **bold** do not meet storm validity criteria identified in Table 4 for the TAPE (Ecology 2004).
ND: no data.

during all 25 storm events. Actual antecedent dry periods during the sampled storm events ranged from 6 to 432 hours, with a median value of 26 hours. Storm durations ranged from 5 to 51 hours, with a median value of 15 hours.

The criterion for minimum number of sample aliquots (10) was met for 68 percent of the sampled storm events (see Table 7). (Note: to meet this criterion, a storm event must have the minimum number of sample aliquots for both the influent and effluent sample.) The criterion was not met during four storm events during the Taylor study (storms 2, 3, 7, and 9) because fewer than ten sample aliquots were collected for either an influent or effluent sample. In these four storms, the number of sample aliquots for the influent or effluent sample not meeting the criterion ranged from 5 to 9. The criterion could not be assessed for an additional four storm events because the number of sample aliquots was not recorded for an associated influent and/or effluent sample. Three of these storm events occurred during the WSDOT study (storms 10, 11, and 12), and one occurred during the Tetra Tech study (storm 13).

The criterion for minimum portion of storm volume covered by sampling (75 percent) was only met for 32 percent of the sampled storm events (see Table 7). (Note: to meet this criterion, a storm event must have the minimum portion of storm volume covered for both the influent and effluent sample.) The criterion could not be assessed for the three storm events that occurred during the WSDOT study (storms 10, 11, and 12) due to a lack of flow data for both the influent and effluent samples. The criterion was not met for one storm during the Taylor study (storm 3), and all of the storm events during the Tetra Tech study (storms 13 through 25). As shown in Figures E10 through E22 in Appendix E, sampling during the Tetra Tech study typically targeted only the rising limb of the storm hydrograph for both the influent and effluent sample; thus, they failed to achieve the minimum coverage specified by the TAPE.

It should be noted that the associated influent pollutant concentrations from the Tetra Tech study may have a high bias because only the initial wash-off or “first flush” of pollutants was typically captured with the rising limb of the hydrograph and not the more dilute runoff that is expected in the falling limb. This could lead system performance to be overestimated for these storms because treatment efficiency for a given system will generally improve as influent pollutant concentrations increase (Schueler 2000). However, analyses performed on the compiled water quality data do not show a consistent pattern of higher influent pollutant concentrations for the Tetra Tech study relative to the two earlier studies. For example, statistical analyses performed using a Mann-Whitney U test showed there were no significant differences ($\alpha = 0.05$) in median influent concentrations between the Tetra Tech and earlier studies for the following three parameters: TSS, total phosphorus, and dissolved zinc. Total zinc was the only parameter that exhibited a significantly higher ($p = 0.0025$) influent concentration during the Tetra Tech study relative to the earlier studies. TSS, total phosphorus, and dissolved zinc are all parameters with specific performance goals pursuant to the TAPE whereas total zinc does not. Based on these considerations, the lack of adequate storm volume coverage during the Tetra Tech study should not substantially diminish the overall validity of the associated data for assessing the performance of the Ecology Embankment.

Water Quality Data

This section summarizes water quality data collected through the Taylor, WSDOT, and Tetra Tech performance monitoring studies. Included are comparisons of influent and effluent concentrations and loads that were measured at SR 167 Ecology Embankment. Where applicable, removal efficiency estimates that were calculated from these data are compared to performance goals identified in Ecology (2004). Results from statistical analyses to assess temporal trends in the water quality data and potential relationships with other hydrologic variables (e.g., storm precipitation) are also described. Summary tables from these statistical analyses are presented in Appendix D. In addition, results from the quality assurance review that was performed on these data are presented in Appendix C. Finally, Appendix F presents all laboratory reports, chain-of-custody records, and quality assurance worksheets for these data.

Total Suspended Solids

Based on the data obtained from all 25 storm events, influent TSS concentrations for the SR 167 Ecology Embankment ranged from 16 to 370 milligrams per liter (mg/L), with a median value of 100 mg/L (Table 8, Figure 5). Across the same storm events, effluent TSS concentrations ranged from undetected (less than 0.8 mg/L) to 26 mg/L, with a median value of 5.0 mg/L. Results from the Mann Kendall test showed that effluent concentrations exhibited a weak but significant decreasing trend ($\tau = -0.378$) over the five year period of data collection (see Appendix D, Table D2). There was no apparent trend in the data for influent concentrations over the same period. Analyses performed to evaluate potential relationships between TSS concentrations and storm event characteristics also showed that influent TSS concentrations exhibited a significant negative correlation ($\tau = -0.338$) with storm precipitation depth (Appendix D, Table D3, Figure D1). At the same time, effluent concentrations showed a significant positive correlation ($\tau = 0.342$) with storm peak intensity. No other significant correlations were observed between influent or effluent concentrations and storm event characteristics.

As shown in Table 8 and Figure 5, effluent TSS concentrations were markedly lower than influent concentrations across all sampled storm events. Results from a one-tailed sign test (see Appendix D, Table D1) that was applied to these data confirmed the observed decrease in effluent TSS concentrations relative to influent was statistically significant ($p < 0.0001$). Across all pairs of influent and effluent samples, the median difference (i.e., influent minus effluent) in TSS concentrations was 95.0 mg/L.

Across the nine storm events for which flow data were available (Taylor study only), influent TSS loads for the SR 167 Ecology Embankment ranged from 0.96 to 8.51 kilograms (kg), with a median value of 3.83 kg (Table 8, Figure 6). Similarly, effluent loads ranged from 0.01 to 0.55 kg, with a median value of 0.27 kg. Effluent TSS loads exhibited a significant positive correlation ($\tau = 0.686$) with storm peak intensity (Appendix D, Table D3, Figure D1).

Similar to the TSS concentrations, effluent TSS loads were markedly lower than influent loads across sampled storm events (Table 8, Figure 6). The results from a one-tailed sign (see Appendix D, Table D1) test also confirmed that the observed decrease in effluent TSS loads

Table 8. Total suspended solids concentrations, loads, and removal efficiency estimates for individual sampling events at the SR 167 Ecology Embankment.

Event No.[a]	Influent Concentration (mg/L)	Effluent Concentration (mg/L)	Method #1 Removal	Influent (kg)	Effluent Load (kg)	Method #3 Removal
Events with influent TSS concentrations < 100 mg/L						
1	88	8.6	90.2%	8.19	0.34	95.9%
3	93	**26**	72.0%	1.73	0.27	84.2%
5	21	6.6	68.6%	0.96	0.36	62.3%
6	49	3.8	92.2%	3.83	0.22	94.3%
9	69	5.3	92.3%	1.40	0.01	99.0%
11	88	4.0	95.5%	NA	NA	NA
13	49	10	79.6%	NA	NA	NA
15	87	2.4	97.2%	NA	NA	NA
18	38	2.4	93.7%	NA	NA	NA
23	16	2.8	82.5%	NA	NA	NA
24	99	2.4	97.6%	NA	NA	NA
25	22	0.8 U	96.4%	NA	NA	NA
Median	59	3.9	92.3%	1.73	0.27	94.3%
Minimum	16	0.8 U	68.6%	0.96	0.01	62.3%
Maximum	99	26	97.6%	8.19	0.36	99.0%
Events with influent TSS concentrations ≥100 mg/L						
2	116	24	**79.3%**	3.15	0.27	91.4%
4	133	21	84.2%	4.10	0.55	86.5%
7	102	4.0	96.1%	8.51	0.16	98.1%
8	204	6.3	96.9%	6.33	0.06	99.1%
10	124	5.0	96.0%	NA	NA	NA
12	103	8.0	92.2%	NA	NA	NA
14	210	2.0	99.1%	NA	NA	NA
16	190	4.2	97.8%	NA	NA	NA
17	150	13	91.3%	NA	NA	NA
19	140	0.8 U	99.4%	NA	NA	NA
20	100	0.8 U	99.2%	NA	NA	NA
21	250	10	96.0%	NA	NA	NA
22	370	22	94.1%	NA	NA	NA
Median	140	6.3	96.0%	5.22	0.22	94.8%
Minimum	100	0.8 U	79.3%	3.15	0.06	86.5%
Maximum	370	24	99.4%	8.51	0.55	99.1%
All events combined						
Median	100	5.0	94.1%	3.83	0.27	94.3%
Minimum	16	0.8 U	68.6%	0.96	0.01	62.3%
Maximum	370	26	99.4%	8.51	0.55	99.1%

[a] Values in **bold** do not meet the peformance goals identified in the TAPE (Ecology 2004) for basic treatment.
NA: load estimates are not availabe for these events because no associated dicharge data are available.
U: undetected at the detection limit noted.
mg/L: milligram/liter
kg: killigram

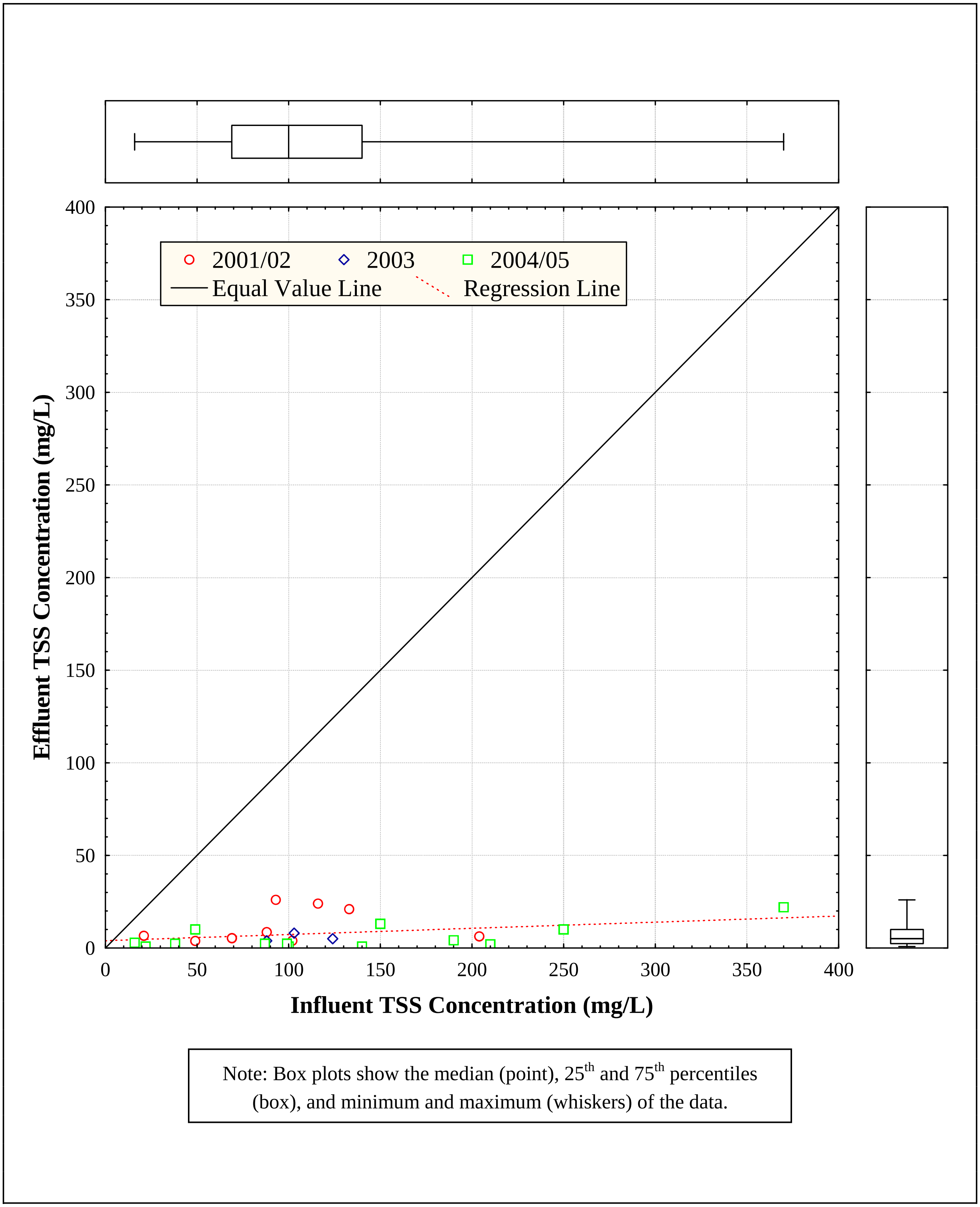
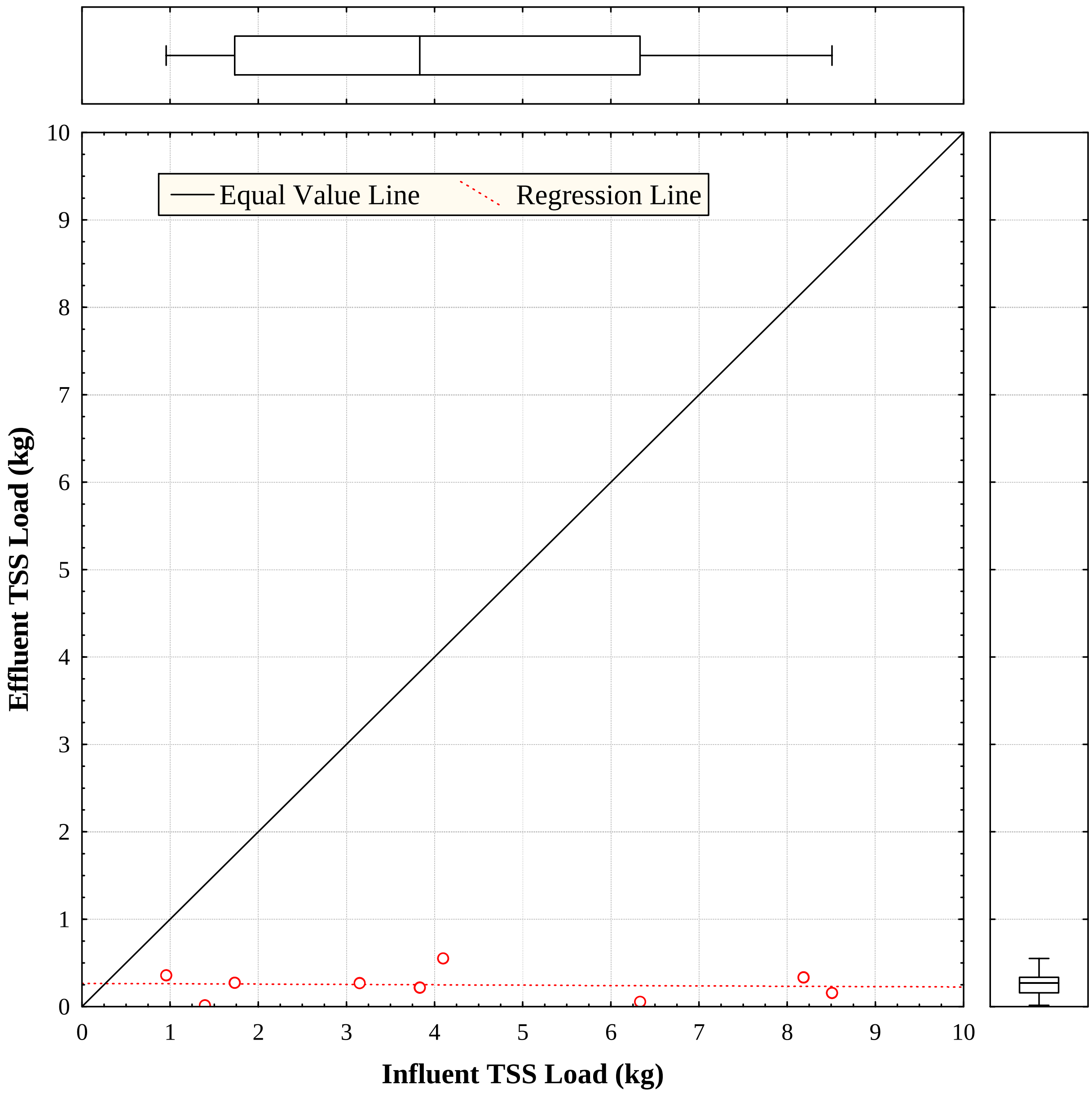


Figure 5. Influent and effluent total suspended solids (TSS) concentrations measured at the SR 167 Ecology Embankment over the period from 2001 to 2005.



Note: Box plots show the median (point), 25th and 75th percentiles (box), and minimum and maximum (whiskers) of the data.

Figure 6. Influent and effluent total suspended solids loads (TSS) measured at the SR 167 Ecology Embankment over the period from 2001 to 2002.

relative to influent was statistically significant ($p < 0.0038$). Across all pairs of influent and effluent samples, the median difference (i.e., influent minus effluent) in TSS loads was 3.55 kg.

Across all storm events, TSS removal efficiency estimates calculated using Method #1 ranged from 68.6 to 99.4 percent, with a median value of 94.1 percent (Table 8, Figure 7). Similarly, for those storms having flow data, removal efficiency estimates calculated using Method #3 ranged from 62.3 to 99.1 percent, with a median value of 94.3 percent. The aggregate TSS removal efficiency calculated using Method #2 was 94.1 percent. Results from the Mann Kendall test showed that Method #1 removal efficiency estimates for TSS exhibited a significant increasing trend ($\tau = 0.360$) over the five year period of data collection (see Appendix D, Table D2). Analyses performed to evaluate potential relationships between removal efficiency estimates and storm event characteristics also showed that Method #1 and Method #3 efficiency estimates exhibited a significant negative correlation with storm peak intensity ($\tau = -0.346$ and $\tau = -0.514$, respectively) (Appendix D, Table D3, Figure D1).

Total Phosphorus

Based on the data obtained from all 25 storm events, influent total phosphorus concentrations for the SR 167 Ecology Embankment ranged from 0.046 to 0.540 mg/L, with a median value of 0.234 mg/L (Table 9, Figure 8). Across the same storm events, effluent total phosphorus concentrations ranged from undetected (less than 0.010 mg/L) to 0.205 mg/L, with a median value of 0.041 mg/L. Results from the Mann Kendall test showed that effluent concentrations exhibited a significant decreasing trend ($\tau = -0.578$) over the five year period of data collection (see Appendix D, Table D2). There was no apparent trend in the data for influent concentrations over the same period. Analyses performed to evaluate potential relationships between total phosphorus concentrations and storm event characteristics also showed that effluent concentrations exhibited a significant negative correlation ($\tau = -0.370$) with storm peak intensity (Appendix D, Table D4, Figure D2). No other significant correlations were observed between influent or effluent concentrations and storm event characteristics.

As shown in Table 9 and Figure 8, effluent total phosphorus concentrations were lower than influent concentrations across all sampled storm events. Results from a one-tailed sign test (see Appendix D, Table D1) that was applied to these data confirmed the observed decrease in effluent total phosphorus concentrations relative to influent was statistically significant ($p < 0.0001$). Across all pairs of influent and effluent samples, the median difference (i.e., influent minus effluent) in total phosphorus concentrations was 0.153 mg/L.

Across the nine storm events for which discharge data are available (Taylor study only), influent total phosphorus loads for the SR 167 Ecology Embankment ranged from 3.56 to 31.9 grams (g), with a median value of 7.27 g (Table 9, Figure 9). Similarly, effluent total phosphorus loads ranged from 0.12 to 7.99 g, with a median value of 2.13 g. Influent total phosphorus loads exhibited a significant positive correlation ($\tau = 0.514$) with storm duration (Appendix D, Table D4, Figure D2). In addition, effluent total phosphorus loads exhibited a significant positive correlation with storm precipitation depth ($\tau = 0.743$) and average intensity ($\tau = 0.556$).

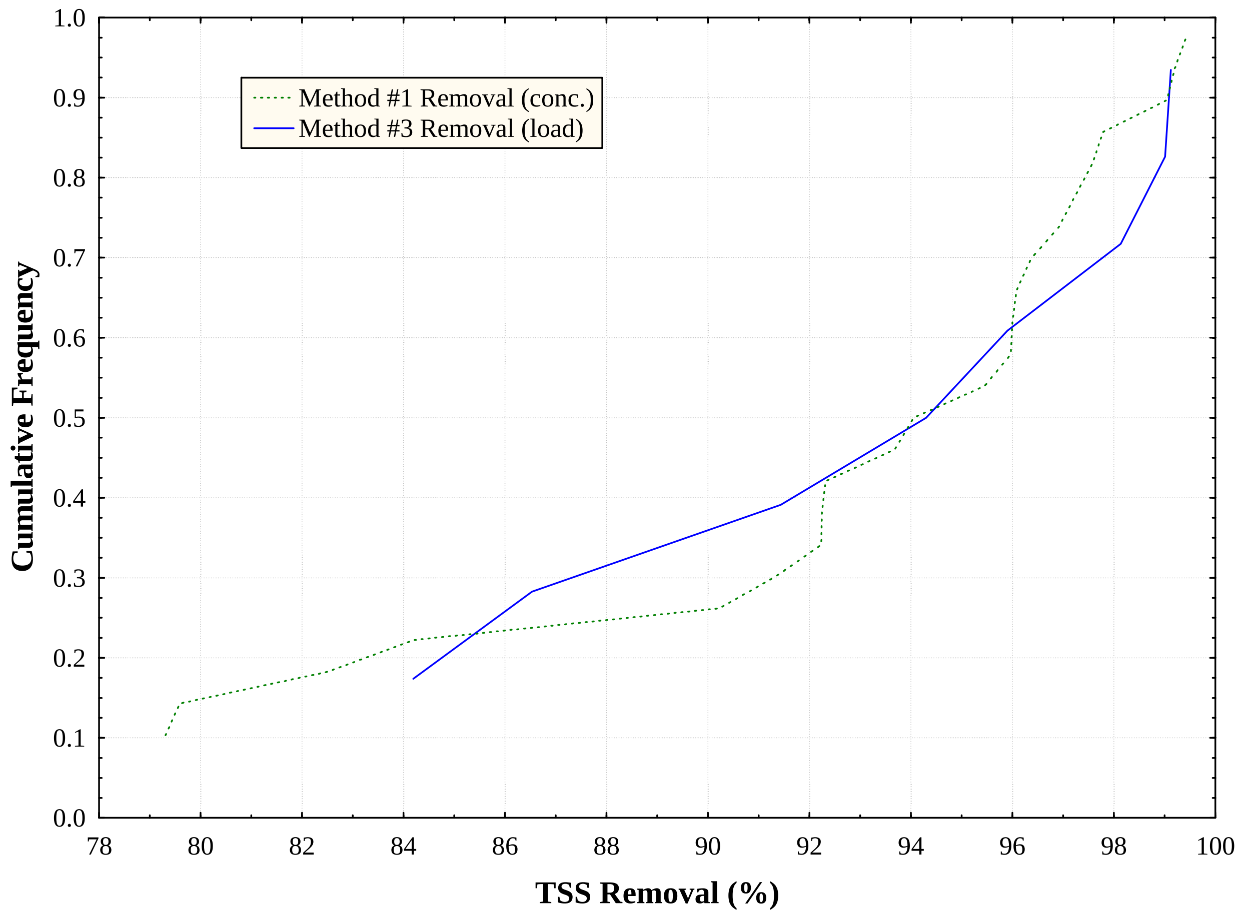


Figure 7. Cumulative frequency plot for total suspended solids (TSS) removal efficiency in the SR 167 Ecology Embankment.

Table 9. Total phosphorus concentrations, loads, and removal efficiency estimates for individual sampling events at the SR 167 Ecology Embankment.

Event No.	Influent Concentration (mg/L)	Effluent Concentration (mg/L)	Method #1 Removal	Influent Load (g)	Effluent Load (g)	Method #3 Removal
Events with influent total phosphorus concentrations less than 0.1 mg/L						
6	0.093	0.051	**45.2%**	7.27	2.93	59.7%
15	0.072	0.014	80.6%	NA	NA	NA
22	0.046	0.040	**13.0%**	NA	NA	NA
Median	0.072	0.040	45.2%	7.270	2.930	59.7%
Minimum	0.046	0.014	13.0%	--	--	--
Maximum	0.093	0.051	80.6%	--	--	--
Events with influent total phosphorus concentrations between 0.1 and 0.5 mg/L						
1	0.234	0.205	**12.4%**	21.8	7.99	63.3%
2	0.433	0.198	54.3%	11.8	2.23	81.1%
3	0.239	0.138	**42.3%**	4.45	1.45	67.4%
4	0.175	0.081	53.7%	5.39	2.13	60.5%
5	0.112	0.043	61.6%	5.09	2.35	54.0%
7	0.382	0.038	90.1%	31.9	1.51	95.3%
8	0.394	0.049	87.6%	12.2	0.43	96.5%
9	0.176	0.046	73.9%	3.56	0.12	96.6%
10	0.180	0.070	61.1%	NA	NA	NA
11	0.130	0.050 U	61.5%	NA	NA	NA
12	0.350	0.050 U	85.7%	NA	NA	NA
13	0.100	0.010 U	90.0%	NA	NA	NA
14	0.370	0.010 U	97.3%	NA	NA	NA
16	0.310	0.041	86.8%	NA	NA	NA
17	0.420	0.041	90.2%	NA	NA	NA
18	0.190	0.018	90.5%	NA	NA	NA
19	0.390	0.039	90.0%	NA	NA	NA
20	0.260	0.010 U	96.2%	NA	NA	NA
23	0.180	0.027	85.0%	NA	NA	NA
25	0.130	0.010 U	92.3%	NA	NA	NA
Median	0.237	0.042	86.3%	8.595	1.820	74.3%
Minimum	0.100	0.010 U	12.4%	3.560	0.120	54.0%
Maximum	0.433	0.205	97.3%	31.90	7.99	96.6%
Events with influent total phosphorus concentrations greater than 0.5 mg/L						
21	0.540	0.028	94.8%	NA	NA	NA
24	0.520	0.014	97.3%	NA	NA	NA
Median	0.530	0.021	96.1%	--	--	--
Minimum	0.520	0.014	94.8%	--	--	--
Maximum	0.540	0.028	97.3%	--	--	--
All events combined						
Median	0.234	0.041	85.7%	7.27	2.13	67.4%
Minimum	0.046	0.010 U	12.4%	3.56	0.12	54.0%
Maximum	0.540	0.205	97.3%	31.9	7.99	96.6%

Values in **bold** do not meet the peformance goals identified in the TAPE (Ecology 2004) for phosphorus treatment.
NA: load estimates are not availabe for these events because no associated dicharge data are available.
U: undetected at the detection limit noted.
mg/L: milligram/liter
g: gram

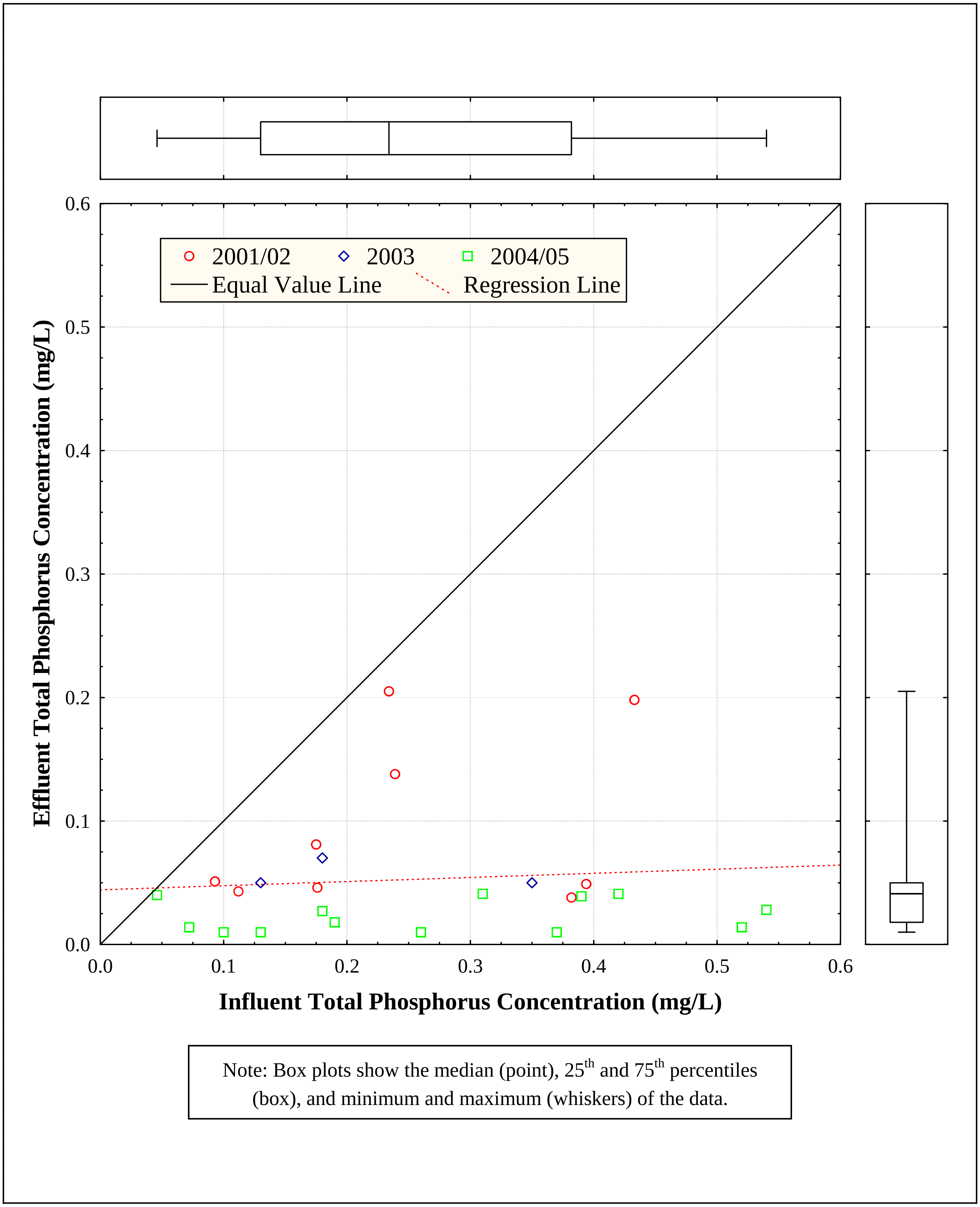
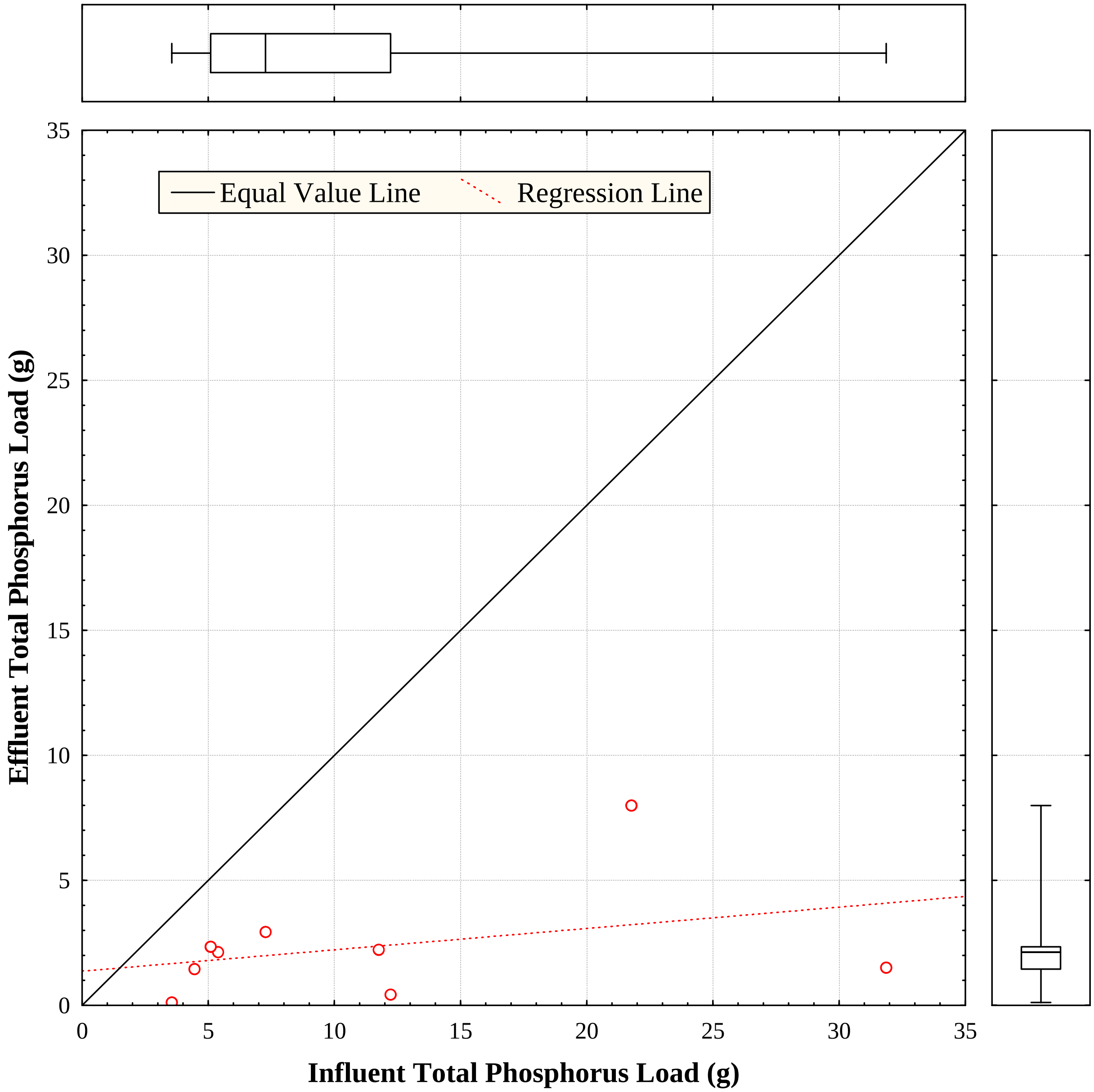


Figure 8. Influent and effluent total phosphorus concentrations measured at the SR 167 Ecology Embankment over the period from 2001 to 2005.



Note: Box plots show the median (point), 25th and 75th percentiles (box), and minimum and maximum (whiskers) of the data.

Figure 9. Influent and effluent total phosphorus loads measured at the SR 167 Ecology Embankment over the period from 2001 to 2002.

Effluent total phosphorus loads were also lower than influent loads across all sampled storm events (Table 9, Figure 9). The results from a one-tailed sign test (see Appendix D, Table D1) confirmed the observed decrease in effluent total phosphorus loads relative to influent was statistically significant ($p = 0.0038$). Across all pairs of influent and effluent samples, the median difference (i.e., influent minus effluent) in total phosphorus loads was 4.34 g.

Across all storm events, total phosphorus removal efficiency estimates calculated using Method #1 ranged from 12.4 to 97.3 percent, with a median value of 85.7 percent (Table 9, Figure 10). Similarly, for those storms having flow data, removal efficiency estimates calculated using Method #3 ranged from 54.0 to 96.6 percent, with a median value of 67.4 percent. The aggregate total phosphorus removal efficiency calculated using Method #2 was 79.6 percent. Results from the Mann Kendall test showed that Method #1 removal efficiency estimates exhibited a significant increasing trend ($\tau = 0.538$) over the five year period of data collection (see Appendix D, Table D2). Analyses performed to evaluate potential relationships between removal efficiencies and storm event characteristics also showed that Method #1 removal efficiency estimates exhibited a significant negative correlation ($\tau = -0.311$) with storm precipitation depth (Appendix D, Table D4, Figure D2). At the same time, Method #3 removal efficiency estimates showed a significant negative correlation with storm average intensity ($\tau = -0.500$) and peak intensity (-0.743).

Soluble Reactive Phosphorus

Based on the data obtained from the nine storm events sampled during the Taylor study, influent soluble reactive phosphorus (SRP) concentrations for the SR 167 Ecology Embankment ranged from 0.002 to 0.119 mg/L, with a median value of 0.011 mg/L (Table 10, Figure 11). Across the same storm events, effluent SRP concentrations ranged from 0.016 to 0.112 mg/L, with a median value of 0.027 mg/L. Analyses performed to evaluate potential relationships between SRP concentrations and storm event characteristics also showed that effluent SRP concentrations exhibited a significant positive correlation ($\tau = 0.500$) with storm antecedent dry period (Appendix D, Table D5, Figure D3). No other significant correlations were observed between influent or effluent concentrations and storm event characteristics.

As shown in Table 10 and Figure 11, effluent SRP concentrations were higher than influent concentrations for all but two of the sampled storm events. Results from a one-tailed sign test (see Appendix D, Table D1) that was applied to these data confirm that no statistically significant decrease ($p = 0.9088$) in SRP concentration was observed in the effluent of the SR 167 Ecology Embankment. Across all pairs of influent and effluent samples, the median difference (i.e., effluent minus influent) in SRP concentrations was -0.013 mg/L.

Influent SRP loads for the SR 167 Ecology Embankment ranged from 0.16 to 3.23 g, with a median value of 0.42 g (Table 10, Figure 12). Similarly, effluent SRP loads ranged from 0.04 to 4.0 g, with a median value of 0.76 g. Effluent SRP loads exhibited a significant positive correlation with storm precipitation depth ($\tau = 0.686$) and average intensity ($\tau = 0.500$) (Appendix D, Table D5, Figure D3). No statistically significant correlations were observed between influent SRP loads and storm parameters.

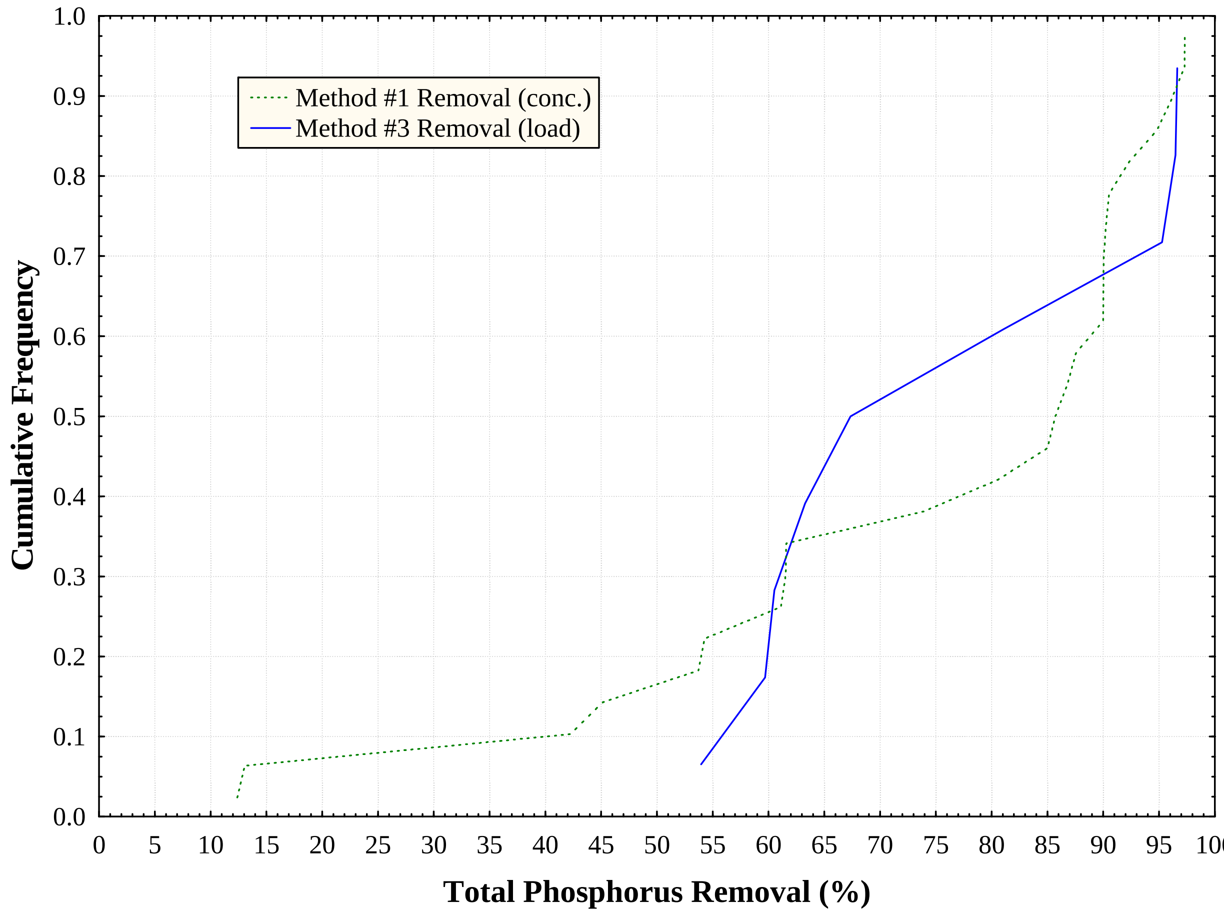


Figure 10. Cumulative frequency plot for total phosphorus removal efficiencies measured in the SR 167 Ecology Embankment.

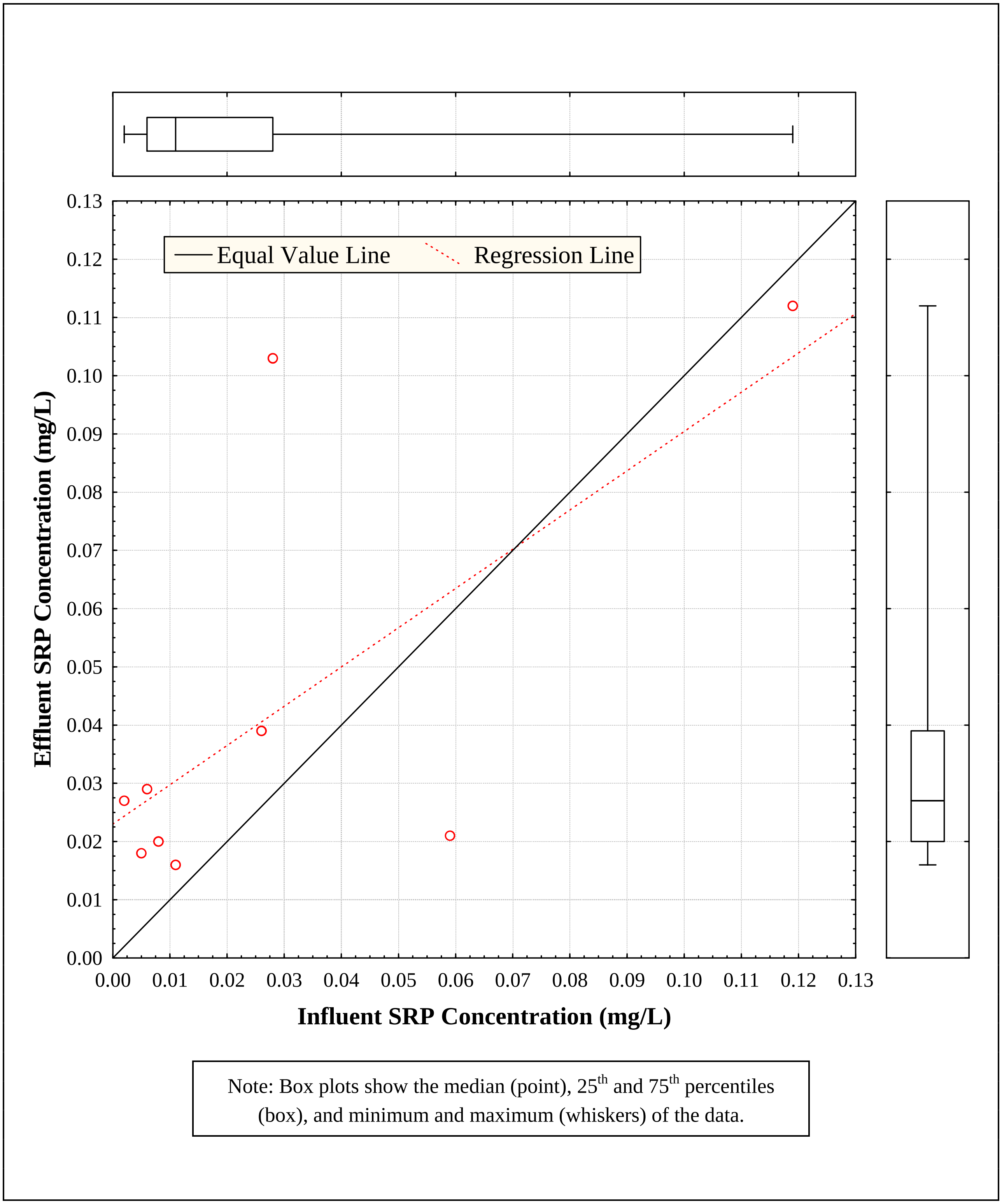


Figure 11. Influent and effluent soluble reactive phosphorus (SRP) concentrations measured at the SR 167 Ecology Embankment over the period from 2001 to 2002.

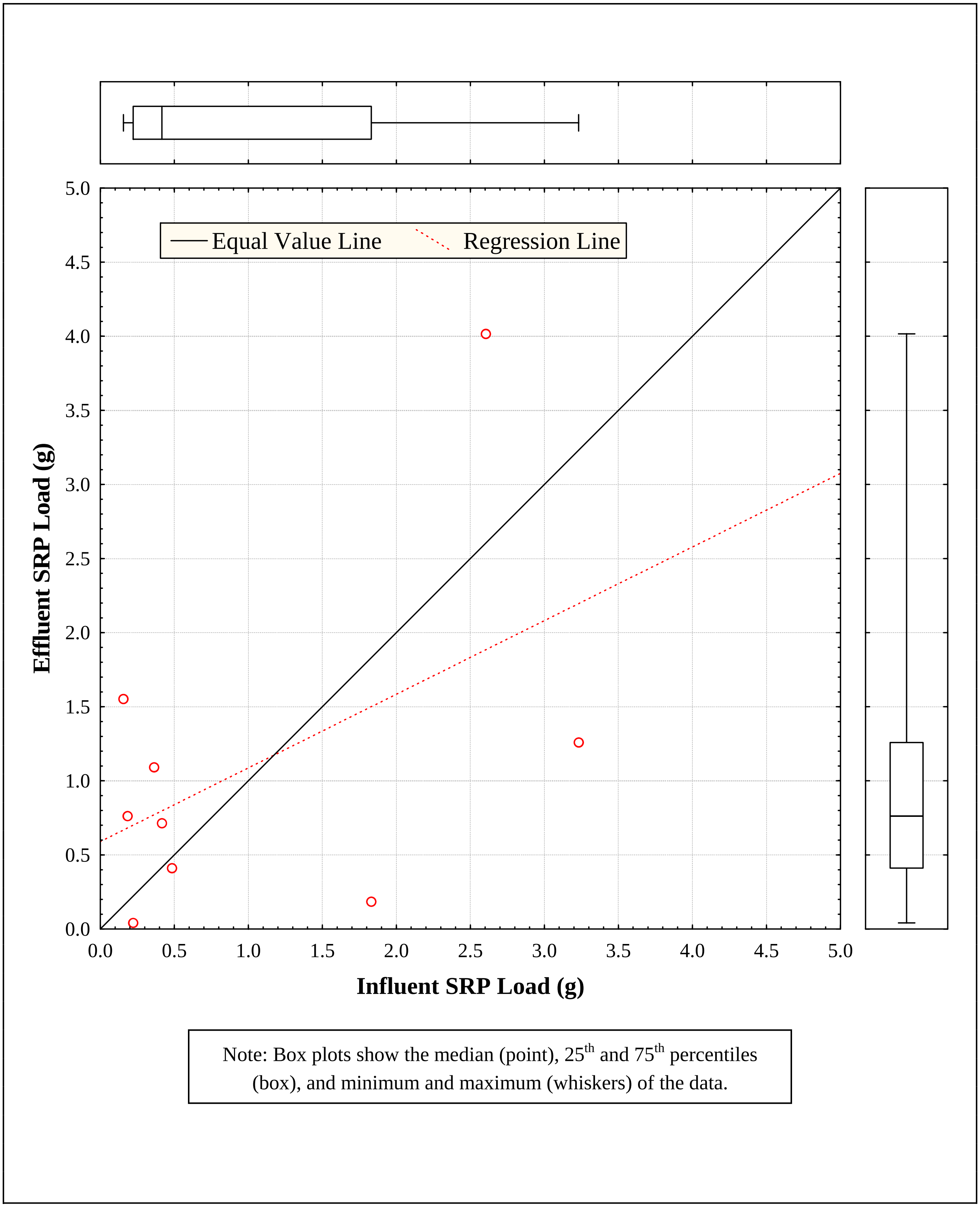


Figure 12. Influent and effluent soluble reactive phosphorus (SRP) loads measured at the SR 167 Ecology Embankment over the period from 2001 to 2002.

Table 10. Soluble reactive phosphorus concentrations, loads, and removal efficiency estimates for individual sampling events at the SR 167 Ecology Embankment.

Event No.	Influent Concentration (mg/L)	Effluent Concentration (mg/L)	Method #1 Removal	Influent Load (g)	Effluent Load (g)	Method #3 Removal
1	0.028	0.103	-267.9%	2.605	4.016	-54.2%
2	0.119	0.112	5.9%	3.232	1.259	61.0%
3	0.026	0.039	-50.0%	0.484	0.411	15.2%
4	0.006	0.029	-383.3%	0.185	0.762	-312.3%
5	0.008	0.020	-150.0%	0.364	1.091	-199.8%
6	0.002	0.027	-1,250.0%	0.156	1.552	-892.2%
7	0.005	0.018	-260.0%	0.417	0.714	-71.2%
8	0.059	0.021	64.4%	1.831	0.185	89.9%
9	0.011	0.016	-45.5%	0.222	0.042	81.3%
Median	0.011	0.027	-150.0%	0.42	0.76	-54.2%
Minimum	0.002	0.016	-1,250.0%	0.16	0.04	-892.2%
Maximum	0.119	0.112	64.4%	3.23	4.0	89.9%

NA: load estimates are not availabe for these events because no associated dicharge data are available.
mg/L: milligram/liter
g: gram

Effluent SRP loads were higher than influent loads during five of the nine sampled storm events where discharge data are available, and were lower during the remaining four storm events (Table 10, Figure 12). The results from a one-tailed sign test (see Appendix D, Table D1) confirmed that a statistically significant decrease in effluent SRP loads relative to influent loads was not observed ($p = 0.5000$). Across all pairs of influent and effluent samples, the median difference (i.e., effluent minus influent) in SRP loads was -0.297 g.

Across all storm events, removal efficiency estimates calculated using Method #1 ranged from -1,250 percent to 64 percent, with a median value of -150 percent (Table 10, Figure 13). The Method #1 removal efficiency estimates exhibited significant negative correlations with storm precipitation depth ($\tau = -0.514$), average intensity ($\tau = -0.611$), and peak intensity ($\tau = -0.572$) (Appendix D, Table D5, Figure D3). Removal efficiency estimates calculated using Method #3 ranged from -892.2 to 89.9 percent, with a median value of -54.2 percent (Table 10, Figure 13). The Method #3 removal efficiency estimates also exhibited significant negative correlations with storm average intensity ($\tau = -0.611$) and peak intensity ($\tau = -0.686$) (Appendix D, Table D5, Figure D3). The aggregate SRP removal efficiency estimate as calculated using Method #2 was -5.6 percent.

Total Zinc

Based on the data obtained from all 25 storm events, influent total zinc concentrations for the SR 167 Ecology Embankment ranged from 68 to 630 micrograms per liter (μg/L), with a median value of 239 μg/L (Table 11, Figure 14). Across the same storm events, effluent total zinc concentrations ranged from 6 to 98 μg/L, with a median value of 35 μg/L. Results from the Mann Kendall test showed that influent concentrations exhibited a significant increasing trend ($\tau = 0.364$) over the five year period of data collection (see Appendix D, Table D2). There was

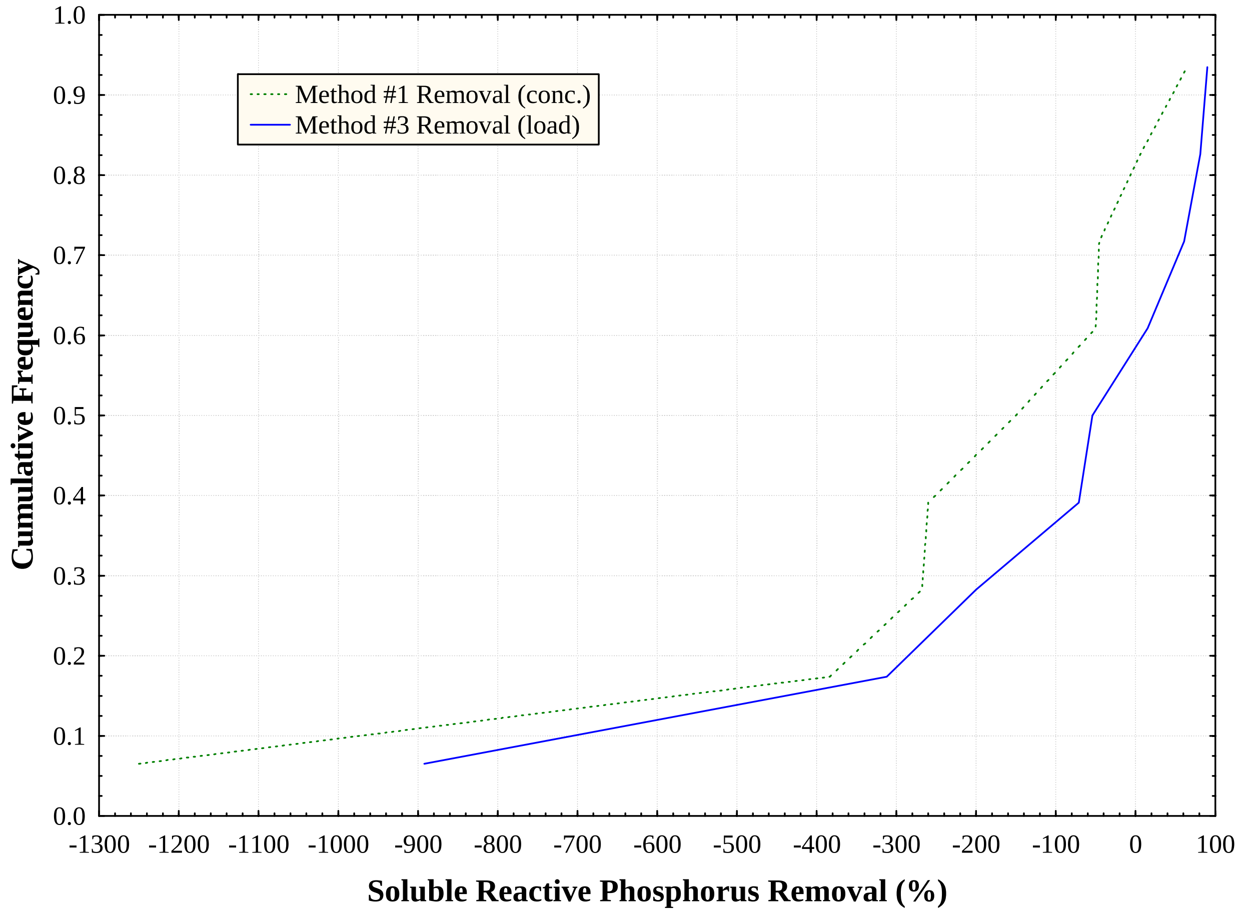


Figure 13. Cumulative frequency plot for soluble reactive phosphorus removal efficiency in the SR 167 Ecology Embankment.

Table 11. Total zinc concentrations, loads, and removal efficiency estimates for individual sampling events at the SR 167 Ecology Embankment.

Event No.	Influent Concentration (μg/L)	Effluent Concentration (μg/L)	Method #1 Removal	Influent Load (g)	Effluent Load (g)	Method #3 Removal
1	186	39	79.0%	17.3	1.52	91.2%
2	239	48	79.9%	6.49	0.54	91.7%
3	150	40	73.3%	2.79	0.42	84.9%
4	137	21	84.7%	4.22	0.55	86.9%
5	106	21	80.2%	4.82	1.15	76.2%
6	68	6	91.2%	5.32	0.34	93.5%
7	123	23	81.3%	10.3	0.91	91.1%
8	587	28	95.2%	18.2	0.25	98.6%
9	185	32	82.7%	3.74	0.08	97.8%
10	284	42	85.1%	NA	NA	NA
11	168	34	79.7%	NA	NA	NA
12	188	39	79.1%	NA	NA	NA
13	300	98	67.3%	NA	NA	NA
14	520	63	87.9%	NA	NA	NA
15	230	38	83.5%	NA	NA	NA
16	500	35	93.0%	NA	NA	NA
17	620	35	94.4%	NA	NA	NA
18	270	35	87.0%	NA	NA	NA
19	480	30	93.8%	NA	NA	NA
20	460	30	93.5%	NA	NA	NA
21	560	26	95.4%	NA	NA	NA
22	630	69	89.0%	NA	NA	NA
23	150	31	79.3%	NA	NA	NA
24	440	54	87.7%	NA	NA	NA
25	190	20	89.5%	NA	NA	NA
Median	239	35	85.1%	5.32	0.54	91.2%
Minimum	68	6	67.3%	2.79	0.08	76.2%
Maximum	630	98	95.4%	18.22	1.5	98.6%

NA: load estimates are not availabe for these events because no associated dicharge data are available.
μg/L: microgram/liter
g: gram

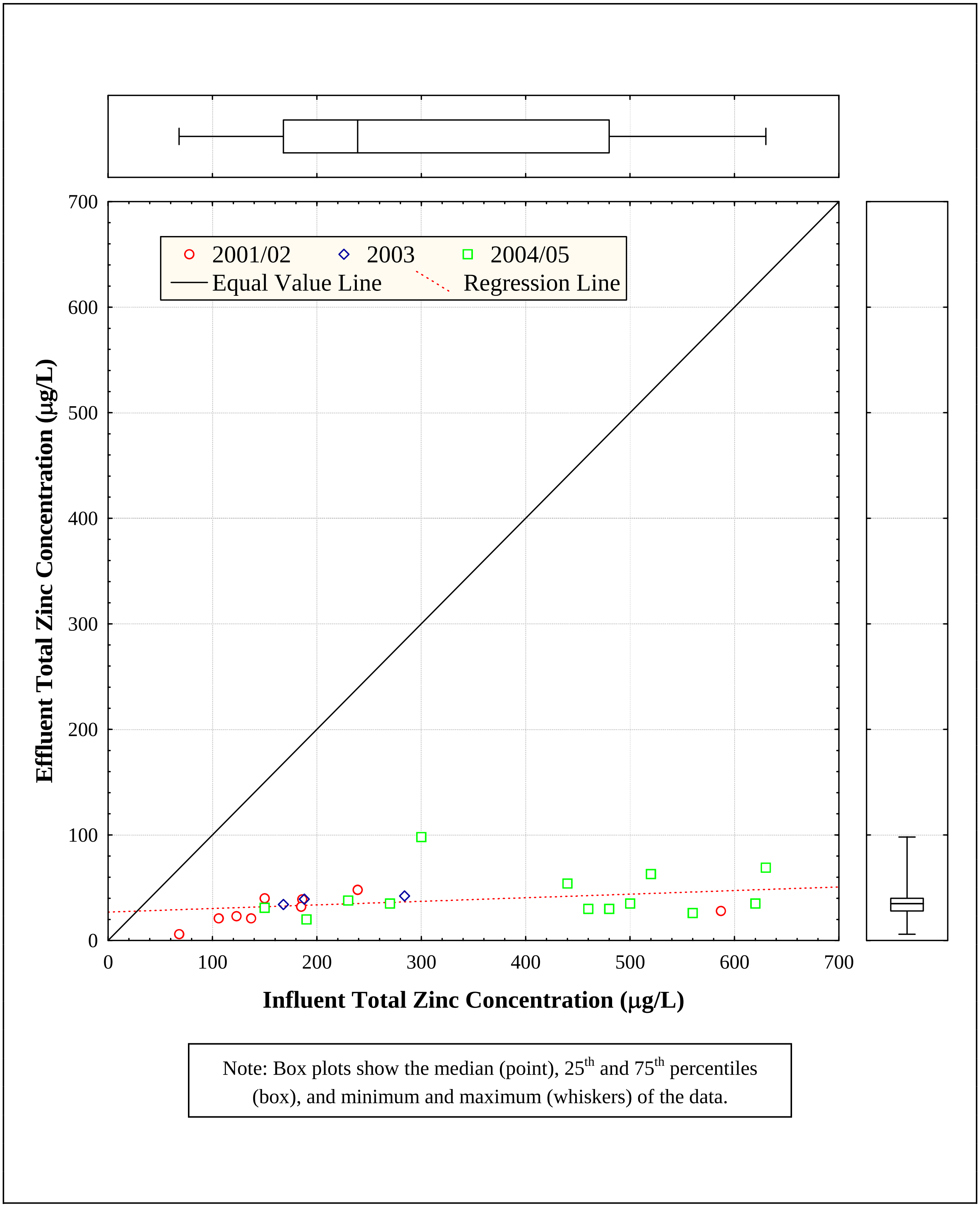


Figure 14. Influent and effluent total zinc concentrations measured at the SR 167 Ecology Embankment over the period from 2001 to 2005.

no apparent trend in the data for effluent concentrations over the same period. Analyses performed to evaluate potential relationships between total zinc concentrations and storm event characteristics also showed that influent concentrations exhibited significant negative correlations with storm precipitation depth (τ = -0.496) and duration (τ = -0.308) (Appendix D, Table D6, Figure D4). No other significant correlations were observed between influent or effluent concentrations and storm event characteristics.

As shown in Table 11 and Figure 14, effluent total zinc concentrations were markedly lower than influent concentrations across all sampled storm events. Results from a one-tailed sign test (see Appendix D, Table D1) that was applied to these data confirmed the observed decrease in effluent total zinc concentrations relative to influent was statistically significant ($p < 0.0001$). Across all pairs of influent and effluent samples, the median difference (i.e., influent minus effluent) in total zinc concentrations was 192 µg/L.

Across the nine storm events for which discharge data are available (Taylor study only), influent total zinc loads for the SR 167 Ecology Embankment ranged from 2.79 to 18.22 g, with a median value of 5.32 g (Table 11, Figure 15). Similarly, effluent total zinc loads ranged from 0.08 to 1.5 g, with a median value of 0.54 g. Influent total zinc loads exhibited a significant positive correlation (τ = 0.572) with storm duration (Appendix D, Table D6, Figure D4). In addition, effluent total zinc loads exhibited significant positive correlations with storm precipitation depth (τ = 0.572), antecedent dry period (τ = 0.556), and duration (τ =0.514).

Similar to total zinc concentrations, effluent loads were markedly lower than influent loads across sampled storm events where discharge data are available (Table 11, Figure 15). The results from a one-tailed sign test (see Appendix D, Table D1) also confirmed the observed decrease in effluent total zinc loads relative to influent was statistically significant ($p = 0.0038$). Across all pairs of influent and effluent samples, the median difference (i.e., influent minus effluent) in total zinc loads was 4.97 g.

Across all sampled storm events, total zinc removal efficiency estimates calculated using Method #1 ranged from 67.3 to 95.4 percent, with a median value of 85.1 percent (Table 11, Figure 16). Results from the Mann Kendall test showed that Method #1 removal efficiency estimates exhibited a significant increasing trend (τ = 0.340) over the five year period of data collection (see Appendix D, Table D2). The Method #1 removal efficiency estimates also exhibited a significant negative correlation (τ = -0.341) with storm precipitation depth (Appendix D, Table D6, Figure D4). Removal efficiency estimates calculated using Method #3 ranged from 76.2 to 98.6 percent with a median value of 91.2 percent (Table 11, Figure 16). There were no statistically significant correlations detected between Method #3 removal efficiency estimates and storm event characteristics. The aggregate total zinc removal efficiency estimate as calculated using Method #2 was 91.2 percent.

Dissolved Zinc

Based on the data obtained from all 25 storm events, influent dissolved zinc concentrations for the SR 167 Ecology Embankment ranged from 49 to 493 µg/L, with a median value of 120 µg/L(Table 12, Figure 17). Across the same storm events, effluent dissolved zinc concentrations ranged from 5 to 63 µg/L, with a median value of 25 µg/L. Results from the Mann Kendall test

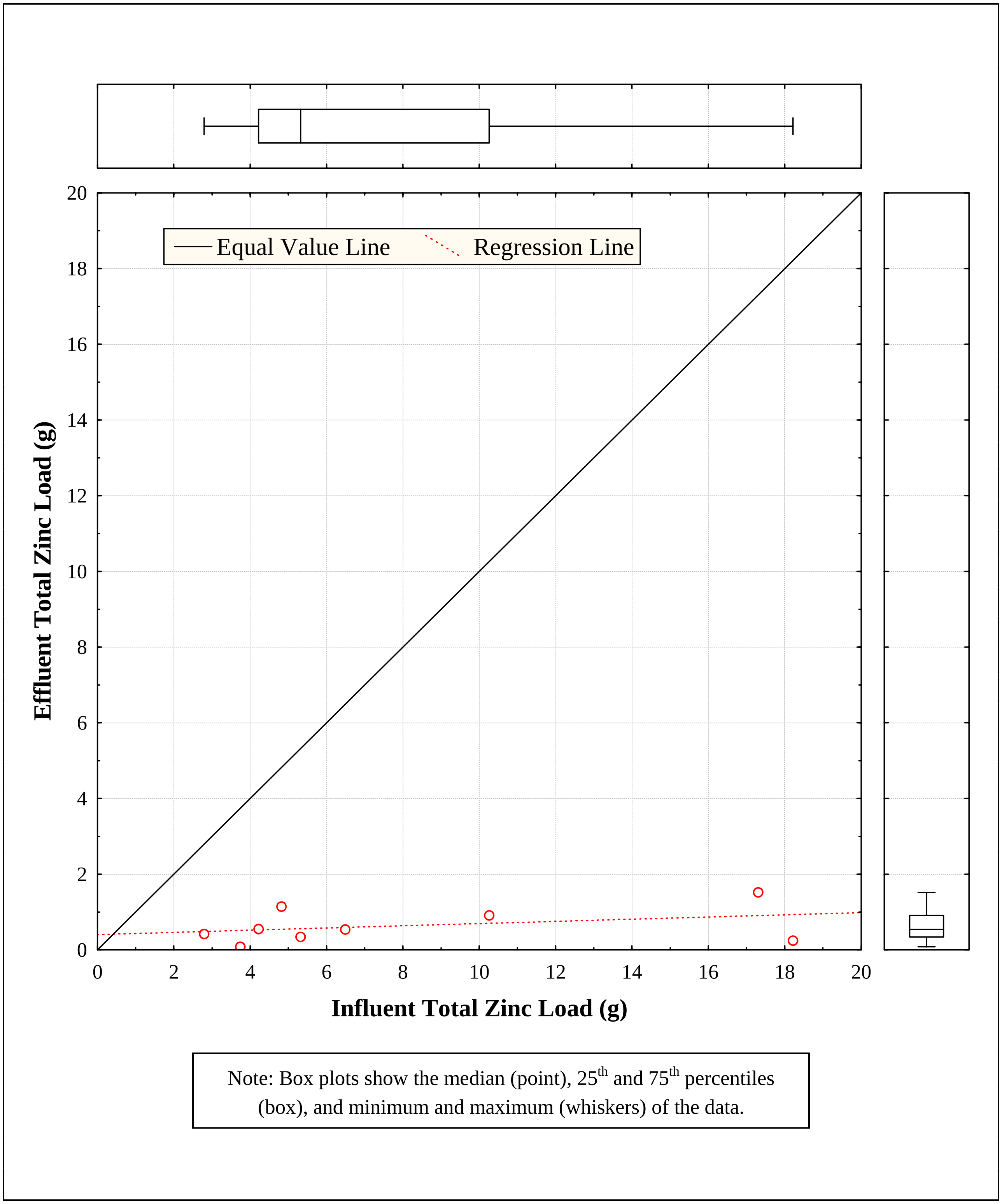


Figure 15. Influent and effluent total zinc loads measured at the SR 167 Ecology Embankment over the period from 2001 to 2002.

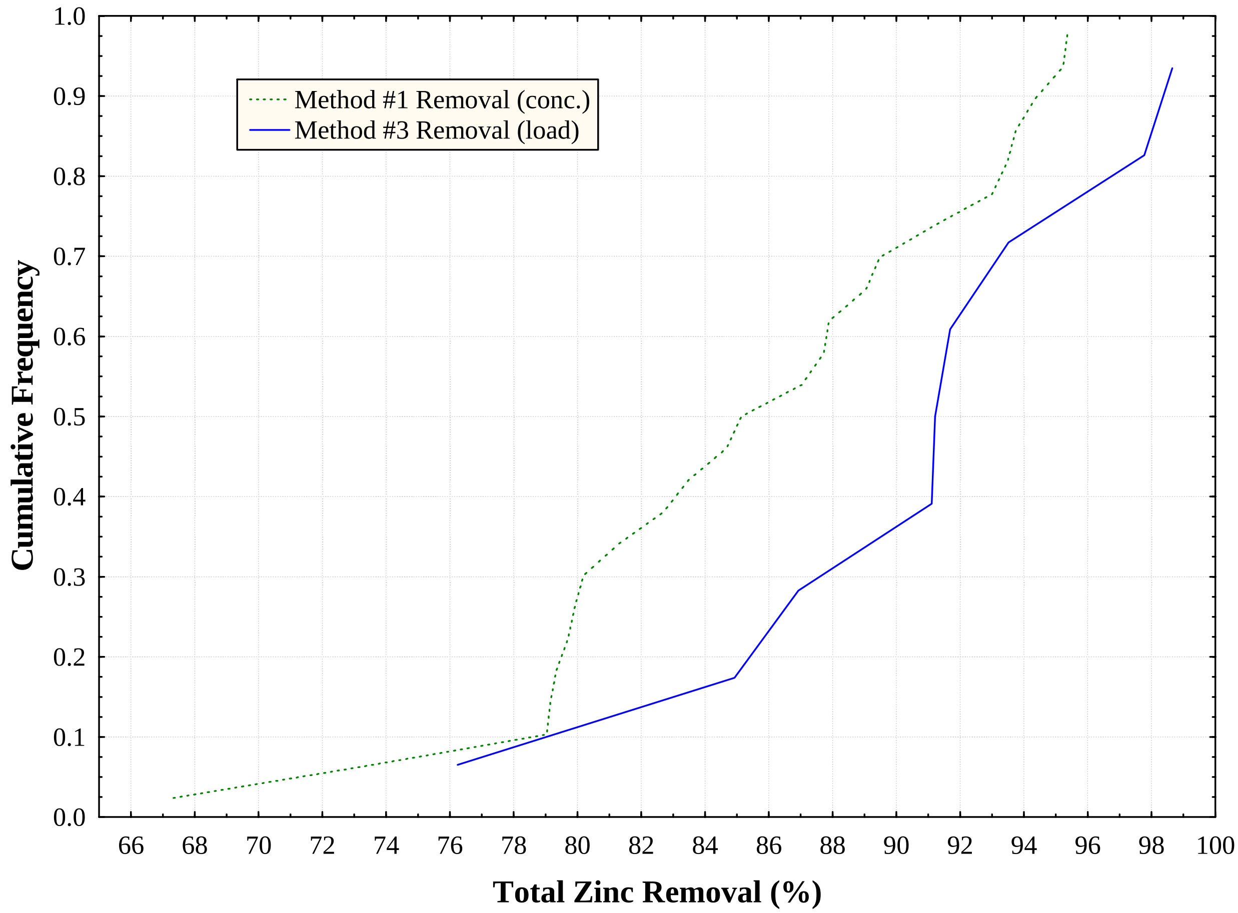
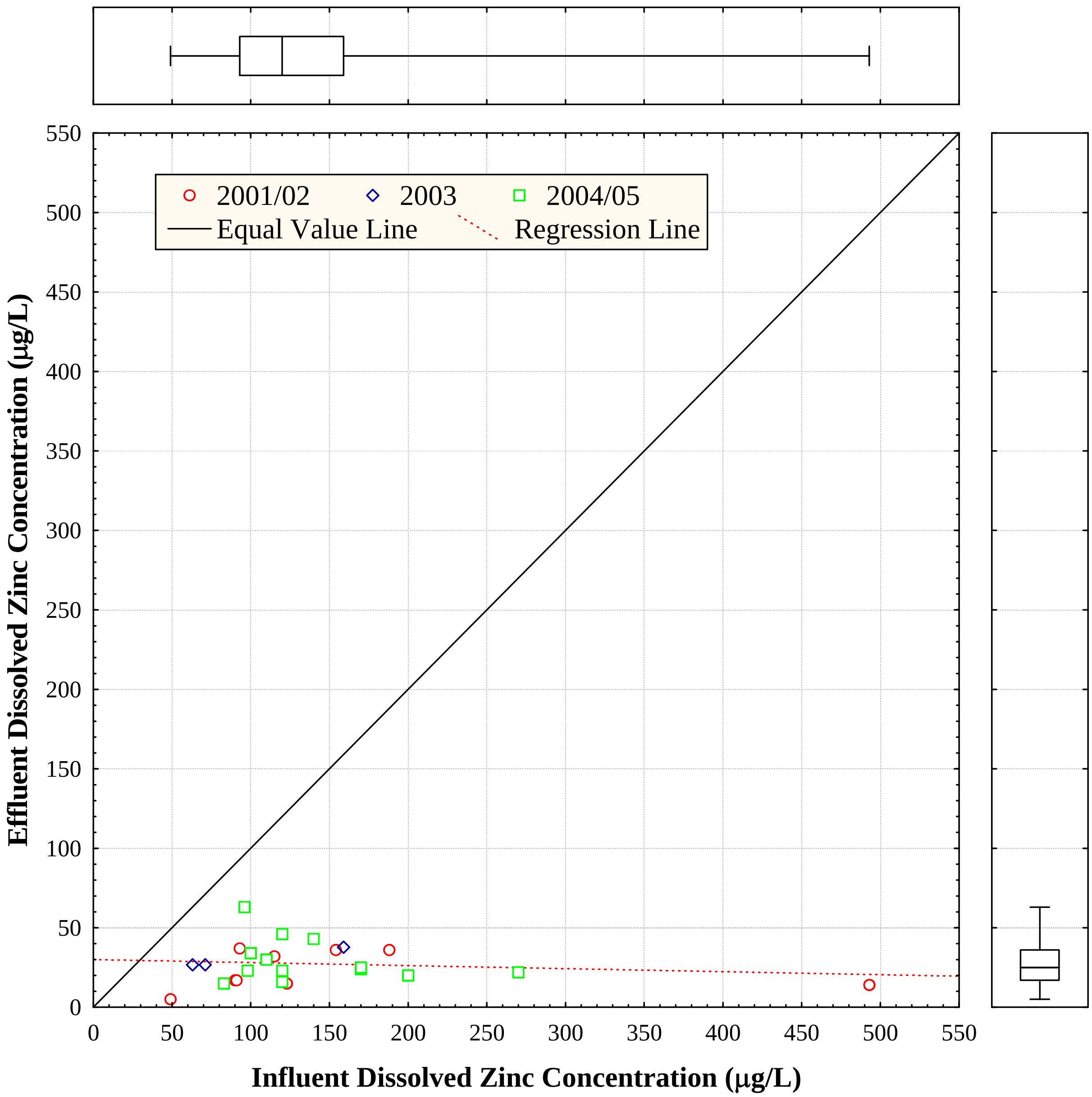


Figure 16. Cumulative frequency plot for total zinc removal efficiency in the SR 167 Ecology Embankment.

Table 12. Dissolved zinc concentrations, loads, and removal efficiency estimates for individual sampling events at the SR 167 Ecology Embankment.

Event No.	Influent Concentration (μg/L)	Effluent Concentration (μg/L)	Method #1 Removal	Influent Load (g)	Effluent Load (g)	Method #3 Removal
Events with influent dissolved zinc concentrations between 20 and 300 μg/L						
1	**154**	36	76.6%	14.3	1.40	90.2%
2	**188**	36	80.9%	5.11	0.40	92.1%
3	**93**	37	60.2%	1.73	0.39	77.5%
4	**123**	15	87.8%	3.79	0.39	89.6%
5	**90**	17	81.1%	4.09	0.93	77.3%
6	**49**	5	89.8%	3.83	0.29	92.5%
7	**91**	17	81.3%	7.59	0.67	91.1%
9	**115**	32	72.2%	2.33	0.08	96.4%
10	**159**	**38**	76.3%	NA	NA	NA
11	**63**	**27**	57.7%	NA	NA	NA
12	71	27	62.4%	NA	NA	NA
13	**96**	**63**	34.4%	NA	NA	NA
14	**140**	**43**	69.3%	NA	NA	NA
15	**100**	34	66.0%	NA	NA	NA
16	**120**	23	80.8%	NA	NA	NA
17	**83**	15	81.9%	NA	NA	NA
18	**170**	24	85.9%	NA	NA	NA
19	**170**	25	85.3%	NA	NA	NA
20	**270**	22	91.9%	NA	NA	NA
21	**200**	20	90.0%	NA	NA	NA
22	**120**	46	61.7%	NA	NA	NA
23	**110**	30	72.7%	NA	NA	NA
24	**98**	23	76.5%	NA	NA	NA
25	**120**	16	86.7%	NA	NA	NA
Median	118	26	78.7%	3.96	0.40	90.7%
Minimum	49	5	34.4%	1.73	0.08	77.3%
Maximum	270	63	91.9%	14.33	1.40	96.4%
Events with influent dissolved zinc concentrations greater than 300 μg/L						
8	**493**	14	97.2%	15.30	0.1	99.2%
All events combined						
Median	120	25	80.8%	4.09	0.39	91.1%
Minimum	49	5	34.4%	1.73	0.08	77.3%
Maximum	493	63	97.2%	15.3	1.40	99.2%

Values in **bold** do not meet acute state water quality standards identified in the WAC 173-201A for dissolved zinc based on the hardness concentration measured in the associated sample (see Table 13).
NA: load estimates are not availabe for these events because no associated dicharge data are available.
μg/L: microgram/liter
g: gram



Note: Box plots show the median (point), 25th and 75th percentiles (box), and minimum and maximum (whiskers) of the data.

Figure 17. Influent and effluent dissolved zinc concentrations measured at the SR 167 Ecology Embankment over the period from 2001 to 2005.

showed there were no temporal trends in the influent or effluent dissolved zinc concentrations over the five year period of data collection (see Appendix D, Table D2). However, analyses performed to evaluate potential relationships between dissolved zinc concentrations and storm event characteristics showed that influent concentrations exhibited a significant negative correlation ($\tau = -0.421$) with storm average intensity (Appendix D, Table D7, Figure D5). No other significant correlations were observed between influent or effluent concentrations and storm event characteristics.

As shown in Table 12 and Figure 17, effluent dissolved zinc concentrations were lower than influent concentrations across all sampled storm events. Results from a one-tailed sign test (see Appendix D, Table D1) that was applied to these data confirmed the observed decrease in effluent dissolved zinc concentrations relative to influent was statistically significant ($p < 0.0001$). Across all pairs of influent and effluent samples, the median difference (i.e., influent minus effluent) in dissolved zinc concentrations was 83.0 μg/L. Influent and effluent dissolved zinc concentrations were also compared to Washington State's acute water quality standard (WAC 177-201A) for this parameter. Because the acute standard varies with water hardness, the actual standard that was applied to each sample was calculated based on the associated hardness concentrations (Table 13) for each influent and effluent sample, respectively. These data showed that 96 percent of the influent samples exceeded the acute standard whereas only 16 percent of the effluent samples had similar exceedances (Table 12).

Across the nine storm events for which discharge data are available (Taylor study only), influent dissolved zinc loads for the SR 167 Ecology Embankment ranged from 1.73 to 15.3 g, with a median value of 4.09 g (Table 12, Figure 18). Similarly, effluent dissolved zinc loads ranged from 0.08 to 1.40 g, with a median value of 0.39 g. Influent dissolved zinc loads exhibited a significant positive correlation ($\tau = 0.629$) with storm duration (Appendix D, Table D7, Figure D5). In addition, effluent dissolved zinc loads exhibited significant positive correlations with storm precipitation depth ($\tau = 0.572$), antecedent dry period ($\tau = 0.611$), and duration ($\tau = 0.572$).

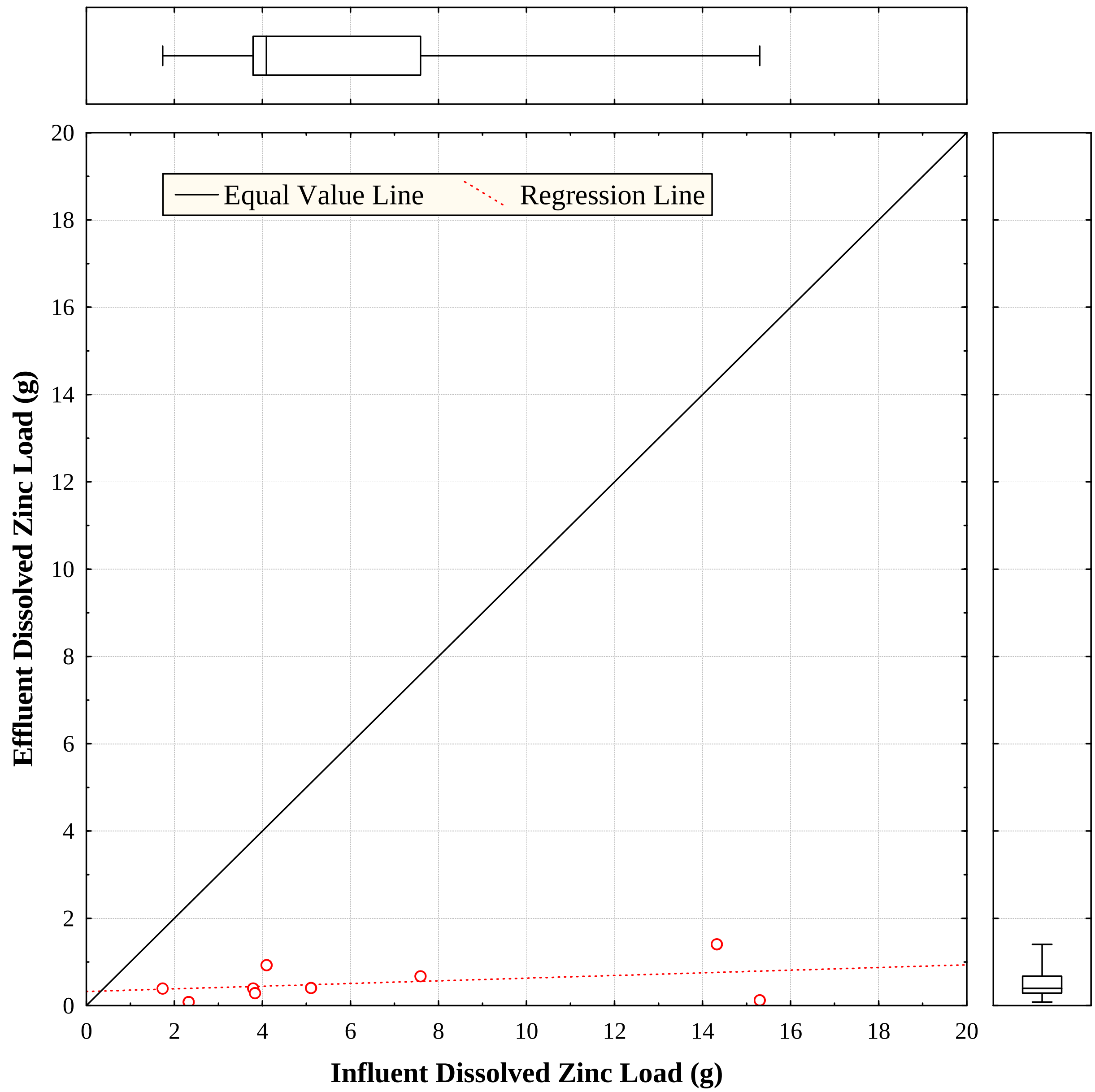
Similar to the dissolved zinc concentrations, effluent loads were lower than influent loads across sampled storm events where discharge data are available (Table 12, Figure 18). The results from a one-tailed sign test (see Appendix D, Table D1) also confirmed the observed decrease in effluent dissolved zinc loads relative to influent was statistically significant ($p = 0.0038$). Across all pairs of influent and effluent samples, the median difference (i.e., influent minus effluent) in dissolved zinc loads was 3.55 g.

Across all sampled storm events, dissolved zinc removal efficiency estimates calculated using Method #1 ranged from 34.4 to 97.2 percent, with a median value of 80.8 percent (Table 12, Figure 19). Results from the Mann Kendall test showed there as no temporal trend the Method #1 removal efficiency estimates over the five year period of data collection (see Appendix D, Table D2). Furthermore, there were no significant correlations between the Method #1 removal efficiency estimates and the storm event characteristics (Appendix D, Table D7, Figure D5). Removal efficiency estimates calculated using Method #3 ranged from 77.3 to 99.2 percent with a median value of 91.1 percent (Table 12, Figure 19). The Method #3 removal values exhibited a significant negative correlation ($\tau = -0.514$) with storm peak intensity (Appendix D, Table D7, Figure D5). The aggregate dissolved zinc removal efficiency estimate as calculated using Method #2 was 91.9 percent.

Table 13. Hardness concentrations for individual sampling events at the SR 167 Ecology Embankment.

Event No.	Influent Concentration (mg/L as $CaCO_3$)	Effluent Concentration (mg/L as $CaCO_3$)
1	23.5	31.0
2	31.1	44.0
3	22.3	34.0
4	20.3	20.5
5	13.9	18.4
6	9.8	18.0
7	20.3	17.0
8	14.3	27.8
9	20.9	37.5
10	20.0	22.0
11	11.0	17.0
12	160	150
13	41.0	14.0
14	49.0	27.0
15	23.0	29.0
16	51.0	27.0
17	46.0	19.0
18	71.0	35.0
19	76.0	36.0
20	110	63.0
21	77.0	56.0
22	56.0	39.0
23	25.0	31.0
24	34.0	33.0
25	32.0	34.0
Median	31.1	31.0
Minimum	9.8	14.0
Maximum	160	150

mg/L: milligram/liter



Note: Box plots show the median (point), 25th and 75th percentiles (box), and minimum and maximum (whiskers) of the data.

Figure 18. Influent and effluent dissolved zinc loads measured at the SR 167 Ecology Embankment over the period from 2001 to 2002.

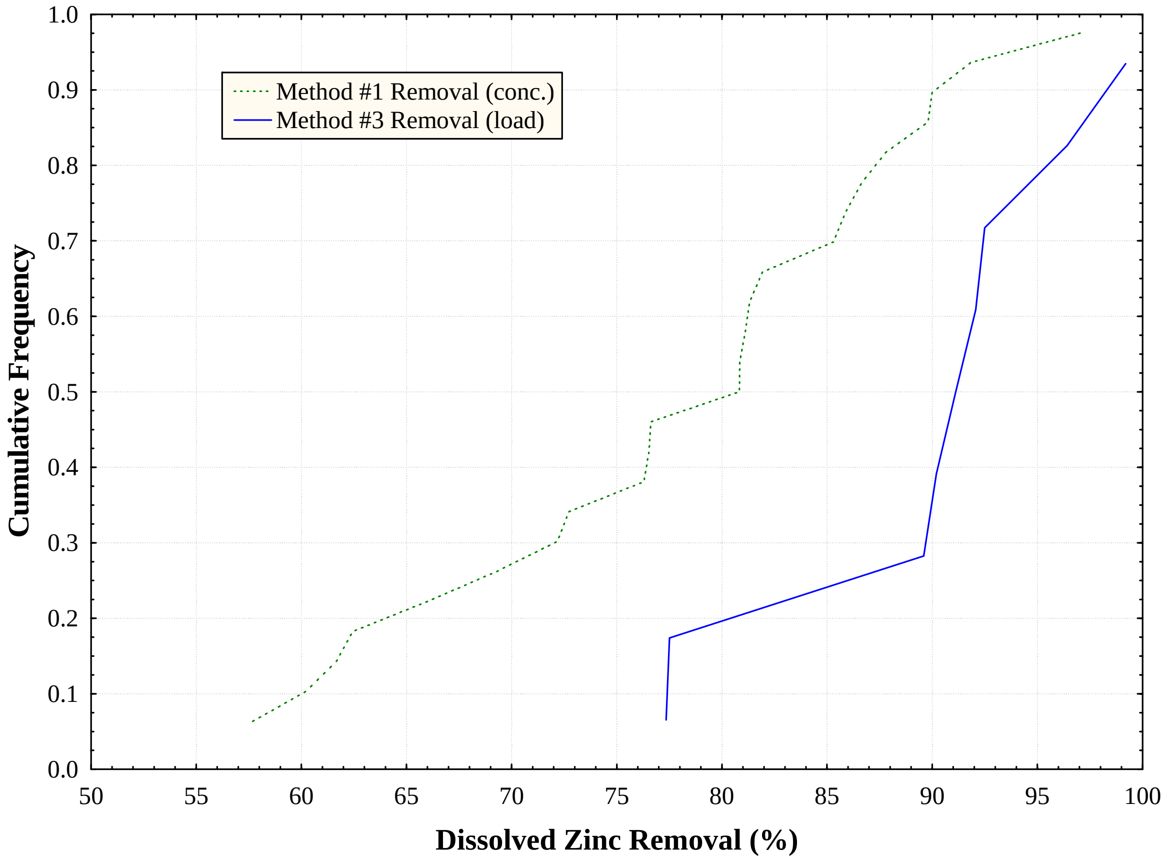


Figure 19. Cumulative frequency plot for dissolved zinc removal efficiency in the SR 167 Ecology Embankment.

Total Copper

Based on data obtained from the 13 storm events sampled during the Tetra Tech study, influent total copper concentrations for the SR 167 Ecology Embankment ranged from 27 to 120 µg/L, with a median value of 62 µg/L (Table 14, Figure 20). Across the same storm events, effluent total copper concentrations ranged from 5.2 to 26 µg/L, with a median value of 9.8 µg/L. Analyses performed to evaluate potential relationships between total copper concentrations and storm event characteristics showed that influent concentrations exhibited a significant negative correlation ($\tau = -0.588$) with storm precipitation depth (Appendix D, Table D8, Figure D6). No other significant correlations were observed between influent or effluent concentrations and storm event characteristics.

As shown in Table 14 and Figure 20, effluent total copper concentrations were markedly lower than influent concentrations across all sampled storm events. Results from a one-tailed sign test (see Appendix D, Table D1) that was applied to these data confirmed the observed decrease in effluent total copper concentrations relative to influent was statistically significant ($p = 0.0004$).

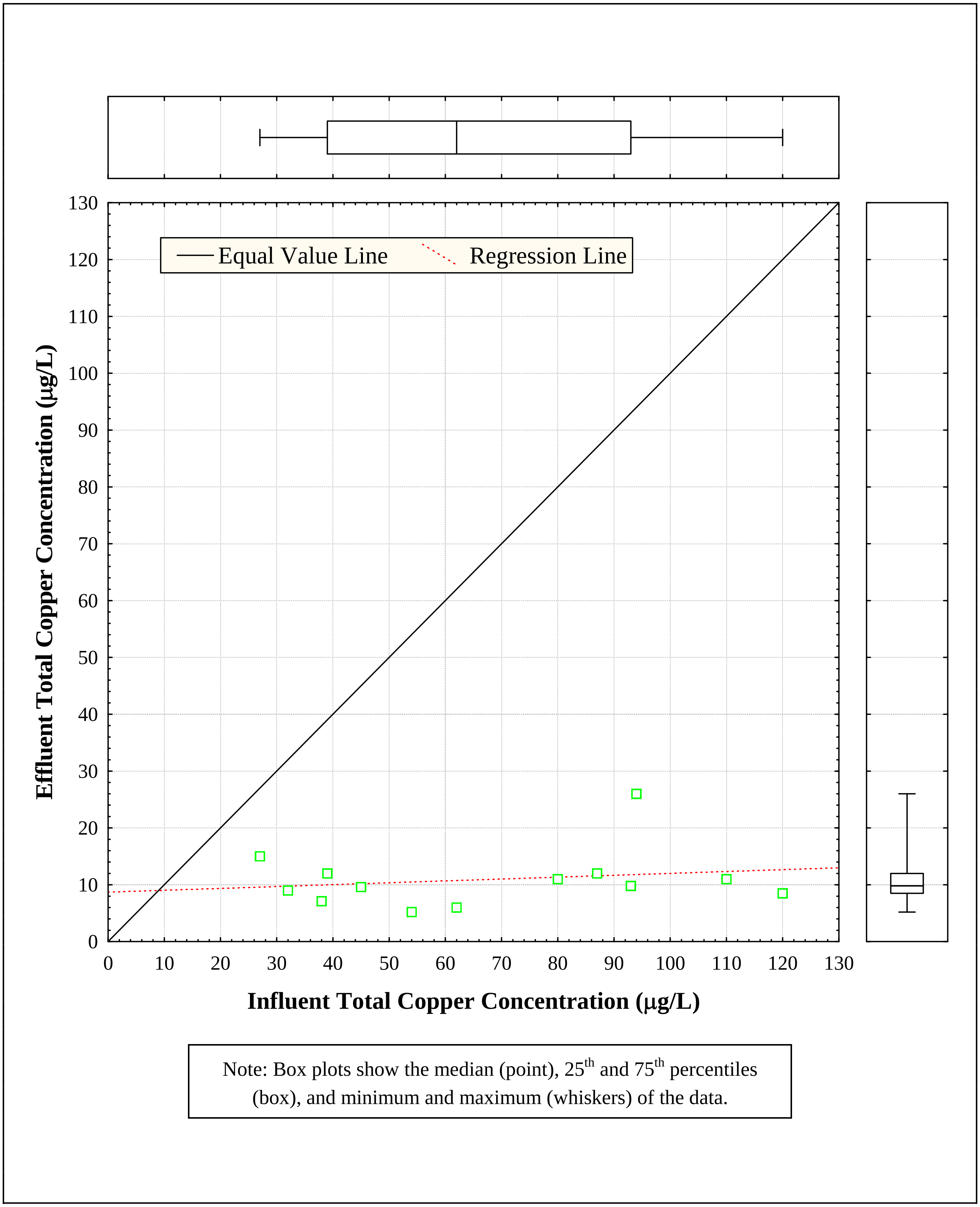


Figure 20. Influent and effluent total copper concentrations measured at the SR 167 Ecology Embankment over the period from 2004 to 2005.

Table 14. Total copper concentrations, loads, and removal efficiency estimates for individual sampling events at the SR 167 Ecology Embankment.

Event No.	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal	Influent Load (g)	Effluent Load (g)	Method #3 Removal
13	45	9.6	78.7%	NA	NA	NA
14	87	12	86.2%	NA	NA	NA
15	32	9.0	71.9%	NA	NA	NA
16	80	11	86.3%	NA	NA	NA
17	110	11	90.0%	NA	NA	NA
18	39	12	69.2%	NA	NA	NA
19	62	6.0	90.3%	NA	NA	NA
20	54	5.2	90.4%	NA	NA	NA
21	120	8.5	92.9%	NA	NA	NA
22	94	26	72.3%	NA	NA	NA
23	27	15	44.4%	NA	NA	NA
24	93	10	89.5%	NA	NA	NA
25	38	7.1	81.3%	NA	NA	NA
Median	62	9.8	86.2%	--	--	--
Minimum	27	5.2	44.4%	--	--	--
Maximum	120	26	92.9%	--	--	--

NA: load estimates are not availabe for these events because no associated dicharge data are available.
µg/L: microgram/liter

Across all pairs of influent and effluent samples, the median difference (i.e., influent minus effluent) in total copper concentrations was 56 µg/L.

Total copper removal efficiency estimates calculated using Method #1 ranged from 44.4 to 92.9 percent, with a median value of 86.2 percent (Table 14, Figure 21). There were no significant correlations observed between these removal efficiency estimates and storm event characteristics (Appendix D, Table D8, Figure D6).

Dissolved Copper

Based on data obtained from the 13 storm events sampled during the Tetra Tech study, influent dissolved copper concentrations for the SR 167 Ecology Embankment ranged from 7.5 to 33 µg/L, with a median value of 16 µg/L (Table 15, Figure 22). Across the same storm events, effluent dissolved copper concentrations ranged from 3.2 to 22 µg/L, with a median value of 7.1 µg/L. Analyses performed to evaluate potential relationships between dissolved copper concentrations and storm event characteristics showed that influent concentrations exhibited a significant negative correlation ($\tau = -0.531$) with storm peak intensity, and a significant positive correlation ($\tau = 0.702$) with storm antecedent dry period (Appendix D, Table D9, Figure D7). No other significant correlations were observed between influent or effluent concentrations and storm event characteristics.

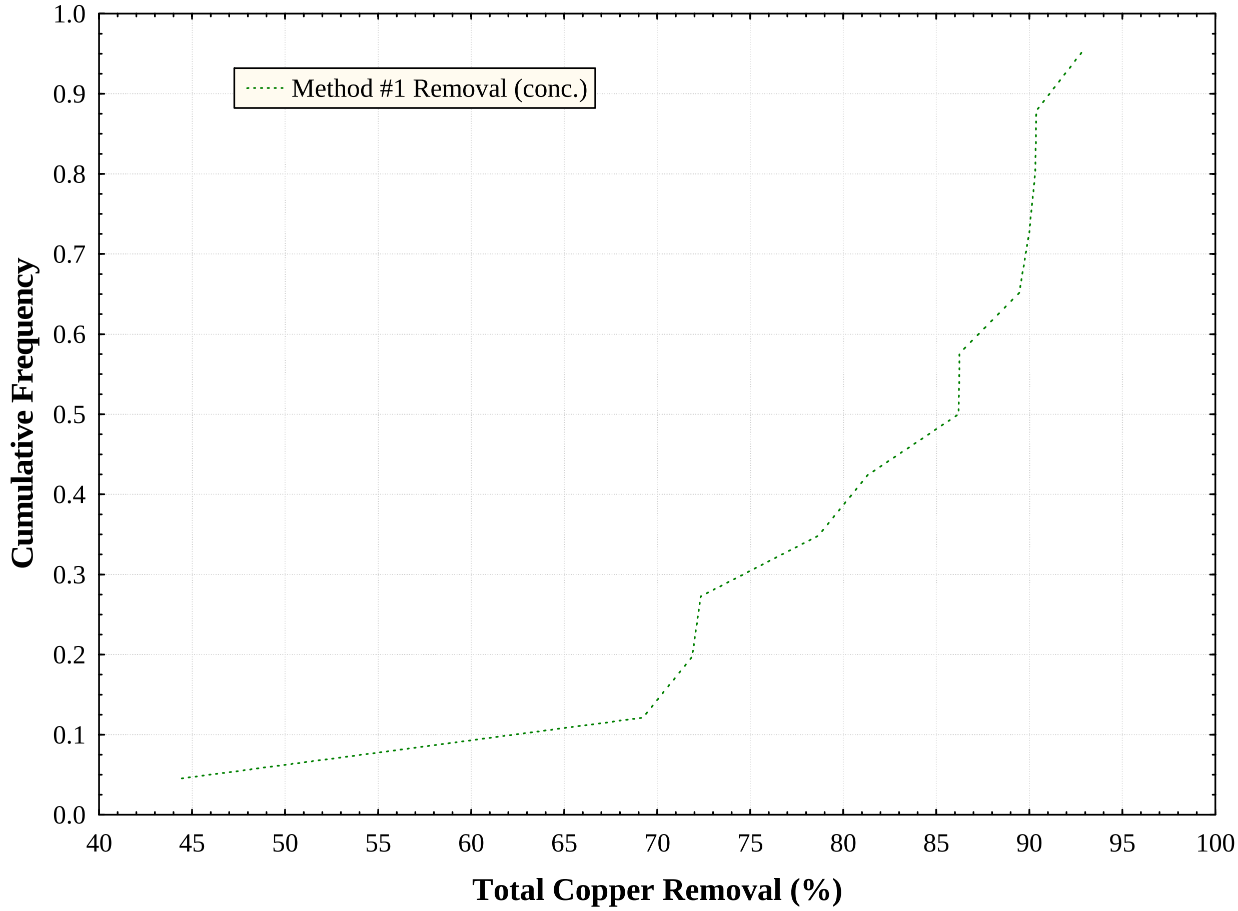
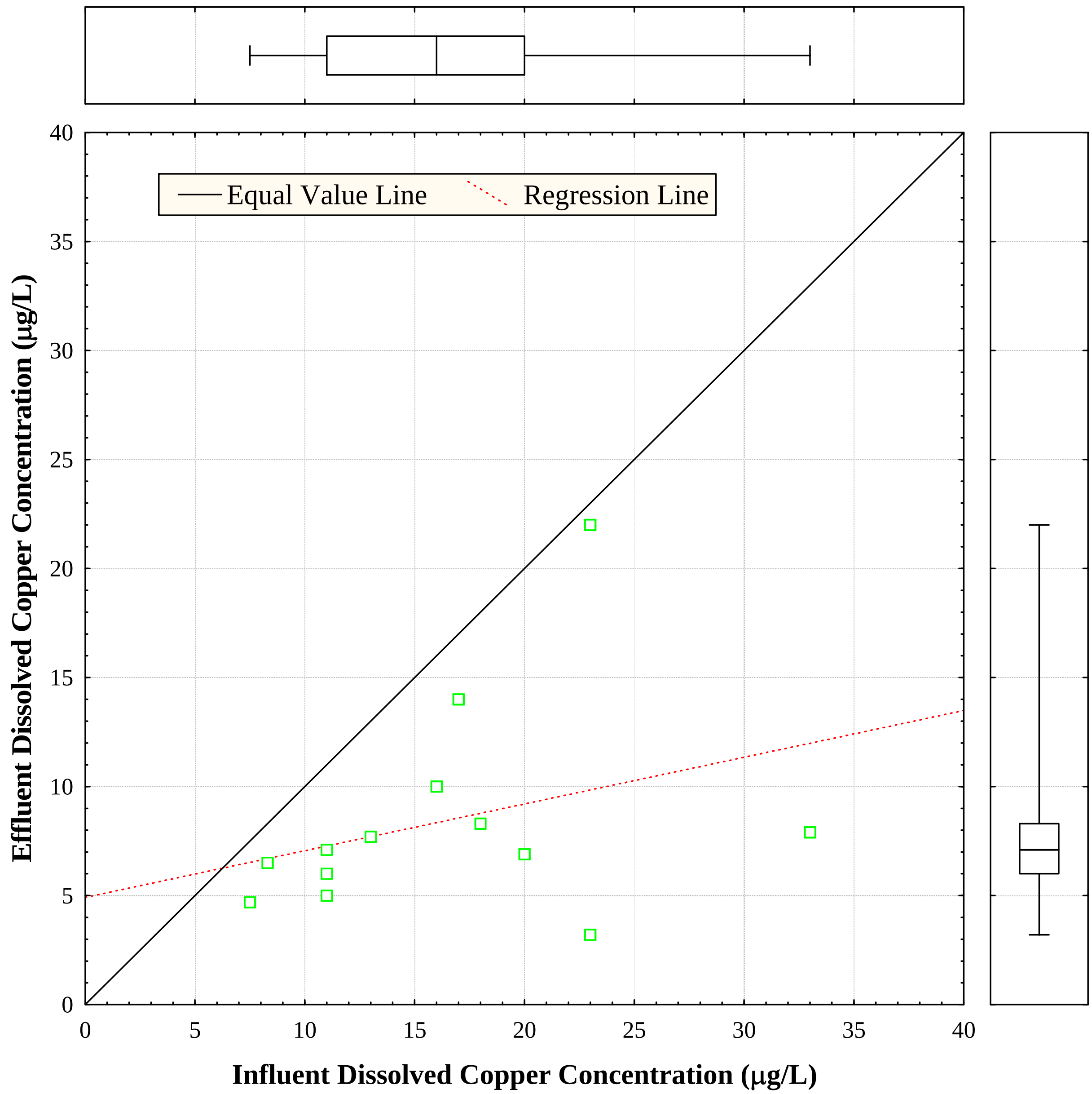


Figure 21. Cumulative frequency plot for total copper removal efficiency in the SR 167 Ecology Embankment.

Table 15. Dissolved copper concentrations, loads, and removal efficiency estimates for individual sampling events at the SR 167 Ecology Embankment.

Event No.	Influent Concentration (μg/L)	Effluent Concentration (μg/L)	Method #1 Removal	Influent Load (g)	Effluent Load (g)	Method #3 Removal
Events with influent dissolved copper concentrations between 3 and 20 μg/L						
13	**11**	**6.0**	45.5%	NA	NA	NA
14	**16**	**10**	37.5%	NA	NA	NA
15	**11**	**7.1**	35.5%	NA	NA	NA
16	8.3	**6.5**	21.7%	NA	NA	NA
17	7.5	**4.7**	37.3%	NA	NA	NA
18	**18**	**8.3**	53.9%	NA	NA	NA
19	11	5.0	54.5%	NA	NA	NA
23	**17**	**14**	17.6%	NA	NA	NA
24	**13**	**7.7**	40.8%	NA	NA	NA
25	**20**	**6.9**	65.5%	NA	NA	NA
Median	12	7.1	39.2%	--	--	--
Minimum	7.5	4.7	17.6%	--	--	--
Maximum	20	14	65.5%	--	--	--
Events with influent dissolved copper concentrations greater than 20 μg/L						
20	**23**	3.2	86.1%	NA	NA	NA
21	**33**	7.9	76.1%	NA	NA	NA
22	**23**	**22**	4.3%	NA	NA	NA
Median	23	7.9	76.1%	--	--	--
Minimum	23	3.2	4.3%	--	--	--
Maximum	33	22	86.1%	--	--	--
All events Combined						
Median	16	7.1	40.8%	--	--	--
Minimum	7.5	3.2	4.3%	--	--	--
Maximum	33	22	86.1%	--	--	--

Values in **bold** do not meet acute state water quality standards identified in the WAC 173-201A for dissolved copper based on the hardness concentration measured in the associated sample (see Table 13).
NA: load estimates are not availabe for these events because no associated dicharge data are available.
μg/L: microgram/liter



Note: Box plots show the median (point), 25th and 75th percentiles (box), and minimum and maximum (whiskers) of the data.

Figure 22. Influent and effluent dissolved copper concentrations measured at the SR 167 Ecology Embankment over the period from 2004 to 2005.

As shown in Table 15 and Figure 22, effluent dissolved copper concentrations were generally lower than influent concentrations across all sampled storm events. Results from a one-tailed sign test (see Appendix D, Table D1) that was applied to these data confirmed the observed decrease in effluent dissolved copper concentrations relative to influent was statistically significant ($p = 0.0004$). Across all pairs of influent and effluent samples, the median difference (i.e., influent minus effluent) in dissolved copper concentrations was 5.0 μg/L. Influent and effluent dissolved copper concentrations were also compared to Washington State's acute water quality standard (WAC 177-201A) for this parameter. Because the acute standard varies with water hardness, the actual standard that was applied to each sample was calculated based on the associated hardness concentrations (Table 13) for each influent and effluent sample, respectively. These data showed that 76 percent of both the influent and effluent samples exceeded the acute standard for dissolved copper (Table 15).

Across all sampled storm events, dissolved copper removal efficiency estimates calculated using Method #1 ranged from 4.3 to 86.1 percent, with a median value of 40.8 percent (Table 15, Figure 23). There were no significant correlations observed between these removal efficiency estimates and storm event characteristics (Appendix D, Table D9, Figure D7).

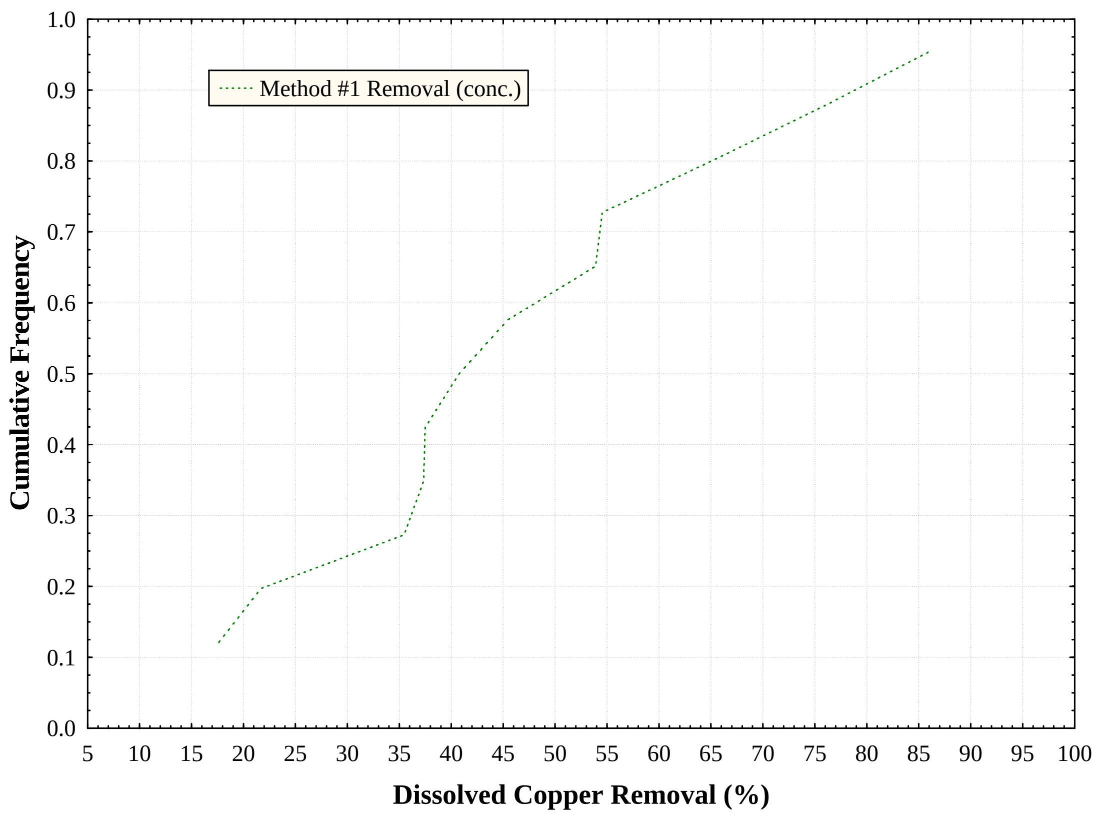


Figure 23. Cumulative frequency plot for dissolved copper removal efficiency in the SR 167 Ecology Embankment.

Turbidity

Based on data obtained from 12 storm events sampled during the Taylor and WSDOT studies, influent turbidity levels for the SR 167 Ecology Embankment ranged from 21 to 204 Nephelometric Turbidity Units (NTU), with a median value of 78.5 NTU (Table 16, Figure 24).

Table 16. Turbidity levels and removal efficiency estimates for individual sampling events at the SR 167 Ecology Embankment.

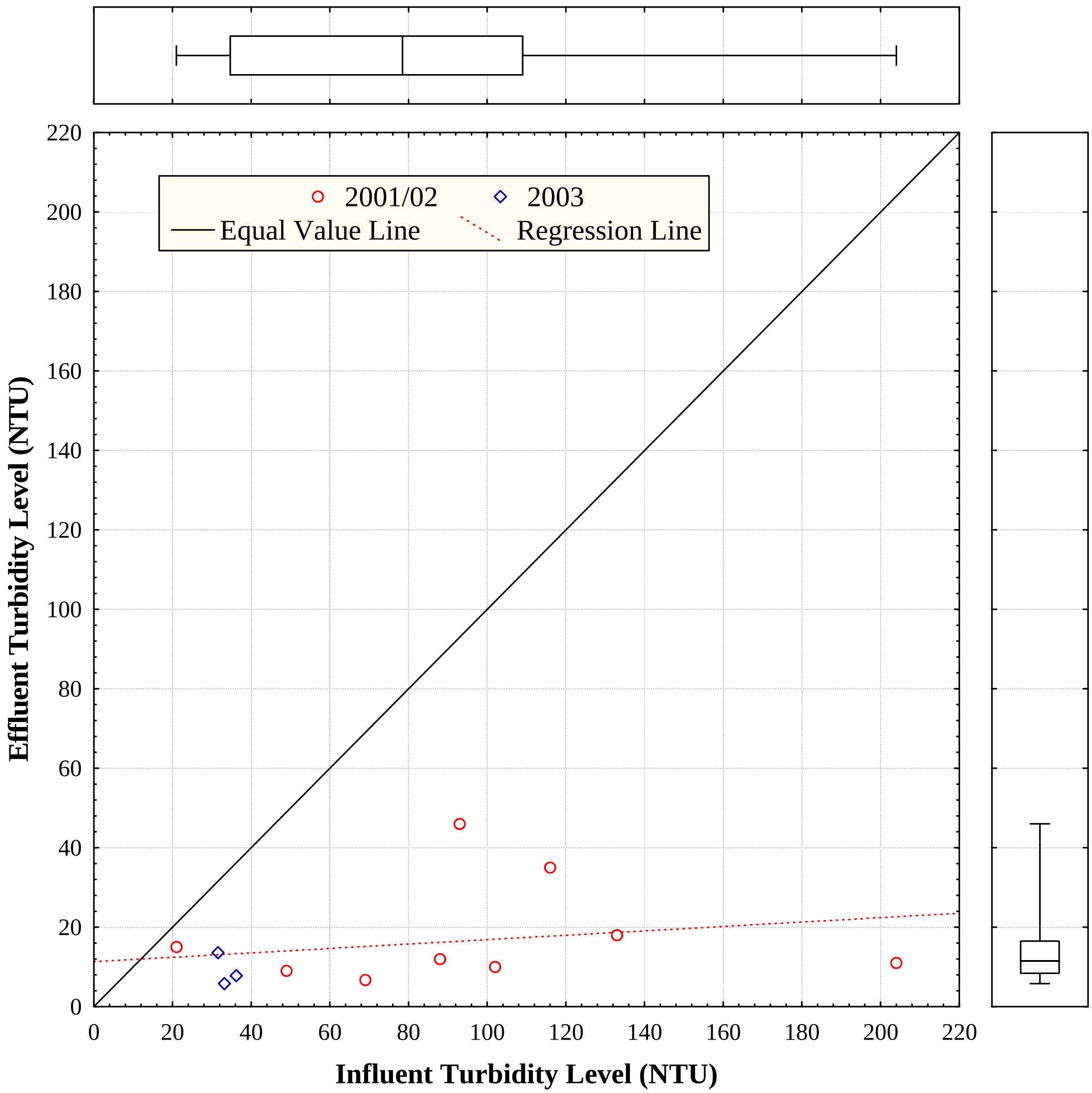
Event No.	Influent Level (NTU)	Effluent Level (NTU)	Method #1 Removal
1	88.0	12.0	86.4%
2	116	35.0	69.8%
3	93.0	46.0	50.5%
4	133	18.0	86.5%
5	21.0	15.0	28.6%
6	49.0	9.0	81.6%
7	102	10.0	90.2%
8	204	11.0	94.6%
9	69.0	6.7	90.3%
10	36.2	7.8	78.5%
11	33.2	5.8	82.5%
12	31.6	13.6	57.0%
Median	78.5	11.5	82.1%
Minimum	21.0	5.8	28.6%
Maximum	204	46.0	94.6%

NTU: Nephelometric Turbidity Unit

Across the same storm events, effluent turbidity levels ranged from 5.8 to 46.0 NTU, with a median value of 11.5 NTU. No significant correlations were observed between influent or effluent levels and storm event characteristics (Appendix D, Table D10, Figure D8).

As shown in Table 16 and Figure 24, effluent turbidity levels were markedly lower than influent levels across all sampled storm events. Results from a one-tailed sign test (see Appendix D, Table D1) that was applied to these data confirmed the observed decrease in effluent turbidity levels relative to influent was statistically significant ($p = 0.0007$). Across all pairs of influent and effluent samples, the median reduction (i.e., influent minus effluent) in turbidity levels was 54.7 NTU.

Removal efficiency estimates for turbidity were calculated from influent and effluent levels using Method #1. Across all storms, these removal efficiency estimates ranged from 28.6 to 94.6 percent, with a median value of 82.1 percent (Table 16, Figure 25). These values also exhibited a significant negative correlation ($\tau = -0.500$) with storm antecedent dry period (Appendix D, Table D10, Figure D8).



Note: Box plots show the median (point), 25th and 75th percentiles (box), and minimum and maximum (whiskers) of the data.

Figure 24. Influent and effluent turbidity levels measured at the SR 167 Ecology Embankment over the period from 2001 to 2003.

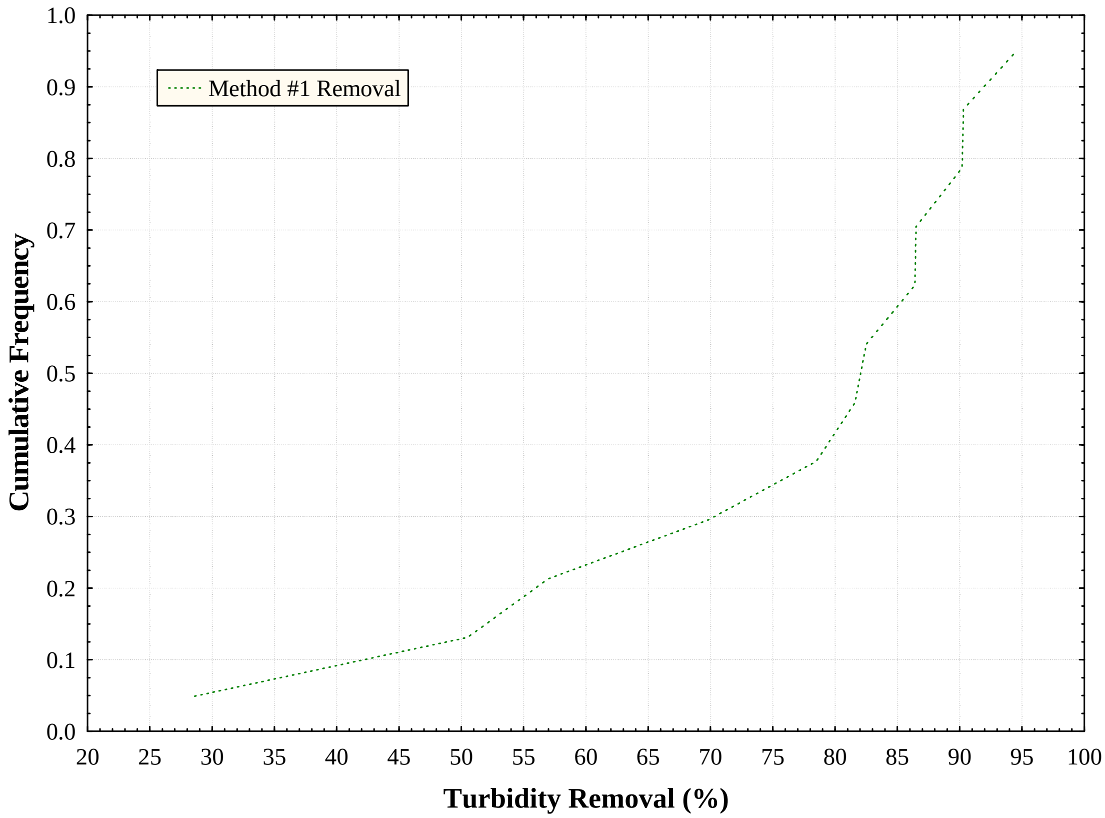
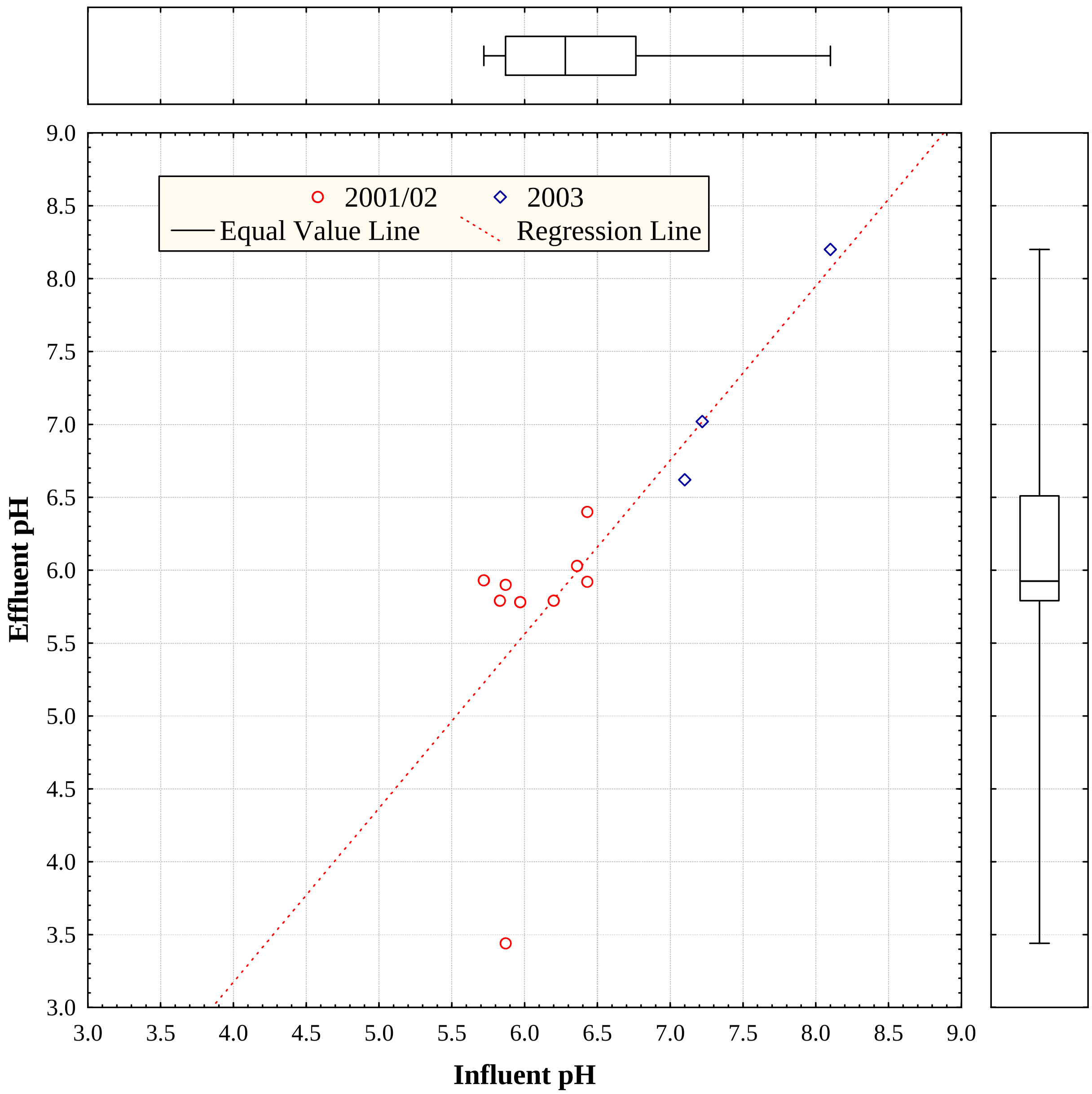


Figure 25. Cumulative frequency plot for turbidity removal efficiency in the SR 167 Ecology Embankment.

pH

Based on data obtained from 12 storm events sampled during the Taylor and WSDOT studies, influent pH levels for the SR 167 Ecology Embankment ranged from 5.72 to 8.10, with a median value of 6.28 (Table 17, Figure 26). Across the same storm events, effluent pH levels ranged from 3.44 to 8.20, with a median value of 5.93. The minimum effluent pH level appears to be an anomaly and may have resulted from residual acid remaining in the sample bottle after being washed at the laboratory (Taylor Associates 2002). No significant correlations were observed between influent or effluent pH levels and storm event characteristics (Appendix D, Table D11, Figure C9). Comparisons of the pH data to Washington State surface water quality standards (WAC 173-201A) showed that 75 percent of both the influent and effluent samples (Table 17) were below the acceptable range (i.e., 6.5 to 8.5) identified by the standard.

As shown in Table 17 and Figure 26, effluent pH levels were generally lower than influent pH levels; however, these differences were not found to be statistically significant (p 0.1489) based on the results from a two-tailed sign test (see Appendix D, Table D1). Across all pairs of influent and effluent samples, the median difference (i.e., influent minus effluent) in pH levels was 0.20.



Note: Box plots show the median (point), 25th and 75th percentiles (box), and minimum and maximum (whiskers) of the data.

Figure 26. Influent and effluent pH levels measured at the SR 167 Ecology Embankment over the period from 2001 to 2003.

Table 17. pH levels for individual sampling events at the SR 167 Ecology Embankment.

Event No.	Influent Level	Effluent Level
1	**5.97**	**5.78**
2	**6.36**	**6.03**
3	**6.43**	**5.92**
4	**5.83**	**5.79**
5	**6.43**	**6.40**
6	**5.87**	**5.90**
7	**5.87**	**3.44**
8	**5.72**	**5.93**
9	**6.20**	**5.79**
10	7.10	6.62
11	8.10	8.20
12	7.22	7.02
Median	6.28	5.93
Minimum	5.72	3.44
Maximum	8.10	8.20

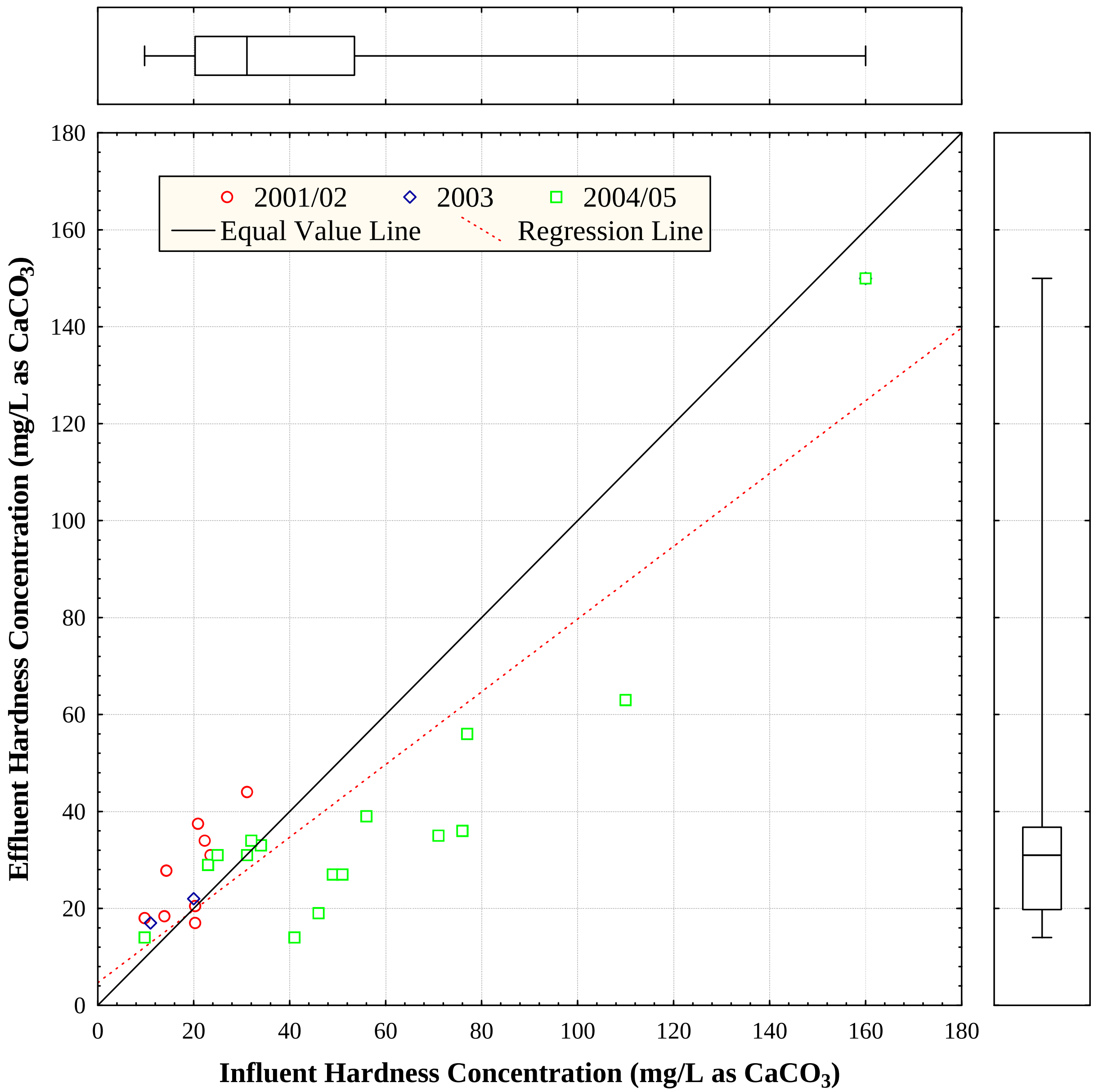
Values in **bold** do not meet state water quality standards identified in the WAC 173-201A for pH.

Hardness

Based on the data obtained from all 25 storm events, influent hardness concentrations for the SR 167 Ecology Embankment ranged from 9.8 to 160 mg/L as $CaCO_3$, with a median value of 31.1 mg/L as $CaCO_3$ (Table 13, Figure 27). Across the same storm events, effluent hardness concentrations ranged from 14.0 to 150 mg/L as $CaCO_3$, with a median value of 31.0 mg/L as $CaCO_3$. Results from the Mann Kendall test showed that influent concentrations exhibited a significant increasing trend (τ = 0.377) over the five year period of data collection (see Appendix D, Table D2). Analyses performed to evaluate potential relationships between hardness

concentrations and storm event characteristics also showed that influent concentrations exhibited a significant negative correlation with storm precipitation depth (τ = -0.469) and storm peak intensity (τ = -0.396), and a significant positive correlation (τ = 0.335) with storm antecedent dry period (Appendix D, Table D12, Figure D10). Effluent concentrations exhibited a significant negative correlation with storm precipitation depth (τ = -0.445), storm average intensity (τ = -0.460, and storm peak intensity (τ = -0.469).

As shown in Table 13 and Figure 27, differences between influent and effluent hardness concentrations were generally small. Results from a two-tailed sign test (see Appendix D, Table D1) that was applied to these data confirmed these differences were not statistically significant (p = 1.0000). Across all pairs of influent and effluent samples, the median reduction (i.e., influent minus effluent) in hardness concentrations was -0.2 mg/L as CaCO3.



Note: Box plots show the median (point), 25th and 75th percentiles (box), and minimum and maximum (whiskers) of the data.

Figure 27. Influent and effluent hardness concentrations measured at the SR 167 Ecology Embankment over the period from 2001 to 2005.

Particle Size Distribution

Particle size distribution was analyzed during the Taylor study for samples from 7 of the 9 storms. Particle size distribution summary data is provided in Table 18. The LISST particle size analyzer used only provides statistics for particles smaller than 212 microns, but estimates the mass of particles of greater size were also determined by manual sieving or filtering. Table 18 provides the mass proportion of particles smaller than 212 microns for evaluation of the particle size statistics. Where this proportion is below 100 percent, the associated D90, D50, and D10 values (sizes at which 90, 50, and 10 percent of particles are finer) may be underestimated. Two separate composite samples were analyzed for storm 1, and the results are labeled storm 1a and storm 1b.

The mass proportion of sediment greater than 212 microns in size was less than 10 percent for five of the eight influent samples analyzed. For the effluent samples, only one sample contained 10 or more percent mass of sediment particles greater than 212 microns in size. TAPE guidelines (Ecology 2004) recommend that samples be screened at 250 microns before particle size analysis, slightly greater than the maximum size of 212 microns analyzed for these samples. As a result, the particle size statistics shown in Table 18 may be underestimated where a substantial amount of material greater than 212 microns was present.

Median D90 values for all influent and effluent samples are 118.67 and 109.62 microns, respectively. Median D50 values for all influent and effluent samples are 31.99 and 19.20 microns, respectively. Median D10 values for all influent and effluent samples are 2.64 and 1.75 microns, respectively.

Table 18. Summary statistics of particle size distribution (PSD) for SR 167 Ecology Embankment water quality samples.

Storm	Station	Mass proportion smaller than 212 microns	D90[a] (microns)	D50[a] (microns)	D10[a] (microns)
1a	Influent (slot drain)	106.15%[b]	118.67	37.24	1.36
	Effluent (embankment drain)	129.70%[b]	165.26	51.86	4.33
1b	Influent (slot drain)	86.16%	118.67	26.74	4.33
	Effluent (embankment drain)	93.94%	118.67	31.56	3.11
2	Influent (slot drain)	49.29%	100.57	22.66	1.36
	Effluent (embankment drain)	95.12%	100.57	19.20	1.89
3	Influent (slot drain)	97.47%	165.26	37.24	3.67
	Effluent (embankment drain)	99.26%	118.67	22.66	1.36
4	Influent (slot drain)	99.91%	85.22	19.20	1.60
	Effluent (embankment drain)	99.58%	118.67	19.20	1.60
5	Influent (slot drain)	84.94%	165.26	61.20	9.90
	Effluent (embankment drain)	100.00%	85.22	16.27	--[c]
6	Influent (slot drain)	99.51%	140.04	43.95	6.03
	Effluent (embankment drain)	100.00%	100.57	11.69	--[c]
8	Influent (slot drain)	95.72%	100.57	19.20	1.60
	Effluent (embankment drain)	75.00%	100.57	19.20	1.60
Median	Influent (slot drain)		118.67	31.99	2.64
	Effluent (embankment drain)		109.62	19.20	1.75

[a] D90, D50, and D10 values represent the particle size at which 90, 50, and 10 percent of the total particle mass is smaller. Values represent only the particles smaller than 212 microns in size.
[b] Value is greater than 100 percent likely due to mass estimation error.
[c] Value not calculated.

Conclusions Based on Data

Study conclusions derived from the monitoring data are presented herein. This section begins with an evaluation of the SR 167 Ecology Embankment's representativeness for assessing the performance goals identified in the TAPE. Separate subsections then summarize study conclusions for each of the treatment goals that are addressed in this TEER. More specifically, these sections verify the performance claims for each treatment goal and, as necessary, provide possible explanations when a particular goal was not completely met.

Test Site Representativeness

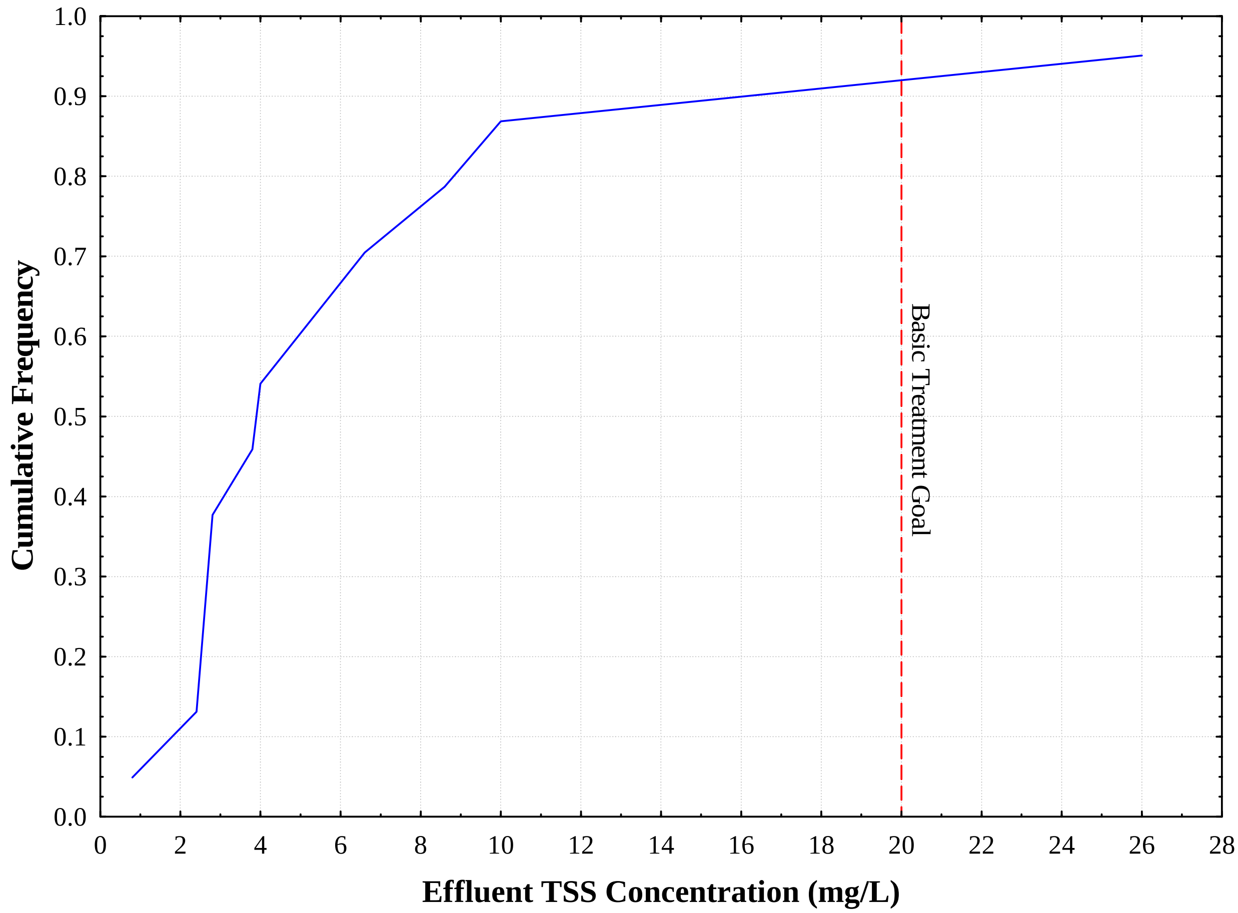
The site for the Ecology Embankment test system was chosen to represent typical rainfall patterns and traffic volumes for urban areas in the Puget Sound region. Specifically, the average annual precipitation total for the site is approximately 39.06 inches (WRCC Undated) and the AADT volume ranges from 105,000 in 2001 to 119,000 in 2004 (WSDOT 2004b).

The configuration of the Ecology Embankment test system varies slightly from the current BMP design criteria. The primary difference is the lack of a vegetated filter strip constructed upslope of the ecology-mix bed. However, presence of a 5.9-foot wide strip of grassy vegetation between the shoulder and the ecology-mix bed was observed at the test site. While this zone was not specifically designed as a vegetated filter strip, it is expected to provide a similar water quality treatment function as it exceeds the current 3-foot minimum width criterion. The Ecology Embankment configuration at the SR 167 test site is very similar to that prescribed by the current design criteria, and is adequate for assessment of pollutant removal.

Basic Treatment

TAPE guidelines (Ecology 2006) indicate that the goal for basic treatment is 80 percent removal for influent total suspended solids (TSS) concentrations that fall within the range (inclusive) from 100 to 200 milligrams per liter (mg/L). For influent concentrations that are greater than 200 mg/L, a higher treatment goal may be appropriate. For influent concentrations less than 100 mg/L, the effluent TSS concentration goal is less than 20 mg/L.

As shown in Table 8, influent concentrations were below 100 mg/L during 12 storms and above this threshold during the remaining 13 storms. Effluent concentrations for the former 12 storms are summarized in Figure 28 using a cumulative frequency plot. Summary statistics for effluent concentrations during these same storms are also provided in Table 8. These data indicate that that 20 mg/L goal established in the TAPE was only exceeded during one storm (i.e., 26 mg/L during storm 3). Effluent concentrations during the remaining 11 storms were all below 10 mg/L and the median across all twelve storms was 3.9 mg/L. These data indicate the SR 167 Ecology Embankment consistently met the basic treatment goal for influent concentrations that are less than 100 mg/L. Furthermore, the COV for the influent concentrations (0.5) indicates the 12 storms used in this evaluation are adequate for assessing this treatment goal with a confidence level of 95 percent and a power of 80 percent (see Appendix D of the TAPE).



Note: As defined in Ecology (2003), the basic treatment goal for TSS is effluent concentrations of less than 20 mg/L when influent concentrations are less than 100 mg/L.

Figure 28. Cumulative frequency plot for total suspended solids (TSS) concentrations measured in the effluent of the SR 167 Ecology Embankment when influent concentrations were less than 100 mg/L.

TSS removal efficiency estimates are summarized in Table 8 and Figure 29 for storm events with influent concentrations that are equal to or greater than the 100 mg/L threshold. Included are 13 removal efficiency estimates that were calculated using Method #1 and 4 that were calculated using Method #3. Based on the Method #1 removal efficiencies, the 80 percent goal established in the TAPE was met during every storm event except one (i.e., storm 2). It should be noted the calculated removal efficiency for this one storm (i.e., 79.3 percent) came very close to meeting the goal. The median for all 13 Method #1 removal efficiency estimates was 96.0 percent. The removal efficiencies calculated using Method #3 were all greater than the 80 percent goal and had a median value of 94.8 percent. The aggregate TSS removal efficiency calculated using Method #2 was also 95.3 percent for these storm events. These data indicate the SR 167 Ecology Embankment consistently met the basic treatment goal for influent concentrations that are equal to or greater than 100 mg/L. Furthermore, the COV for the influent concentrations (0.5) indicates the 13 storms used in this evaluation are adequate for assessing this treatment goal with a confidence level of 95 percent and a power of 80 percent (see Appendix D of the TAPE).

Removal efficiency of TSS as measured by Method #1 increased over the duration of the monitoring study. It is expected that this improvement in performance is due to collection of coarse sediment in the void spaces of the ecology-mix bed. This process reduces the infiltration rate, increases the corresponding hydraulic residence time, and also allows the media to physically filter finer sediment particles. This process is anticipated, and is the reason that the Ecology Embankment is designed using a long-term infiltration rate that is lower than the initial infiltration rate of the media.

Phosphorus Treatment

TAPE guidelines (Ecology 2004) indicate the goal for phosphorus treatment is 50 percent removal for influent total phosphorus concentrations that are greater than 0.1 mg/L but less than 0.5 mg/L. For influent concentrations that are greater than 0.5 mg/L, a higher treatment goal may be appropriate. As shown in Table 9, influent concentrations were between 0.1 and 0.5 mg/L during 20 storms, below 0.1 mg/L during 3 storms, and greater than 0.5 mg/L during the 2 remaining storms. Pollutant removal efficiency estimates for the 20 storms having the targeted influent concentration range are summarized in Figure 30 using a cumulative frequency plot. Summary statistics for removal efficiency estimates during these same storms are also provided in Table 9. Based on Method #1 removal efficiency estimates that were calculated from these data, the 50 percent removal goal established in the TAPE was met during all but two storms (i.e., 12.4 percent during storm 1 and 42.3 percent during storm 3). The median removal efficiency for total phosphorus based on these data was 86.3 percent. Method #3 removal efficiency estimates showed the 50 percent removal goal was met during all storms. The median removal efficiency estimate from these data was 74.3 percent. Finally, the aggregate total phosphorus removal efficiency estimate as calculated using Method #2 was 81.1 percent. These data indicate the SR 167 Ecology Embankment consistently met the treatment goal for phosphorus. Furthermore, the COV for the influent concentrations (0.4) indicates the 20 storms used in this evaluation are adequate for assessing this treatment goal with a confidence level of 95 percent and a power of 80 percent (see Appendix D of the TAPE).

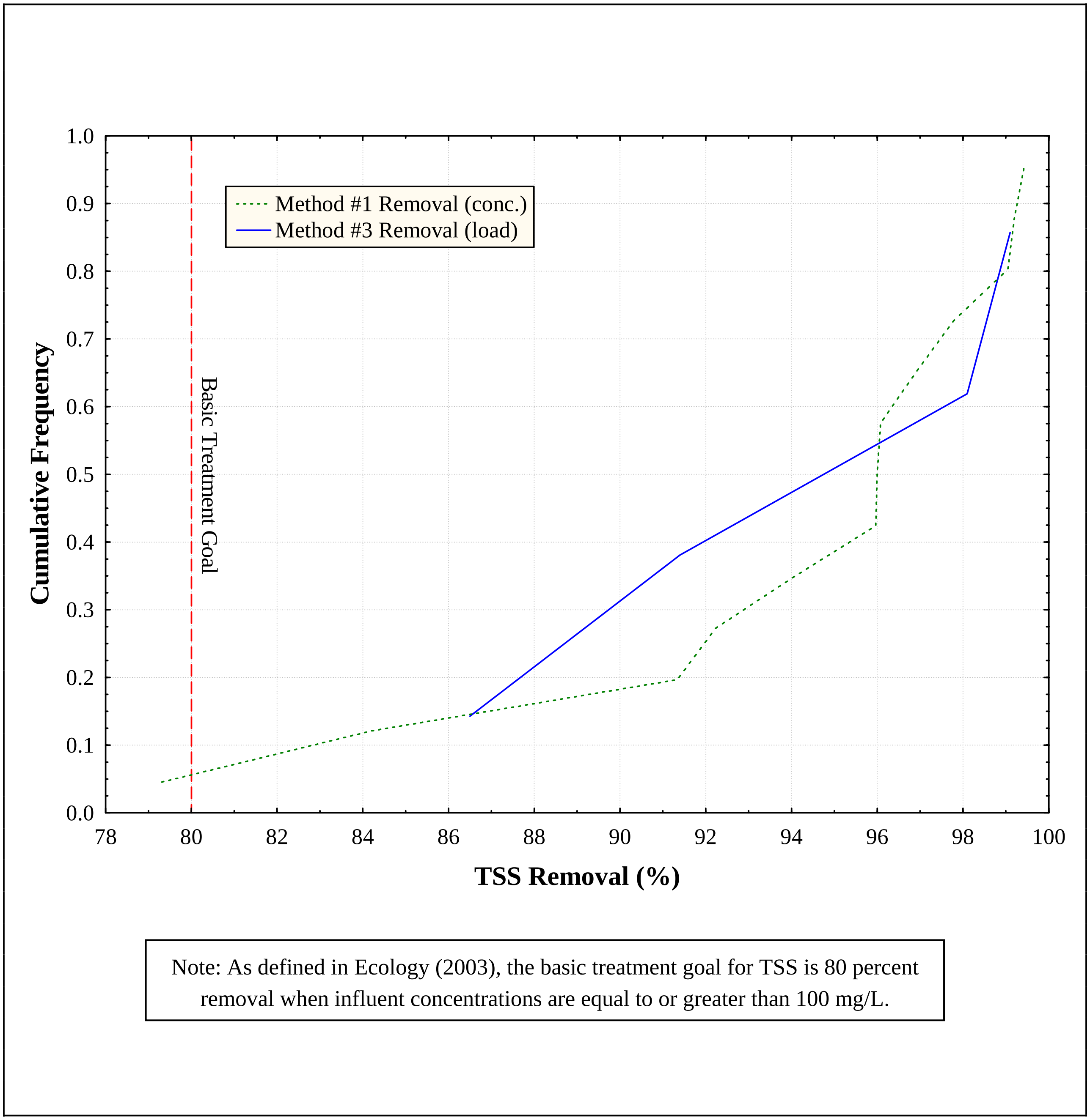


Figure 29. Cumulative frequency plot for total suspended solids (TSS) removal efficiency in the SR 167 Ecology Embankment when influent concentrations were equal to or greater than 100 mg/L.

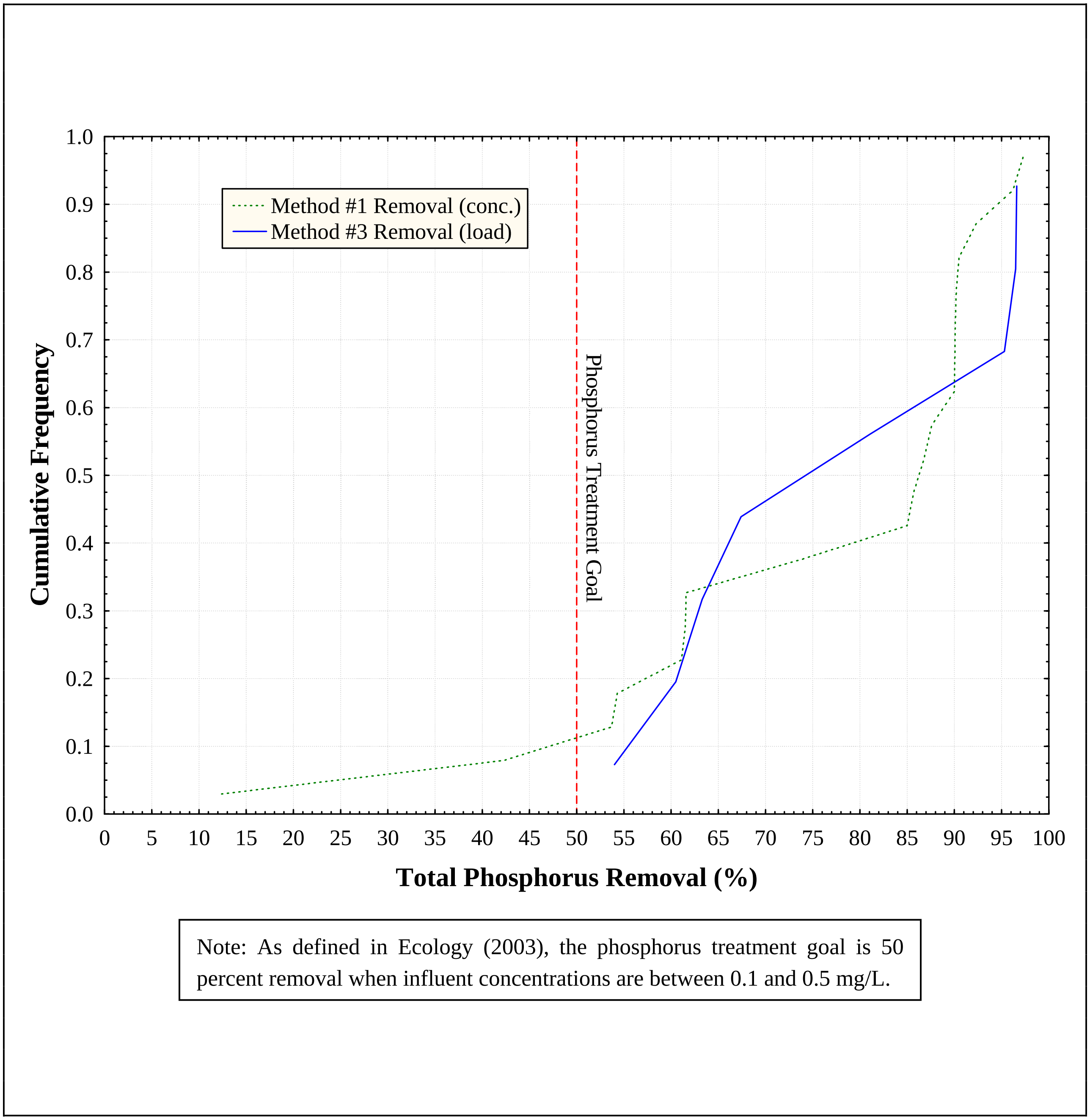


Figure 30. Cumulative frequency plot for total phosphorus removal efficiencies measured in the SR 167 Ecology Embankment when influent concentrations were between 0.1 and 0.5 mg/L.

Removal efficiency of total phosphorus as measured by Method #1 increased over the duration of the monitoring study. Much of the phosphorus present in the influent samples was in the particulate form, and therefore the reduction in infiltration rate due to sedimentation (as described in the *Basic Treatment* section above) is likely the primary cause of this trend.

An increase in effluent SRP concentrations relative to influent was also observed in the monitoring data from the Taylor study. This increase was likely caused by the transformation of removed particulate phosphorus into the dissolved phase as evidenced by the percentages of SRP that made up the total phosphorus concentration of influent and effluent samples, respectively.

Specifically, the percentage of phosphorus as SRP averaged 10 percent in influent samples whereas this percentage averaged 44 percent in effluent samples. However, it is not uncommon for soluble phosphorus to be exported from stormwater BMPs that trap sediment (CASQA 2003, Koon 1995). Of primary importance, however, is that the overall reduction in total phosphorus meets the goal identified in the TAPE for phosphorus treatment. Phosphorus can readily transform between particulate and dissolved phases in different environments. By reducing the overall source of phosphorus to a receiving water, less phosphorus is available for cycling through the system and potential biological uptake. This, in turn, will lead to an overall reduction in phosphorus related water quality problems.

Enhanced Treatment

TAPE guidelines (Ecology 2004) indicate that the data collected for an “enhanced” BMP should demonstrate significantly higher removal rates for dissolved metals than basic treatment facilities. Furthermore, the performance goal assumes that the facility is treating stormwater with dissolved zinc concentrations ranging from 20 to 300 μg/L, and dissolved copper concentrations ranging from 3 to 20 μg/L. To evaluate the monitoring results relative to this goal, dissolved zinc and copper removal efficiency data were obtained for several types of basic treatment facilities. Moreover, these data were screened to only include removal efficiency estimates that were measured when influent dissolved zinc and copper concentrations were within the ranges described above.

The primary source for data on basic treatment facility performance was the International Stormwater Best Management Practices Database (ISBMPD) that is maintained by the American Society of Civil Engineers (ASCE 2006). This database provided pollutant removal efficiency estimates for dissolved zinc and copper from 228 and 195 individual storm events, respectively. These data were obtained from monitoring that was conducted in the following types of basic treatment facilities: biofiltration systems, detention basins, media filters (e.g., sand filters), and retention ponds. Influent and effluent concentrations measured in these facilities during each of the sampled storm events are provided in Appendix G with the associated Method #1 removal efficiency estimates (see Tables G1 and G2 for dissolved zinc and copper, respectively). The cumulative frequency distribution of the Method #1 removal efficiency estimates are also show in Figures 31 and 32 for dissolved zinc and copper, respectively. Based on these data, the median removal efficiency for dissolved zinc in basic treatment facilities is 45.8 percent, while the median removal efficiency for dissolved copper is 8.3 percent.

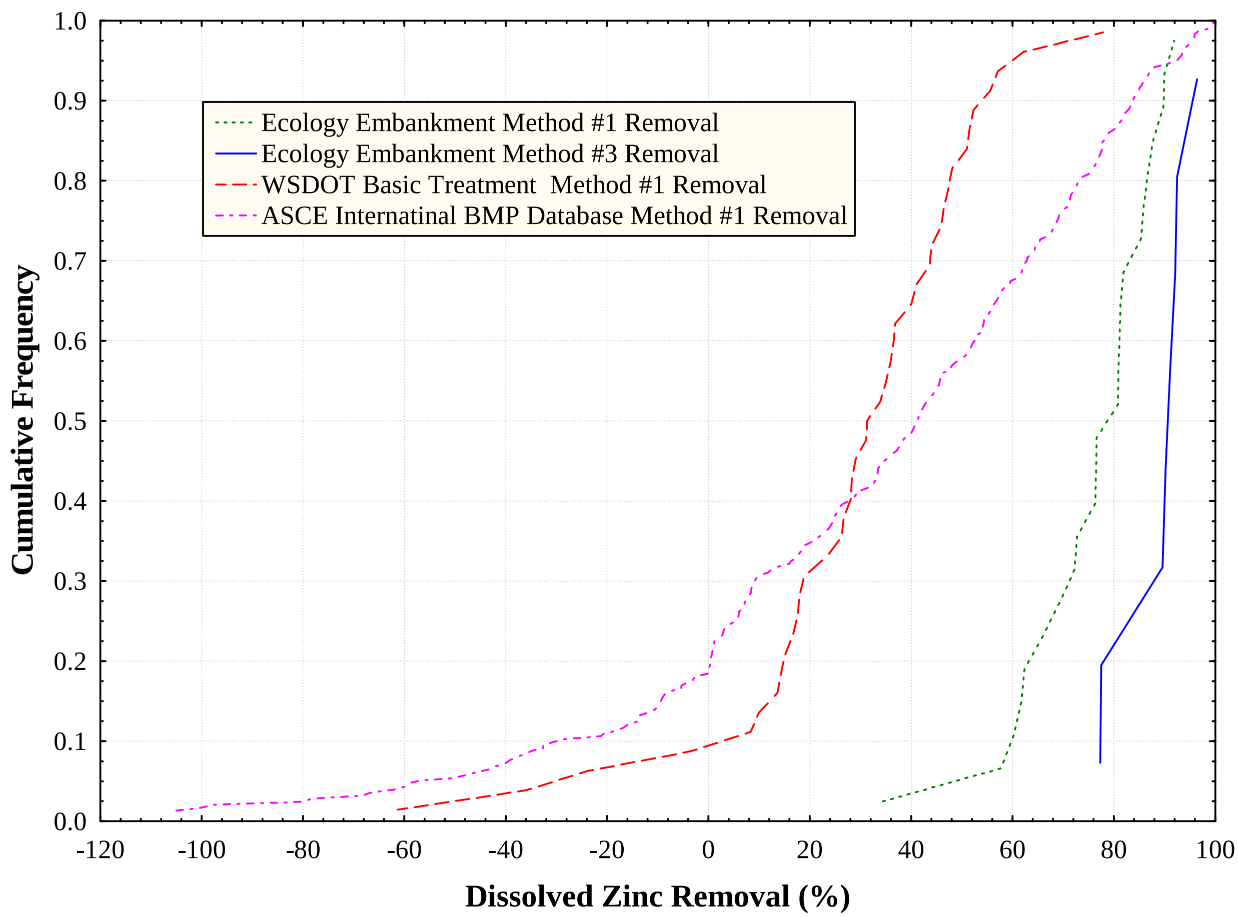


Figure 31. Cumulative frequency plot for dissolved zinc removal efficiency in basic treatment facilities (ASCE 2006, WSDOT 2006a) and the SR 167 Ecology Embankment when influent concentrations were between 20 and 300 µg/L.

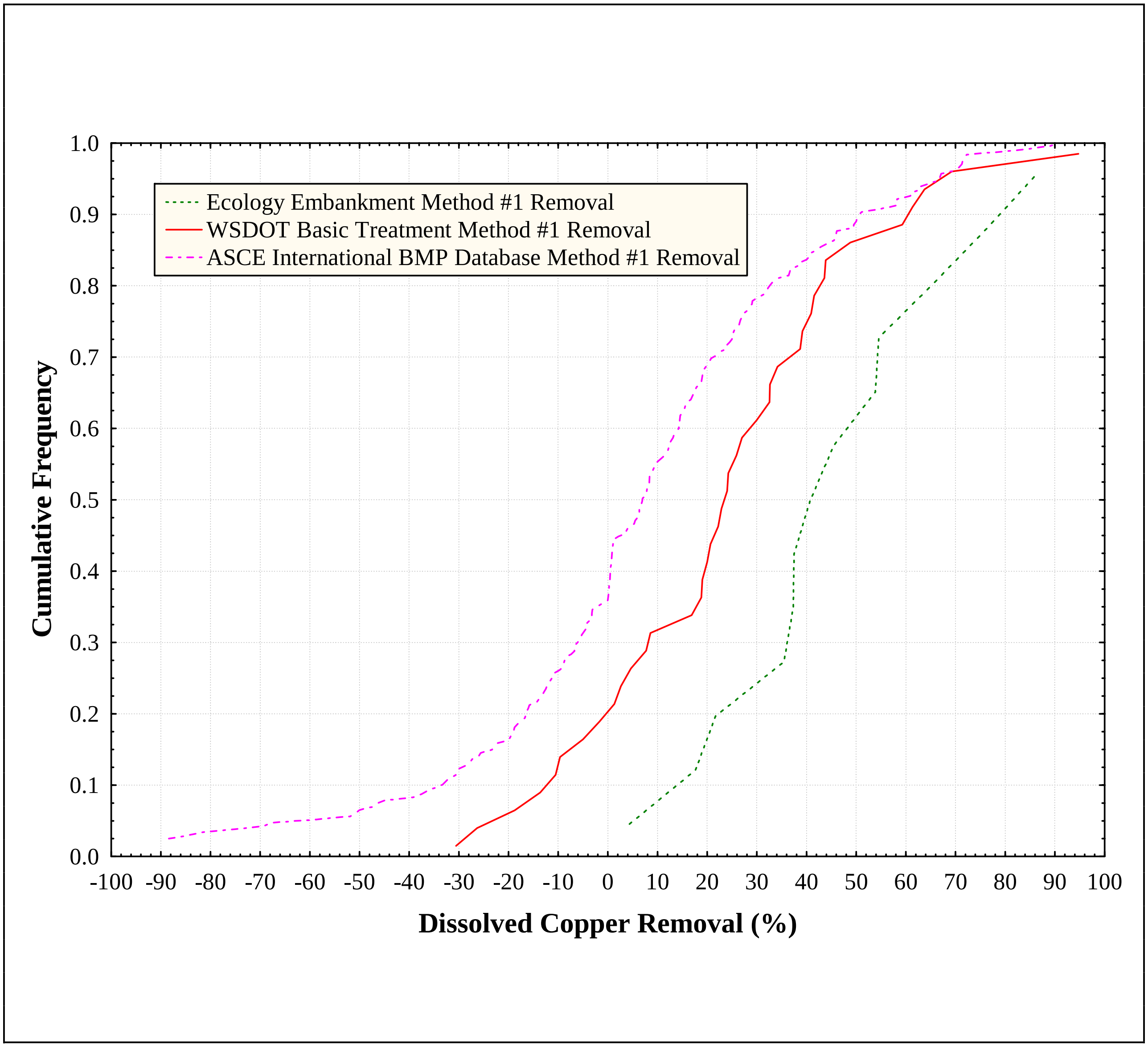


Figure 32. Cumulative frequency plot for dissolved copper removal efficiency in basic treatment facilities (ASCE 2006, WSDOT 2006a) and the SR 167 Ecology Embankment when influent concentrations were between 3 and 20 µg/L.

In addition to the above data, dissolved zinc and copper removal efficiency estimates for basic treatment facilities were also compiled from monitoring that was conducted pursuant to WSDOT's National Point Source Discharge Elimination System (NPDES) permit over the period from 2003 through 2005 (WSDOT 2006a). Included were pollutant removal efficiency estimates for dissolved zinc and copper from 41 and 40 individual storm events, respectively. These data were obtained from monitoring that was conducted in dry ponds, vaults, and wet ponds. Influent and effluent concentrations measured in these facilities during each of the sampled storm events are provided in Appendix G with the associated Method #1 removal efficiency estimates (see Tables G3 and G4 for dissolved zinc and copper, respectively). The cumulative frequency distribution of the Method #1 removal efficiency estimates are also show in Figures 31 and 32 for dissolved zinc and copper, respectively. Based on these data, the median removal efficiency for dissolved zinc in basic treatment facilities is 31.3 percent, while the median removal efficiency for dissolved copper is 23.4 percent.

Only one of the sampled storm events for the SR 167 Ecology Embankment had an influent concentration that was not within the target range (i.e., 20 to 300 μg/L) for assessing the enhanced treatment performance goal (storm 8 at 493 μg/L). Excluding this data point, dissolved zinc removal efficiency estimates calculated using Method #1 ranged from 34.4 to 91.9 percent, with a median value of 78.7 percent (Table 12, Figure 31). Similarly, removal efficiency estimates calculated using Method #3 for these storms ranged from 77.3 to 96.4 percent, with a median value of 90.7 percent (Table 12, Figure 31). Finally, the aggregate removal efficiency for dissolved zinc based on Method #2 was 89.4 percent.

As described in the Methods section, the goal identified in the TAPE for enhanced treatment was evaluated based on one-tailed Mann Whitney U tests comparing the median removal efficiency for dissolved zinc in the Ecology Embankment to the median values reported above for basic treatment facilities. Based on analyses performed using only the data from the 24 storm events with the targeted influent concentration range (i.e., 20 to 300 μg/L), results from these statistical tests showed that the median removal efficiency for dissolved zinc in the Ecology Embankment was significantly higher than the median values reported for basic treatment as calculated from both the compiled ISBMPD data ($p < 0.0001$) and WSDOT NPDES monitoring data ($p < 0.0001$). (In tests performed using data from all 25 storm events, the p-values from comparisons to the ISBMPD data and WSDOT NPDES monitoring data were both < 0.0001.) These results indicate that the Ecology Embankment meets the goal identified in the TAPE guidelines for enhanced treatment in relation to dissolved zinc. Furthermore, the COV for the influent concentrations (0.4) indicates the 24 samples used in this analysis is adequate for assessing this treatment goal with a confidence level of 95 percent and power of 80 percent (see Appendix D of the TAPE).

With regard to dissolved copper, three of the sampled storm events for the SR 167 Ecology Embankment had influent concentrations that were not within the target range (i.e., 3 to 20 μg/L) for assessing the enhanced treatment performance goal (storm 20 at 23 μg/L, storm 21 at 33 μg/L, and storm 22 at 23 μg/L). Excluding these values and considering only the remaining ten storm events with dissolved copper data, the calculated removal efficiency estimates for this parameter from Method #1 ranged from 17.6 to 65.5 percent, with a median value of 39.2

percent (Table 15, Figure 32). (Method #2 and Method #3 removal efficiency estimates cannot be calculated for these storms due to a lack of flow data for the associated samples.)

One-tailed Mann Whitney U tests were also used to compare the median removal efficiency for dissolved copper in the Ecology Embankment to the median values reported above for basic treatment facilities. Based on analyses performed using only the data from the 10 storm events with the targeted influent concentration range (i.e., 3 to 20 μg/L), results from these statistical tests showed that the median removal efficiency for dissolved copper in the Ecology Embankment was significantly higher than the median values reported for basic treatment as calculated from both the compiled ISBMPD data ($p < 0.0001$) and WSDOT NPDES monitoring data ($p = 0.0164$). (In tests performed using data from all 13 storm events, the p-values from comparisons to the ISBMPD data and WSDOT NPDES monitoring data were < 0.00001 and 0.0082, respectively.) These results indicate that the Ecology Embankment also meets the goal identified in the TAPE guidelines for enhanced treatment in relation to dissolved copper. Furthermore, the COV for the influent concentrations (0.3) indicates the 10 storms used in this analysis are adequate for assessing this treatment goal with a confidence level of 95 percent and power of 80 percent (see Appendix D of the TAPE).

Oil Treatment

Current TAPE guidelines (Ecology 2004) for oil treatment require the effluent to have no visible sheen, and total petroleum hydrocarbon concentrations must be no greater than 10 mg/L (daily average) and 15 mg/L (discrete sample). Petroleum products are hydrophobic and tend to separate from water and bond to solid materials including suspended particulates, soil, exposed vegetation and roots, as well as filter media. While no water quality monitoring was conducted at the SR 167 Ecology Embankment site for petroleum products, the system is expected to provide adequate removal of these compounds based on the treatment mechanisms involved. Specifically, treatment for petroleum products within the Ecology Embankment is expected to occur in several system components (i.e., vegetated filter strip, ecology-mix bed) that all rely on filtration. In addition, biodegradation of petroleum hydrocarbons is also expected to occur with exposure to indigenous soil microorganisms (Wisconsin DNR 1994; Zheng and Obbard 2003) and the biofilm present within the ecology mix (Wolverton, B.C. and McDonald-McCaleb 1986).

Table 19 summarizes compiled treatment effectiveness data (ACWA 2006) for petroleum hydrocarbons in two types of stormwater treatment systems that have similar removal mechanisms to the Ecology Embankment: vegetated swales and media filters. Vegetated swales and media filters generally provide good treatment performance for petroleum products, as evidenced by their associated removal efficiencies for total petroleum hydrocarbons (TPH) (median values of 49 and 47 percent, respectively). The effluent TPH concentrations reported for media filters (median value of 0.75 mg/L) are also substantially below the effluent goal identified in the TAPE guidelines for oil treatment. Based on these data, it is expected that the Ecology Embankment will also provide adequate treatment in relation to this goal.

Table 19. Removal effectiveness (in percent) and effluent concentration (in milligrams per liter [mg/L]) of vegetated swales and media filters for total petroleum hydrocarbons (TPH).

Treatment BMP	n	TPH Removal Effectiveness			TPH Effluent Concentration (mg/L)		
		Min.	Median	Max.	Min.	Median	Max.
Vegetated Swale	3	1.7%	49%	75%	NA.	NA	NA
Media Filter	7	22%	47%	87%	0.05	0.75	1.0

Source: ACWA 2006.
TPH removal represents results for gasoline, diesel, and oil fractions
n = Number of studies from which results are summarized
Min = Minimum
Max = Maximum

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APPENDIX A

As-built Drawings for the SR 167 Ecology Embankment

Washington State Department of Transportation

As Built Cover Sheet

AB 0244

Instructions: Enter all available data. Attach cover sheet to accompanying documentation and submit to:

Engineering Records
Transportation Building, Room SC-17
310 Maple Park Avenue SE
PO Box 47410
Olympia, WA 98504-47410
E-Mail: recimages@wsdot.wa.gov

General Data

Contract No. 014771	County King
Contract Title 15TH NW TO 84TH AVE SO HOV AND SC&DI STAGE 2	Federal Aid Number STATE

L No. 2183	Structure ID N/A	Job No. 95W036
Range 4E	Township 22N	Section 12

Horizontal Scale 1 Inch =	Vertical Scale 1 Inch =

Date Work Began (MM/DD/YY)	Date Work Completed (MM/DD/YY)	Contractor Name M J KUNEY CO

Project Engineer I GOLLER	Region Transportation Engineer N/A

WSF Data

Terminal Name	Vessel Name

Highway Data

Beginning Milepost SR 15.77 ☒A ☐B	Ending Milepost SR 22.39 ☐A ☒B

Construction Length Mile(s)	SR No. 167	Highway Also Known As

Bridge Data

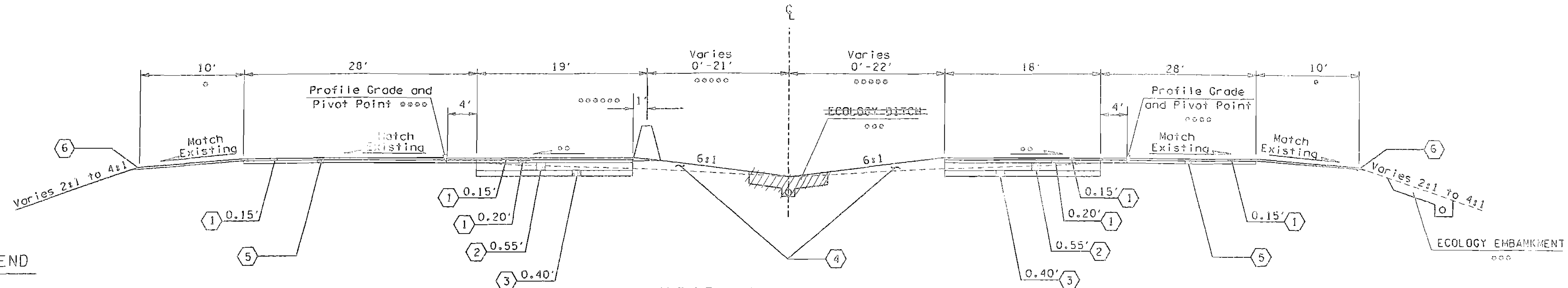
Bridge No.

Facilities Data

FCR No.

General Notes / Comments

Date Scanned (MM/DD/YY):	No. of Sheets Scanned:



ROADWAY SECTION A

STA. LM 599+10.60 TO LM 686+00

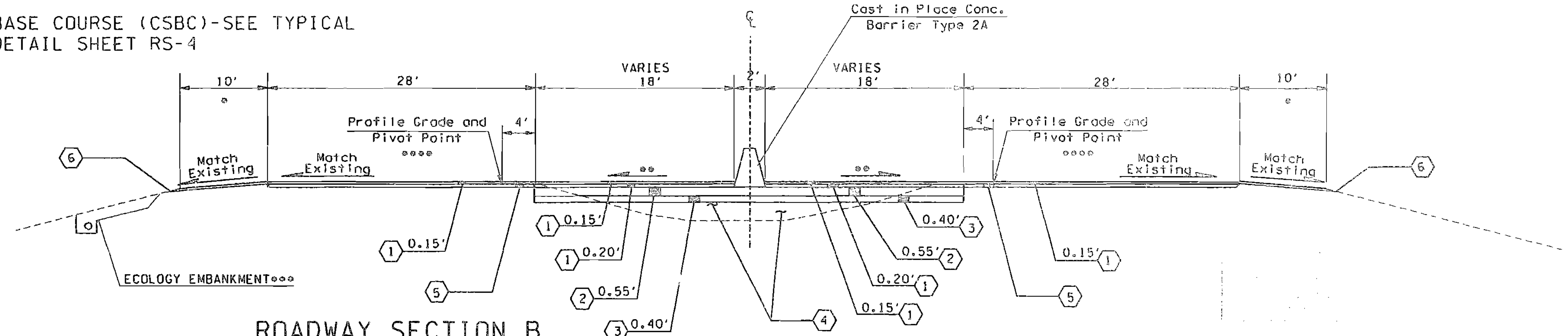
*SEE BEAM GUARDRAIL PLACEMENT DETAILS RS-4
**FOR SLOPES ON PAVEMENT WIDENING SEE ROADWAY PROFILES
***~~SEE DRAINAGE PLANS, PROFILES AND DETAILS~~
****PROFILE GRADE AND PIVOT POINT ARE LOCATED AT THE EXISTING INSIDE EDGE OF TRAVELLED WAY
*****MEDIAN TRANSITION FROM STA L 665+00 TO L 686+00. SEE PAVING PLANS.
******SEE PAVING PLAN FOR BARRIER LOCATIONS

LEGEND

1. ASPHALT CONCRETE PAVEMENT (ACP) CLASS A
2. ASPHALT TREATED BASE (ATB)
3. CRUSHED SURFACING TOP COURSE (CSTC)
4. GRAVEL BORROW
5. ASPHALT CONCRETE PAVEMENT (ACP) FOR PRELEVELING CL.G 300 TONS/LANE MILE
6. CRUSHED SURFACING BASE COURSE (CSBC)-SEE TYPICAL SHOULDER ROUNDING DETAIL SHEET RS-4

ALL DEPTHS SHOWN ARE COMPACTED DEPTHS

PLANING BITUMINOUS PAVEMENT ON THE MAINLINE SHALL BE 0.30'. SEE PAVING PLANS FOR LOCATIONS.



ROADWAY SECTION B

STA. LM 686+00 TO LM 718+40
L 773+56.78 TO L 800+78.43
L 802+68.43 TO L 813+21.45*****
L 814+79.45 TO L 832+57.57*****
L 834+48.59 TO L 841+96.37

STA. L 846+38.44 TO L 842+87.84******
L 846+02.12 TO L 858+90.02******
L 861+36.02 TO L 872+78.53
L 875+92.53 TO L 891+26.82
L 893+55.82 TO L 895+75.00

*SEE BEAM GUARDRAIL PLACEMENT DETAIL RS-4
**FOR SLOPES ON PAVEMENT WIDENING SEE ROADWAY PROFILES.
***SEE DRAINAGE PLANS, PROFILES AND DETAILS.
****PROFILE GRADE AND PIVOT POINT ARE LOCATED AT THE EXISTING INSIDE EDGE OF THE TRAVELLED WAY
*****SEE SHOULDER SECTION E
******SEE SHOULDER SECTION D

BRIDGES

BRIDGE #	LOCATION
167/121 E&W	L 771+15 TO L 773+56.78
167/122 E&W	L 800+78.43 TO L 802+68.43
167/123 E&W	L 813+21.45 TO L 814+79.45
167/124 E&W	L 832+57.57 TO L 834+48.59
167/125 E	L 841+96.37 TO L 846+38.44
167/125 W	L 842+87.84 TO L 846+02.12
167/126 E&W	L 858+90.02 TO L 861+36.02
167/127 E&W	L 872+78.53 TO L 875+92.53
167/128 E&W	L 891+26.82 TO L 893+55.82

DESIGNED BY	G. STELLMACH		
ENTERED BY	C. BERG		
CHECKED BY	M. ASKARIAN		
PROJ. ENGR.	J. JOHNSON	10/18/88	REVISED STA. LIMITS FOR ROWY. SECT. B AND BRIDGE STA. TABLE
DIST. ADM.	R.O. ANDERSON		
	DATE	DATE	REVISION

REGION NO. 10 | STATE WASH | FED. AID PROJ. NO. | JOB NUMBER 95W036 | CONTRACT NO. 4777

PROGRAM DEVELOPMENT DIVISION

Washington State Department of Transportation

SR 167
15TH NW TO 84TH AVE SO.
HOV AND SC&DI - STAGE 2

ROADWAY SECTIONS

RS-1 | SHEET 14 OF 663 SHEETS

SR 167 15TH ST NW TO 84TH AVE. S. HOV LANES AND SC&DI C.S. 176600, 176601, 176603 SHEET OF

Oct 20,1999 13:29 G:\USERS\HCK\95036\REV036T.DGN HST

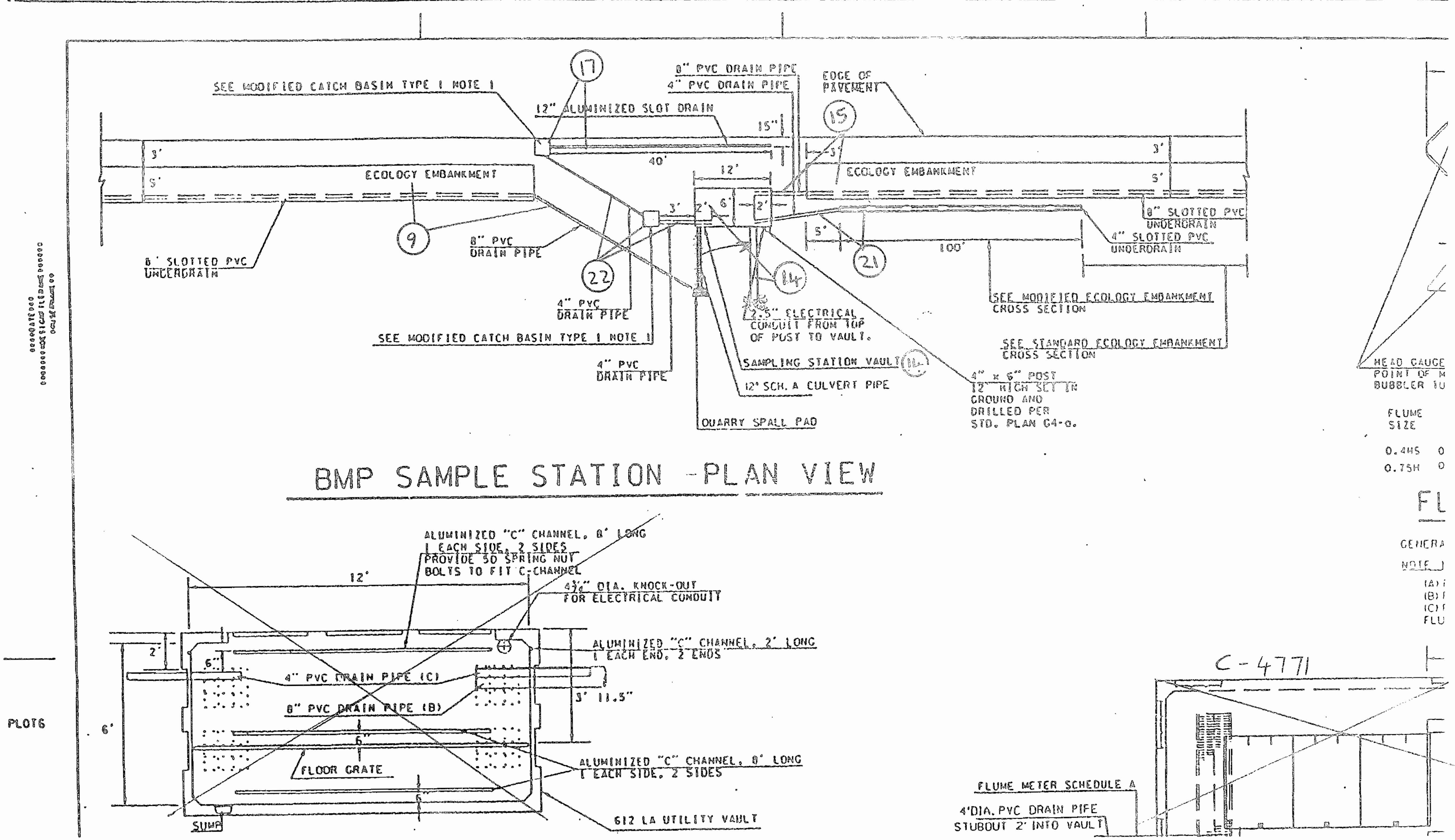
PLOT1

SR 167/91

SR 167
15TH ST. NW TO 84TH AVE S
HOV AND SC&DI - STAGE 2

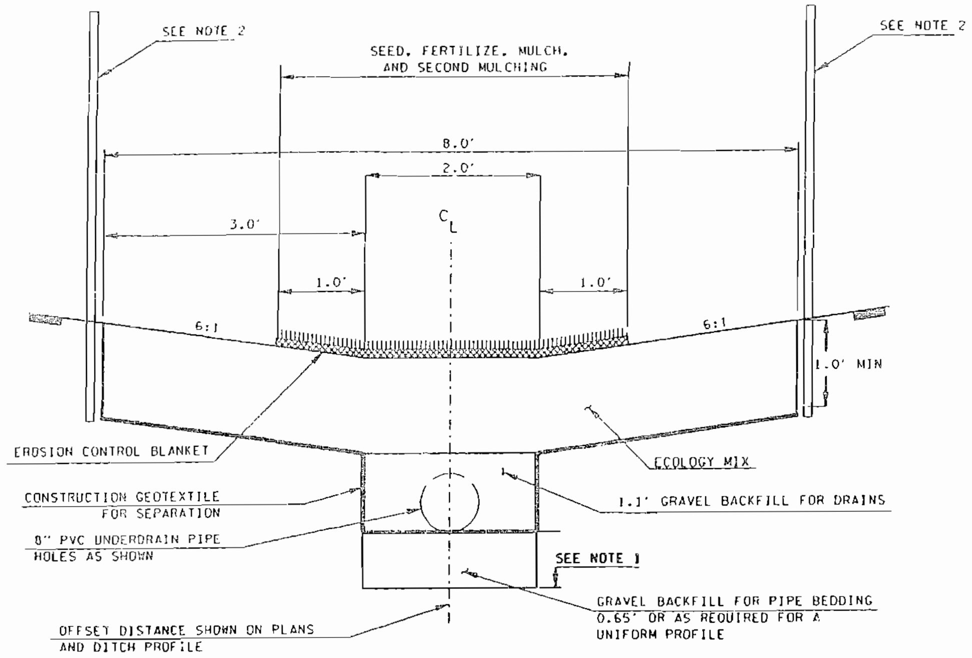
SHEET 95A

C-4771
C.O.# 40

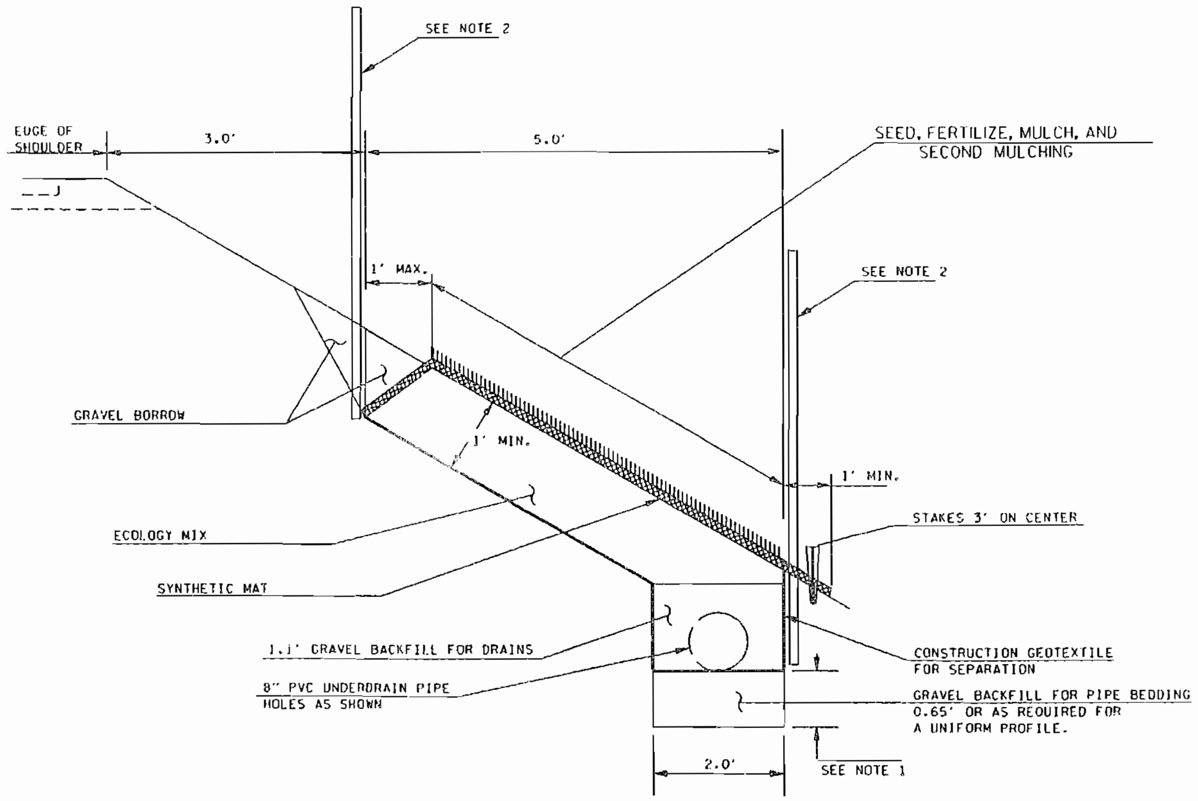


09/25/95
E:\USERS\HCK\W95036\REV036A.DGN
CARL HANSON

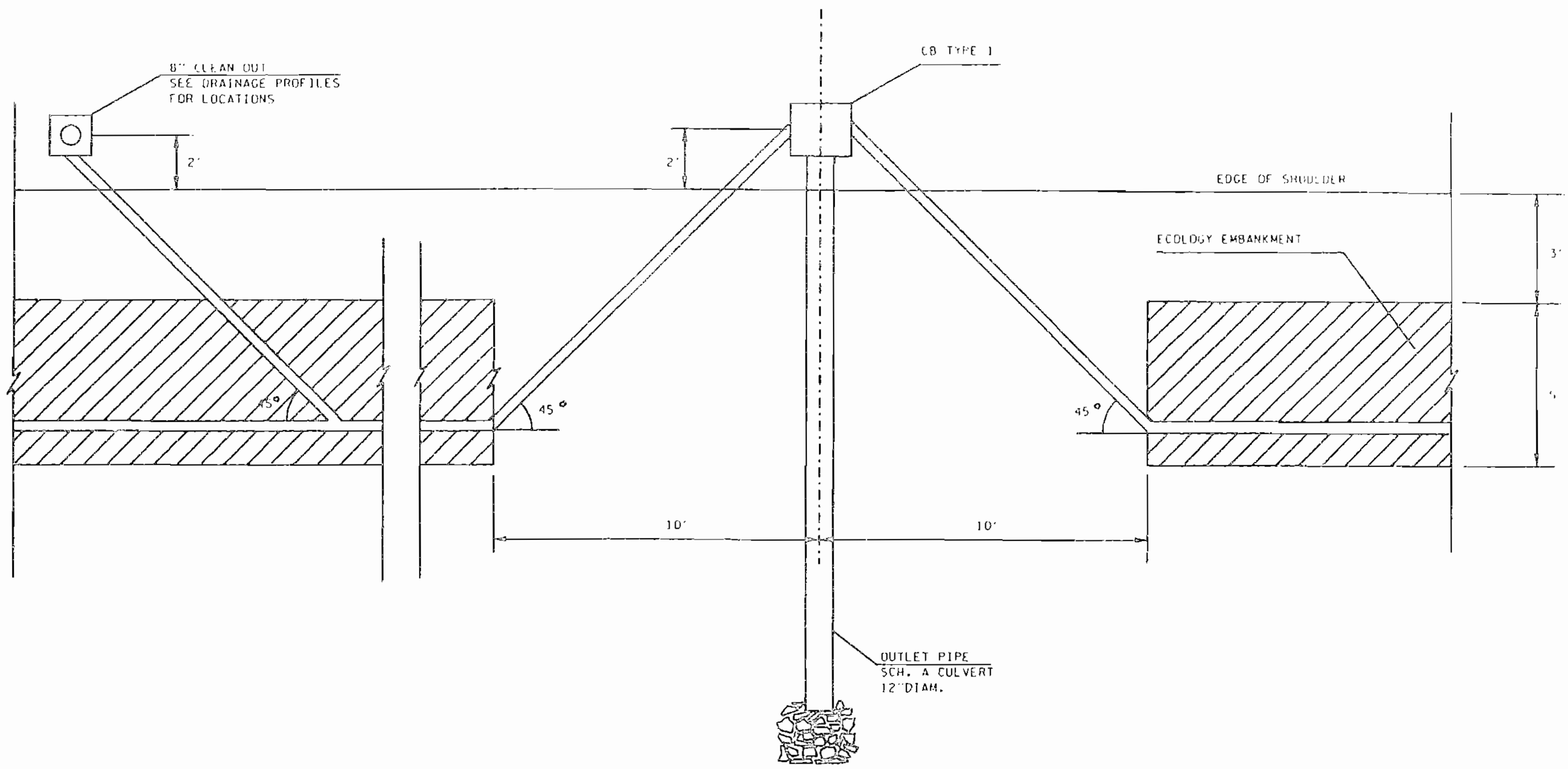
PLOT3



ECOLOGY DITCH CROSS SECTION



ECOLOGY EMBANKMENT CROSS SECTION



ECOLOGY EMBANKMENT OUTFALL DETAIL

GENERAL NOTES FOR ECOLOGY EMBANKMENT CROSS SECTION.

NOTE 1

SEE PROFILE FOR UNDERDRAIN ELEVATION AND CLEAN OUT LOCATIONS.

NOTE 2

SET FLEXIBLE GUIDE POSTS AT EACH CORNER OF THE ECOLOGY DITCH AND AT 50' STATIONS.

SR 167
15TH ST NW TO 84TH AVE. S.
HOV LANES AND SC&DI
C.S. 176600, 176601, 176603
SHEET OF

DESIGNED BY	R. EMMONS			
ENTERED BY	C. BERG			
CHECKED BY	M. ASKARIAN			
PROJ. ENGR.	J. JOHNSON			
DIST. ADM.	R.O. ANDERSON	DATE	DATE	REVISION	BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER 95W036

CONTRACT NO. 4771

PROGRAM DEVELOPMENT DIVISION

Washington State Department of Transportation

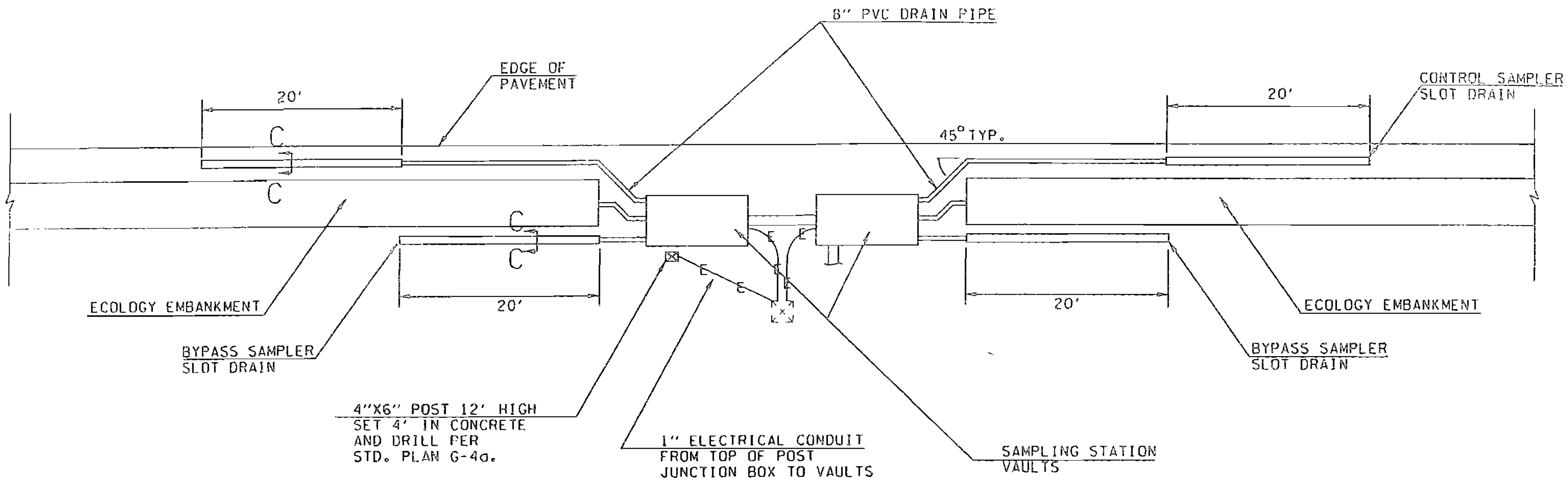
SR 167
15TH NW TO 84TH AVE SO.
HOV AND SC&DI - STAGE 2

DRAINAGE DETAILS

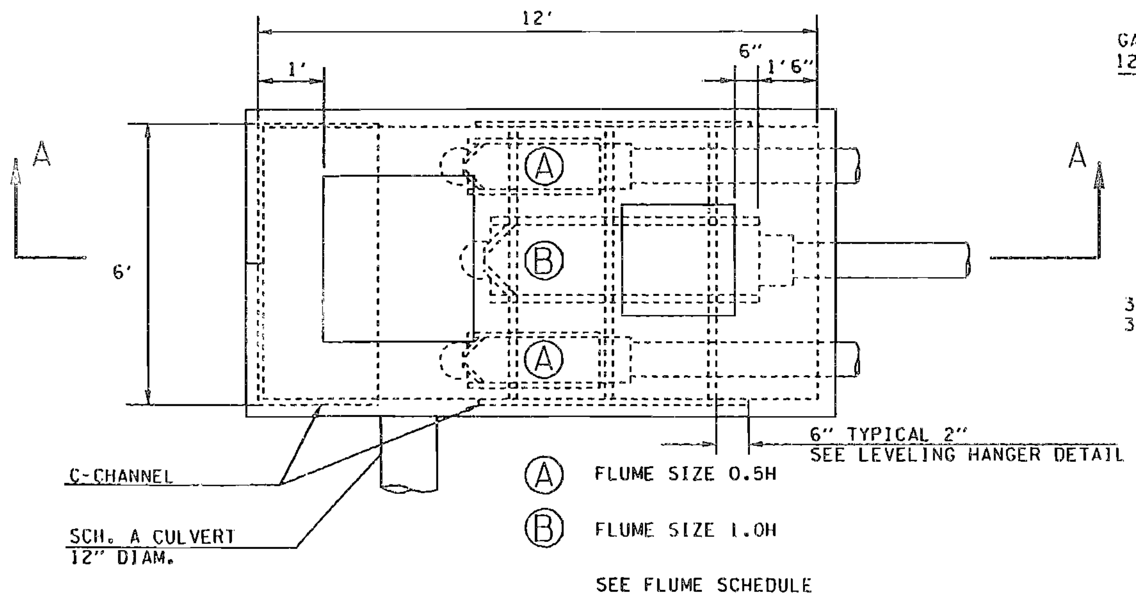
DD-4

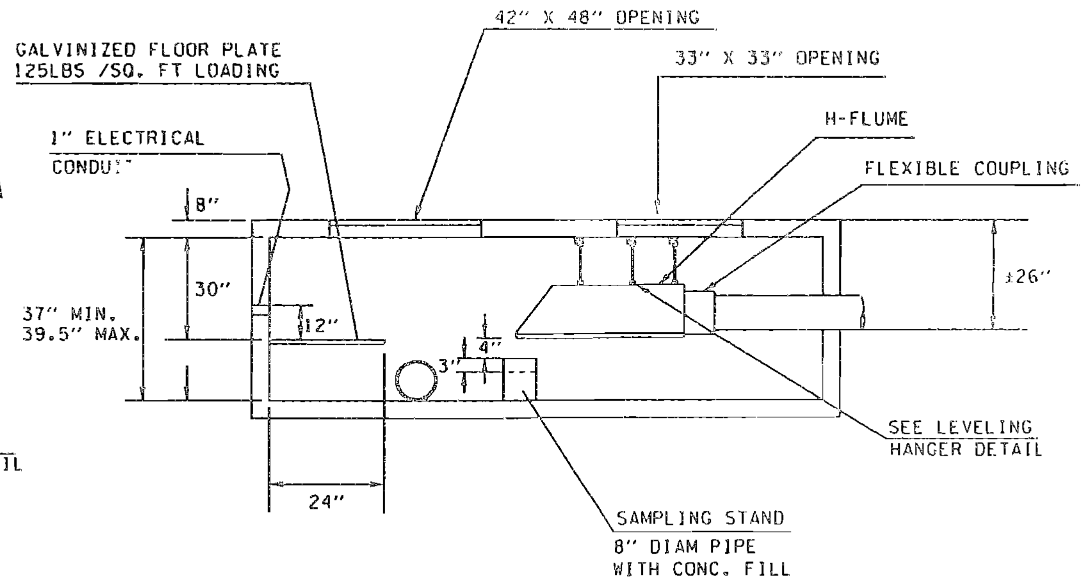
SHEET 137 OF 663 SHEETS

SR 167/91



SAMPLE STATION VAULT-PLAN VIEW





SECTION A-A

PLAN VIEW-SAMPLE STATION VAULT

DESIGNED BY	R. EMMONS			
ENTERED BY	C. BERG			
CHECKED BY	M. ASKARIAN			
PROJ. ENGR.	J. JOHNSON			
DIST. ADM.	R.O. ANDERSON	DATE	DATE	REVISION	BY

REGION NO.	STATE	FED. AID PROJ. NO.
10	WASH	
JOB NUMBER 95W036		
CONTRACT NO. 4771		

PROGRAM DEVELOPMENT DIVISION

Washington State Department of Transportation

SR 167
15TH NW TO 84TH AVE SO.
HOV AND SC&DI - STAGE 2

DRAINAGE DETAILS

DD-10
SHEET 143 OF 663 SHEETS

SR 167
15TH ST NW TO 84TH AVE. S.
HOV LANES AND SC&DI
C.S. 176600, 176601, 176603
SHEET OF

PLOT6

SR167/91

APPENDIX B

Hydrologic Data Quality Assurance Memorandum

Herrera Environmental Consultants, Inc.

Memorandum

To Project file 04-02915-004

From Dylan Ahearn and John Lenth

Date July 14, 2006

Subject Data Validation Review of SR 167 Ecology Embankment Hydrologic Monitoring Data

This memorandum presents a review of hydrologic monitoring data collected at the Ecology Embankment test system over a five year period from 2001 through 2005. This monitoring was implemented in three separate phases as follows:

- August 2001 through April 2002 – Monitoring conducted by Taylor Associates (Taylor study)
- November through December 2003 – Monitoring conducted by Washington State Department of Transportation (WSDOT) Environmental Services Office (WSDOT study)
- November 2004 through April 2005 – Monitoring conducted by Tetra Tech, Inc. (Tetra Tech study).

Because no hydrologic monitoring data were recorded during the WSDOT study, this review is limited to those data there were collected during the Taylor and Tetra Tech studies.

This memorandum initially describes the procedures that were used in this data quality review. Specific quality assurance issues that were identified through this review are then documented in the concluding section along with any associated limitations on the use and interpretation of the data.

Data Quality Review Procedures

The following procedures were used in the hydrologic data quality assurance review for the Taylor and WSDOT studies:

1. Precipitation data from each study were reviewed to identify any significant data gaps. These gaps were then filled using data obtained

from a rain gauge (32C) near Auburn, WA that is operated by King County (Undated).

2. The precipitation record was then analyzed to identify every individual storm that occurred during the monitoring period. The individual storms were defined based on a minimum 6-hour dry period separating each event. Once defined, these storms were sequentially numbered starting with the first storm in the monitoring period and progressing through the last. Summary statistics for these storm events are presented in Table A1.

3. The available discharge data from each monitoring station was then reviewed for the storm events identified in step 2 in order to assess their quality. This review included an examination of the hydrograph for each station and tabular data summaries showing both the water level and discharge data. The following issues relating to flow monitoring data accuracy were specifically examined:

    - Gaps in the data record
    - Methodologies used to convert water stage data to flow estimates
    - Inconsistencies between the influent and effluent flow monitoring data
    - Inconsistencies between the flow monitoring and precipitation data
    - Inconsistencies between the flow monitoring and sample collection time data
    - Inconsistencies in the flow monitoring data between studies.

4. If minor quality assurance issues were identified in any portion of the discharge data from a particular station and storm event, all the data from that station and event were qualified as an estimate (J). If major quality assurance issues were identified in any portion of the discharge data from a particular station and storm event, all the data from that station and event were rejected (R).

Data Quality Assurance Review Results

In general, the acquisition of accurate flow data from the SR 167 Ecology Embankment was a challenge during both the Taylor and Tetra Tech studied due to backwater conditions that frequently developed within the vault that housed the flow monitoring equipment. These conditions were a particular problem in the monitoring location for the Ecology Embankment's underdrain. Taylor Associates initially attempted to measure flow volumes at this location using an H-flume equipped with an ISCO 730 bubbler flow module; however, preliminary flow monitoring indicated the backwater conditions made use of the H-flume impractical. To remedy this, the bubbler flow module was removed and replaced with an ISCO 750 area-velocity probe. Although the area-velocity sensor is generally a good technology for measuring flow under backwater conditions, the sensor can becomes unreliable in low water, low velocity flow, or in water that does not have adequate particles concentrations to reflect the Doppler signal.

Tetra Tech did not account for the backwater conditions in their equipment set up for the Ecology Embankment underdrain. Instead, the monitoring equipment installed at this location consisted of an ISCO 730 bubbler flow module that was installed within the underdrain pipe. The measured water levels were subsequently converted to estimates of flow using the Manning's equation (roughness coefficient [n] = 0.013 and slope = 0.001). However, because the backwater conditions caused the stage in the pipe to increase without a proportional increase in discharge, flow estimates derived from the Manning's equation likely over estimated the actual flow rate during periods of monitoring. Comparisons of data from the Taylor and Tetra Tech studies indicated there were frequently gross differences in measured flow volumes for storms with approximately equal precipitation depths. These results confirmed the quality of flow monitoring data obtained during the Tetra Tech study was likely compromised due to these issues. Taylor Associates (2002) estimated that backwater conditions developed in the vault approximately 22 percent of the time in the course of their monitoring. Given this relatively high percentage, a decision was made to reject all the Tetra Tech flow monitoring data for the Ecology Embankment underdrain due to these concerns over their quality.

There were also differences in the equipment set up for the slot drain between the Taylor and Tetra Tech studies that effected data accuracy. Taylor Associates measured flow volumes from the slot drain using an ISCO 730 bubbler flow module installed in a 0.4 ft HS-flume. Both the bubbler flow module and HS-flume were installed within the vault referenced above. Tetra Tech, however, measured flow volumes from the slot drain using an ISCO 730 bubbler flow module that was installed within a 12 inch pipe in the actual slot drain as opposed to the vault. The measured water levels were again converted to estimates of flow using the Manning's equation (roughness coefficient [n] = 0.013 and slope = 0.001).

However, analyses of the data from the Tetra Tech study suggested that backwater conditions also affected the accuracy of flow estimates derived from the Manning's equation at this monitoring location. Specifically, the peak influent discharge rate measured during the Tetra Tech study was 43 cubic feet per second (cfs). Given a contributing basin area of 0.5 acres for the SR 167 Ecology Embankment and the precipitation depth of 0.63 inches, a peak discharge of 43 cfs is unreasonably high. As shown in Figure A1, a comparison of storm depth to influent discharge was also conducted for the data obtained through the Taylor and Tetra Tech studies. It is apparent from this figure that flow volume estimates from Tetra Tech study were substantially higher than those from the Taylor study for storms with approximately equal precipitation depths.

To assess whether these discrepancies were due to inaccurate estimates of inlet pipe roughness and slope, a sensitivity analyses was performed for the Tetra Tech flow estimates as derived using the Manning equation. Specifically, the slope value used in the equation was decreased 10 fold and the roughness coefficient increased by a factor of 1.7 (or from the roughness of a smooth ABS pipe to a corrugated ABS pipe). Figure A1 also shows the resultant volume estimates plotted against storm precipitation depth with data from the Taylor study provided for comparison. It is apparent from this figure that this adjustment did not completely compensate for the large discrepancies between the Tetra Tech and Talyor data sets. Thus it was concluded that the Tetra Tech flow monitoring data for the slot drain were also unreliable and should be rejected.

Additional flow monitoring data that were qualified as estimates (J) are identified in Table A2 with the associated reasoning for this designation.

References

King County. Undated. Precipitation data from the rain gauge 32U near Auburn, Washington. Department of Natural Resources. Obtained April 2006 from agency website: <http://dnr.metrokc.gov/wlr/waterres/hydrology/GaugeSelect.aspx>.

Taylor Associates. 2002. SR 167 Ecology Embankment Water Quality Monitoring Project: Final Report. Prepared for Washington Department of Transportation, Olympia, Washington by Taylor Associates, Inc., Seattle, Washington.

Table B1. Summary statistics for storm events at the SR 167 Ecology Embankment during monitoring conducted over the period from 2001 to 2005.

Storm Start Date & Time	Storm Stop Date & Time	Storm Precipitation Depth (inch)	Storm Duration (hours)	Storm Average Intensity (inch/hour)	Storm Antecedent Dry Period (hour)
Taylor Study					
6/24/2001 12:00	6/24/2001 21:00	0.20	9	0.02	
6/25/2001 12:00	6/25/2001 13:00	0.01	1	0.01	15
6/27/2001 9:00	6/28/2001 1:00	0.80	16	0.05	44
7/15/2001 23:00	7/17/2001 5:00	0.21	30	0.01	430
7/17/2001 17:00	7/17/2001 18:00	0.01	1	0.01	12
7/19/2001 4:00	7/19/2001 5:00	0.01	1	0.01	34
7/21/2001 12:00	7/21/2001 13:00	0.01	1	0.01	55
7/21/2001 22:00	7/21/2001 23:00	0.01	1	0.01	9
7/28/2001 2:00	7/29/2001 2:00	0.13	24	0.01	147
7/29/2001 16:00	7/29/2001 17:00	0.01	1	0.01	14
8/1/2001 19:00	8/1/2001 20:00	0.01	1	0.01	74
8/3/2001 10:00	8/3/2001 11:00	0.01	1	0.01	38
8/3/2001 22:00	8/3/2001 23:00	0.01	1	0.01	11
8/21/2001 11:00	**8/22/2001 22:00**	**1.29**	**35**	**0.04**	**432**
8/23/2001 9:00	8/23/2001 19:00	0.23	10	0.02	10
9/1/2001 8:00	9/1/2001 14:00	0.03	6	0.01	205
9/18/2001 22:00	9/19/2001 2:00	0.02	4	0.01	416
9/25/2001 16:00	**9/26/2001 16:00**	**0.49**	**24**	**0.02**	**144**
10/7/2001 22:00	10/8/2001 3:00	0.05	5	0.01	269
10/10/2001 9:00	**10/10/2001 19:00**	**0.34**	**10**	**0.03**	**55**
10/30/2001 2:00	**10/30/2001 20:00**	**0.49**	**18**	**0.03**	**6**
10/31/2001 14:00	10/31/2001 16:00	0.07	2	0.04	8
11/1/2001 5:00	11/1/2001 9:00	0.02	4	0.01	13
11/1/2001 16:00	11/1/2001 17:00	0.01	1	0.01	7
11/2/2001 0:00	11/2/2001 6:00	0.13	6	0.02	7
11/4/2001 14:00	11/5/2001 1:00	0.32	11	0.03	56
11/5/2001 9:00	11/5/2001 14:00	0.04	5	0.01	8
11/11/2001 16:00	11/11/2001 22:00	0.03	6	0.01	146
11/12/2001 7:00	11/14/2001 18:00	3.68	59	0.06	9
11/15/2001 6:00	11/15/2001 16:00	0.29	10	0.03	12
11/16/2001 0:00	11/16/2001 10:00	0.09	10	0.01	8
11/18/2001 7:00	11/18/2001 8:00	0.01	1	0.01	45

Storms in **bold** were sampled for water quality

Table B1. Summary statistics for storm events at the SR 167 Ecology Embankment during monitoring conducted over the period from 2001 to 2005 (continued).

Storm Start Date & Time	Storm Stop Date & Time	Storm Precipitation Depth (inch)	Storm Duration (hours)	Storm Average Intensity (inch/hour)	Storm Antecedent Dry Period (hour)
11/19/2001 4:00	11/20/2001 5:00	0.71	25	0.03	20
11/20/2001 15:00	11/21/2001 2:00	0.18	11	0.02	10
11/21/2001 19:00	11/22/2001 23:00	1.04	28	0.04	17
11/25/2001 9:00	11/25/2001 18:00	0.08	9	0.01	58
11/26/2001 1:00	11/26/2001 7:00	0.07	6	0.01	7
11/27/2001 7:00	11/27/2001 8:00	0.01	1	0.01	24
11/28/2001 4:00	**11/29/2001 8:40**	**1.03**	**29**	**0.03**	**21**
12/27/2001 22:00	12/28/2001 2:00	0.19	4	0.05	684
12/30/2001 23:00	12/31/2001 11:00	0.18	12	0.02	69
1/1/2002 12:00	1/2/2002 1:00	0.53	13	0.04	25
1/3/2002 9:00	1/3/2002 10:00	0.01	1	0.01	32
1/5/2002 5:00	1/5/2002 8:00	0.02	3	0.01	43
1/5/2002 17:00	1/6/2002 0:00	0.10	7	0.01	9
1/6/2002 12:00	**1/7/2002 10:00**	**1.05**	**22**	**0.05**	**13**
1/23/2002 22:00	1/26/2002 4:00	2.03	54	0.04	395
1/26/2002 16:00	1/26/2002 17:00	0.01	1	0.01	12
1/27/2002 11:00	1/27/2002 12:00	0.01	1	0.01	18
1/27/2002 20:00	1/27/2002 21:00	0.01	1	0.01	8
1/29/2002 6:00	1/29/2002 7:00	0.01	1	0.01	33
1/29/2002 17:00	1/30/2002 7:00	0.25	14	0.02	10
1/30/2002 14:00	1/30/2002 16:00	0.02	2	0.01	7
1/31/2002 0:00	1/31/2002 14:00	0.35	14	0.03	8
2/1/2002 5:00	2/1/2002 6:00	0.01	1	0.01	15
2/2/2002 22:00	2/3/2002 13:00	0.05	15	0	40
2/4/2002 9:00	2/4/2002 10:00	0.01	1	0.01	20
2/5/2002 11:00	2/5/2002 14:00	0.17	3	0.06	25
2/6/2002 6:00	2/7/2002 2:00	0.22	20	0.01	16
2/7/2002 11:00	2/8/2002 1:00	0.69	14	0.05	9
2/8/2002 10:00	2/8/2002 11:00	0.01	1	0.01	9
2/10/2002 17:00	2/10/2002 18:00	0.01	1	0.01	54
2/16/2002 9:00	2/16/2002 11:00	0.02	2	0.01	135
2/16/2002 17:00	2/16/2002 20:00	0.02	3	0.01	6
2/17/2002 8:00	2/17/2002 9:00	0.01	1	0.01	12

Storms in **bold** were sampled for water quality

Table B1. Summary statistics for storm events at the SR 167 Ecology Embankment during monitoring conducted over the period from 2001 to 2005 (continued).

Storm Start Date & Time	Storm Stop Date & Time	Storm Precipitation Depth (inch)	Storm Duration (hours)	Storm Average Intensity (inch/hour)	Storm Antecedent Dry Period (hour)
2/17/2002 18:00	2/18/2002 1:00	0.05	7	0.01	9
2/17/2002 18:00	2/18/2002 1:00	0.05	7	0.01	9
2/18/2002 8:00	2/19/2002 14:00	0.27	30	0.01	7
2/21/2002 0:00	2/21/2002 11:00	0.78	11	0.07	34
2/22/2002 2:00	2/22/2002 11:00	0.42	9	0.05	15
2/23/2002 5:00	2/24/2002 0:00	0.51	19	0.03	18
2/24/2002 7:00	2/24/2002 8:00	0.01	1	0.01	7
3/5/2002 1:00	3/5/2002 7:00	0.11	6	0.02	209
3/10/2002 12:00	3/10/2002 17:00	0.02	5	0	125
3/10/2002 23:00	3/11/2002 15:00	0.87	16	0.05	6
3/11/2002 22:00	3/13/2002 15:00	0.57	41	0.01	7
3/14/2002 13:00	3/14/2002 14:00	0.09	1	0.09	22
3/15/2002 3:00	3/15/2002 4:00	0.01	1	0.01	13
3/15/2002 16:00	3/15/2002 17:00	0.02	1	0.02	12
3/16/2002 9:00	3/16/2002 20:00	0.46	11	0.04	16
3/18/2002 9:00	3/18/2002 18:00	0.15	9	0.02	37
3/19/2002 9:00	**3/20/2002 10:00**	**1.04**	**25**	**0.04**	**16**
3/24/2002 8:00	3/24/2002 11:00	0.05	3	0.02	86
4/1/2002 7:00	4/1/2002 8:00	0.01	1	0.01	188
4/5/2002 20:00	4/5/2002 21:00	0.01	1	0.01	108
4/6/2002 5:00	4/6/2002 6:00	0.01	1	0.01	8
4/9/2002 6:00	**4/10/2002 6:00**	**0.45**	**24**	**0.02**	**72**
4/10/2002 13:00	4/10/2002 16:00	0.02	3	0.01	7
4/26/2002 13:00	**4/27/2002 14:00**	**0.34**	**22**	**0.02**	**96**
WSDOT Study					
11/24/2003 0:00	**11/24/2003 6:00**	**0.21**	**6**	**0.04**	**20**
11/25/2003 8:00	**11/25/2003 15:00**	**0.15**	**7**	**0.02**	**26**
11/28/2003 7:00	11/29/2003 23:00	1.53	40	0.04	64
11/30/2003 6:00	11/30/2003 7:00	0.01	1	0.01	7
12/1/2003 16:00	12/2/2003 2:00	0.12	10	0.01	33
12/2/2003 15:00	12/2/2003 16:00	0.01	1	0.01	13
12/2/2003 23:00	12/3/2003 13:00	0.34	14	0.02	7
12/4/2003 23:00	12/6/2003 0:00	0.67	25	0.03	34

Storms in **bold** were sampled for water quality

Table B1. Summary statistics for storm events at the SR 167 Ecology Embankment during monitoring conducted over the period from 2001 to 2005 (continued).

Storm Start Date & Time	Storm Stop Date & Time	Storm Precipitation Depth (inch)	Storm Duration (hours)	Storm Average Intensity (inch/hour)	Storm Antecedent Dry Period (hour)
12/4/2003 23:00	12/6/2003 0:00	0.67	25	0.03	34
12/6/2003 7:00	12/6/2003 10:00	0.20	3	0.07	7
12/7/2003 13:00	12/7/2003 20:00	0.13	7	0.02	27
12/8/2003 6:00	12/8/2003 21:00	0.14	15	0.01	10
12/9/2003 17:00	12/9/2003 18:00	0.01	1	0.01	20
12/10/2003 11:00	**12/11/2003 8:00**	**0.35**	**21**	**0.02**	**17**
Tetra Tech Study					
10/5/2004 17:00	10/6/2004 7:00	0.30	14	0.021	
10/8/2004 6:00	10/8/2004 22:00	0.92	16	0.058	47
10/9/2004 9:00	10/9/2004 18:00	0.05	9	0.006	11
10/16/2004 6:00	10/16/2004 11:00	0.21	5	0.042	156
10/16/2004 17:00	10/17/2004 23:00	0.82	30	0.027	6
10/18/2004 12:00	10/18/2004 21:00	0.07	9	0.008	13
10/19/2004 4:00	10/19/2004 12:00	0.15	8	0.019	7
10/21/2004 5:00	10/21/2004 9:00	0.08	4	0.02	41
10/22/2004 10:00	10/22/2004 11:00	0.01	1	0.01	25
10/29/2004 21:00	10/30/2004 2:00	0.05	5	0.01	178
11/1/2004 8:00	11/1/2004 21:00	0.17	13	0.013	54
11/2/2004 3:00	**11/2/2004 14:00**	**0.73**	**11**	**0.066**	**6**
11/13/2004 2:00	11/13/2004 3:00	0.01	1	0.01	252
11/14/2004 14:00	11/14/2004 15:00	0.01	1	0.01	35
11/15/2004 5:00	**11/15/2004 19:00**	**0.24**	**14**	**0.017**	**14**
11/23/2004 18:00	11/25/2004 11:00	0.72	41	0.018	191
11/26/2004 21:00	11/27/2004 7:00	0.03	10	0.003	34
11/29/2004 10:00	11/29/2004 11:00	0.01	1	0.01	51
11/29/2004 20:00	11/30/2004 23:00	0.32	27	0.012	9
12/4/2004 7:00	12/4/2004 12:00	0.09	5	0.018	80
12/4/2004 19:00	12/5/2004 1:00	0.12	6	0.02	7
12/5/2004 9:00	12/5/2004 10:00	0.01	1	0.01	8
12/6/2004 5:00	12/6/2004 11:00	0.16	6	0.027	19
12/6/2004 23:00	**12/9/2004 2:00**	**0.66**	**51**	**0.013**	**12**
12/9/2004 13:00	**12/10/2004 3:00**	**0.64**	**14**	**0.046**	**11**
12/10/2004 12:00	12/11/2004 5:00	0.49	17	0.029	9

Storms in **bold** were sampled for water quality

Table B1. Summary statistics for storm events at the SR 167 Ecology Embankment during monitoring conducted over the period from 2001 to 2005 (continued).

Storm Start Date & Time	Storm Stop Date & Time	Storm Precipitation Depth (inch)	Storm Duration (hours)	Storm Average Intensity (inch/hour)	Storm Antecedent Dry Period (hour)
12/13/2004 9:00	12/13/2004 11:00	0.07	2	0.035	52
12/13/2004 17:00	**12/13/2004 23:00**	**0.24**	**6**	**0.04**	**6**
12/14/2004 8:00	12/14/2004 13:00	0.16	5	0.032	9
12/19/2004 15:00	12/19/2004 16:00	0.03	1	0.03	122
12/25/2004 9:00	**12/25/2004 17:00**	**0.24**	**8**	**0.03**	**137**
12/25/2004 23:00	12/26/2004 0:00	0.01	1	0.01	6
12/26/2004 7:00	12/26/2004 10:00	0.02	3	0.007	7
12/27/2004 10:00	12/27/2004 11:00	0.01	1	0.01	24
12/29/2004 4:00	**12/29/2004 18:00**	**0.26**	**14**	**0.019**	**41**
12/30/2004 9:00	12/30/2004 15:00	0.04	6	0.007	15
1/1/2005 0:00	1/1/2005 4:00	0.03	4	0.008	33
1/1/2005 14:00	1/1/2005 15:00	0.01	1	0.01	10
1/1/2005 23:00	1/2/2005 0:00	0.01	1	0.01	8
1/6/2005 10:00	1/7/2005 2:00	0.21	16	0.013	106
1/7/2005 23:00	1/8/2005 5:00	0.06	6	0.01	21
1/9/2005 4:00	1/9/2005 10:00	0.04	6	0.007	23
1/15/2005 14:00	**1/16/2005 5:00**	**0.30**	**15**	**0.02**	**148**
1/17/2005 1:00	1/18/2005 21:00	2.22	44	0.05	20
1/19/2005 9:00	1/19/2005 10:00	0.01	1	0.01	12
1/20/2005 11:00	1/20/2005 19:00	0.07	8	0.009	25
1/21/2005 9:00	1/21/2005 10:00	0.01	1	0.01	14
1/22/2005 8:00	1/22/2005 9:00	0.01	1	0.01	22
1/25/2005 12:00	1/25/2005 13:00	0.01	1	0.01	75
1/26/2005 14:00	1/27/2005 4:00	0.04	14	0.003	25
1/28/2005 14:00	1/28/2005 15:00	0.01	1	0.01	34
1/31/2005 4:00	1/31/2005 5:00	0.01	1	0.01	61
2/4/2005 8:00	2/4/2005 10:00	0.11	2	0.055	99
2/6/2005 8:00	2/6/2005 20:00	0.48	12	0.04	46
2/8/2005 10:00	2/8/2005 11:00	0.01	1	0.01	38
2/12/2005 5:00	2/12/2005 13:00	0.08	8	0.01	90
2/28/2005 7:00	**3/1/2005 4:00**	**0.24**	**21**	**0.011**	**378**
3/2/2005 10:00	3/2/2005 16:00	0.08	6	0.013	30
3/9/2005 12:00	3/9/2005 14:00	0.07	2	0.035	164

Storms in **bold** were sampled for water quality

Table B1. Summary statistics for storm events at the SR 167 Ecology Embankment during monitoring conducted over the period from 2001 to 2005 (continued).

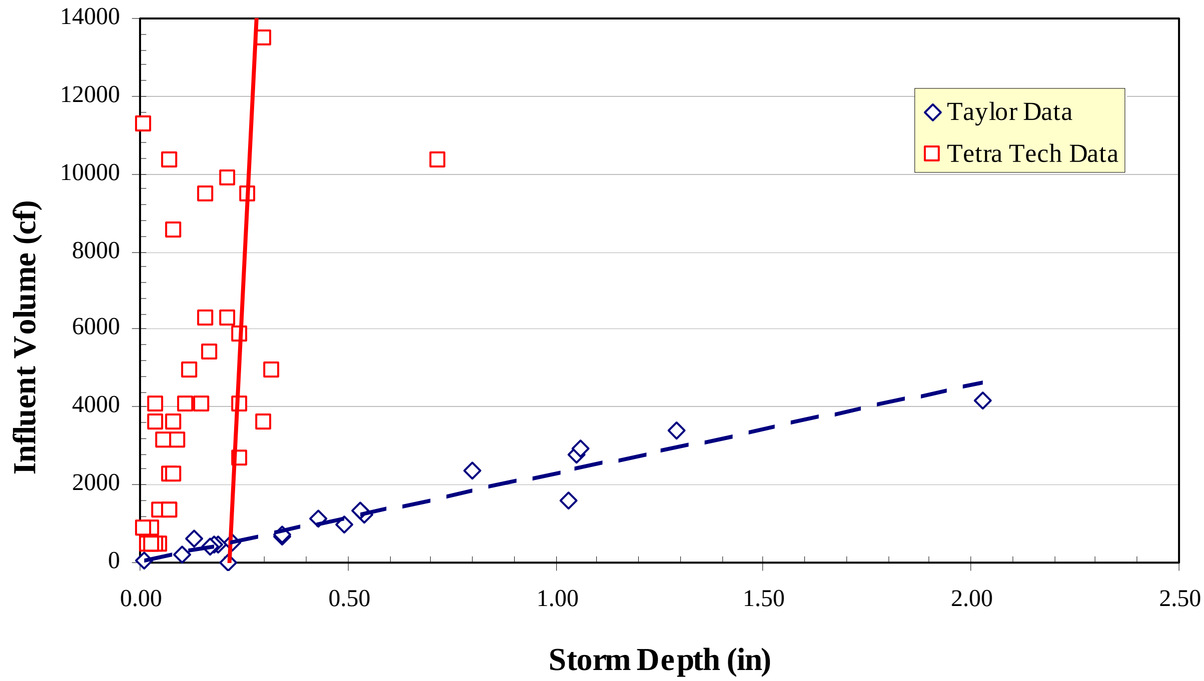
Storm Start Date & Time	Storm Stop Date & Time	Storm Precipitation Depth (inch)	Storm Duration (hours)	Storm Average Intensity (inch/hour)	Storm Antecedent Dry Period (hour)
3/16/2005 9:00	**3/16/2005 16:00**	**0.23**	**7**	**0.033**	**163**
3/26/2005 1:00	3/27/2005 18:00	1.84	41	0.045	225
3/28/2005 5:00	**3/29/2005 17:00**	**0.43**	**36**	**0.012**	**11**
3/31/2005 19:00	4/1/2005 8:00	0.37	13	0.028	50
4/1/2005 17:00	4/1/2005 22:00	0.14	5	0.028	9
4/3/2005 0:00	4/3/2005 17:00	0.27	17	0.016	26
4/5/2005 20:00	4/6/2005 6:00	0.03	10	0.003	51
4/7/2005 9:00	**4/7/2005 14:00**	**0.16**	**5**	**0.032**	**27**
4/10/2005 19:00	**4/11/2005 5:00**	**0.41**	**10**	**0.041**	**77**

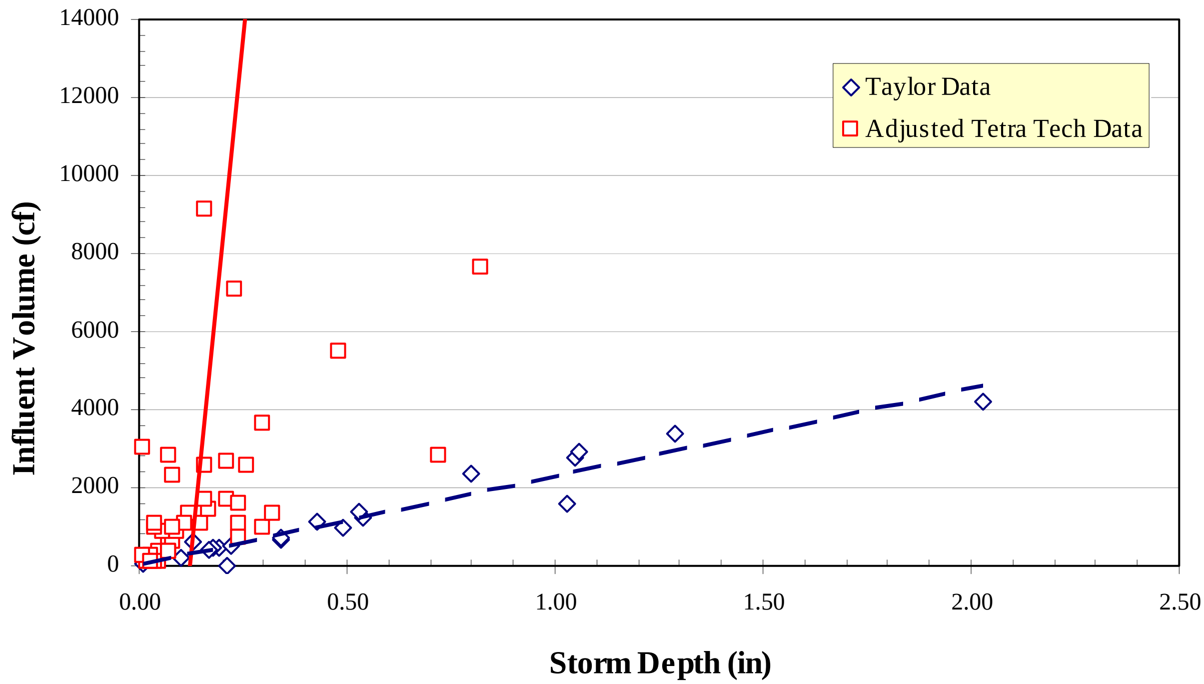
Storms in **bold** were sampled for water quality

Table B2. Flow monitoring data qualified as estimates due to quality assurance issues.

Rainfall Start Date & Time	Storm Stop Date & Time	Influent Volume (cf)	Effluent Volume (cf)	Quality Assurance Issue
8/21/2001 11:00	8/22/2001 22:00	3285	**1377**	Velocity sensor not functioning at lower flows (Taylor 2002)
9/25/01 16:00	9/26/01 17:00	**959**	**397**	Samples collected across 2 storms, storm statistics for each were combined
10/30/01 2:00	10/31/01 6:00	**1088**	**928**	Samples collected across 2 storms, storm statistics for each were combined
4/26/02 13:00	4/27/02 14:00	**714**	**92**	Samples collected across 2 storms, storm statistics for each were combined

Values in **bold** were qualified as estimates based on quality assurance review.
cf: cubic feet





Upper plot represents comparisons of actual Tetra Tech flow volume data, while the bottom plot displays the Tetra Tech flow volume data after adjusting for possible error in the inlet pipe slope and roughness

Figure B1. Relationships between storm depth and influent volume for data collected during the Taylor and Tetra Tech studies.

APPENDIX C

Water Quality Data Quality Assurance Memorandum

Herrera Environmental Consultants, Inc.

Memorandum

To	Project file 04-02915-004
cc	John Lenth
From	Gina Catarra and Rob Zisette
Date	July 14, 2006
Subject	Data Validation Review of SR 167 Ecology Embankment Water Quality Monitoring Data

This memorandum presents a review of surface water monitoring data collected at the Ecology Embankment test system over a five year period from 2001 through 2005. This monitoring was implemented in three separate phases as follows:

- August 2001 through April 2002 – Monitoring conducted by Taylor Associates (Taylor study)
- November through December 2003 – Monitoring conducted by Washington State Department of Transportation (WSDOT) Environmental Services Office (WSDOT study)
- November 2004 through April 2005 – Monitoring conducted by Tetra Tech, Inc. (Tetra Tech study).

During these studies, a total of 25 separate storm events were sampled (9 during the Taylor study, 3 during the WSDOT study, and 13 during the Tetra Tech study). Review of the initial calibration, continuing calibration, and raw data is not required and was not conducted. The laboratory's performance was reviewed in accordance with the quality control specifications outlined in: the *USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review* (Functional Guidelines) (USEPA 2004a); and the specified analytical methods (USEPA 1983, 2004b).

Taylor Study

Data validation was conducted for the water samples by Taylor Associates collected from August 2001 through April 2002 and analyzed by Aquatic Research (Seattle, WA) for the following analyses:

- Total suspended solids (USEPA Method 160.2)

- Turbidity (USEPA Method 180.1)
- Hardness (USEPA Method 130.1)
- Total and dissolved zinc analysis (USEPA Method 200.7)
- Total phosphorus and orthophosphate phosphorus (USEPA Method 365.1)
- pH (USEPA Method 150.1).

No laboratory problems were reported, and all quality control data were within the criteria as stated in the project quality assurance project plan (QAPP) (Taylor 2002).

WSDOT and Tetra Tech Studies

Six water samples collected from November through December 2003 (WSDOT study) were analyzed by STL Seattle (Tacoma, WA) and 32 water samples (including three field duplicate samples) collected from November 2004 through April 2005 (Tetra Tech study) were analyzed by OnSite Environmental, Inc. (Redmond, WA). Data validation of all water samples was conducted by Herrera Environmental Consultants for the following analyses:

- Total and dissolved zinc analyses using USEPA Method 6020 (WSDOT study)
- Total and dissolved zinc and copper analyses using USEPA Method 200.8 (Tetra Tech study)
- Total suspended solids using USEPA Method 160.2 (WSDOT and Tetra Tech studies)
- Turbidity using USEPA Method 180.1 (WSDOT study only)
- Hardness using USEPA method 130.1 (WSDOT study) and USEPA method 6010B (Tetra Tech study)
- Total phosphorus using USEPA Method 365.3 (Tetra Tech study only)
- Total phosphorus using USEPA Method 365.1 and orthophosphate phosphorus using USEPA 300A (WSDOT study)
- pH using USEPA Method 150.1 (WSDOT study only).

Quality assurance worksheets and laboratory reports are presented in Appendix E of the WSDOT Ecology Embankments Technology Evaluation and Engineering report. In addition, data quality objectives are assessed and data qualifiers defined herein.

Custody, Preservation, Holding Times, and Completeness—Acceptable

The samples were properly preserved and sample custody was maintained from sample collection to receipt at the laboratory. All samples were analyzed within the required holding times. The laboratory report was complete and contained results for all samples and tests requested on the chain-of-custody (COC) form.

Laboratory Reporting Limits—Acceptable

The detection limits reported for both the WSDOT and Tetra Tech studies are reasonable for the specified methods and no data were qualified.

Blank Analysis—Acceptable

Method (reagent) blanks were analyzed at the required frequency. The method blanks did not contain reportable levels above the practical quantitation limit (PQL) (i.e., reporting limit) for any analysis and no data have been qualified.

Laboratory Control Sample Analysis—Acceptable

Laboratory control samples were analyzed with the samples for total phosphorus (WSDOT and Tetra Tech studies), orthophosphate (WSDOT study), and total suspended solids (Tetra Tech study). The percent recovery values for total phosphorus (ranging from 84 to 110 percent), orthophosphate (ranging from 91 to 110 percent), and total suspended solids (ranging from 85 to 98 percent) met the quality control criteria (80 to 12 percent) established by functional guidelines.

Matrix Spike Sample Analysis—Acceptable with Discussion

Matrix spike/matrix spike duplicate (MS/MSD) or MS samples were analyzed by Onsite Environmental for all analyses except total suspended solids. MS samples were analyzed by STL Seattle for total and dissolved zinc, total phosphorus, and orthophosphate. With two exceptions noted below, all percent recovery values (ranging from 77 to 111 percent) met the quality control criteria (75 to 125 percent) established by functional guidelines.

A batch sample was analyzed as the total phosphorus MS sample for samples collected on 11/24/03 and 11/26/03. The percent recovery value (200 percent) exceeded the 75 to 125 percent criteria. No data were qualified because the sample analyzed as the MS was a batch sample and all other quality control criteria for total phosphorus were met.

A batch sample was analyzed as the total phosphorus MS sample for samples collected on 11/24/04. The percent recovery value (74 percent) exceeded the 75 to 125 percent criteria. No data were qualified because the sample analyzed as the MS was a batch sample and all other quality control criteria for total phosphorus were met.

Duplicate Sample Analysis—Acceptable

Matrix spike/matrix spike duplicate (MS/MSD) or laboratory duplicate samples were analyzed by Onsite Environmental for all analyses. Laboratory duplicate samples were analyzed by STL Seattle for all analyses except pH. All relative percent difference (RPD) values (ranging from 0 to 18 percent) met the quality control criteria (less than 20 percent) established by functional guidelines.

Field Duplicates—Acceptable with Qualification

Three field duplicates were collected for the Tetra Tech study. As shown in the following table, the relative percent difference (RPD) values (ranging from 0 to 20 percent) met the project criterion (RPD less than 20 percent) with the exceptions noted below.

Event Sample Date	Relative Percent Difference (percent)						
	Total Phosphorus	Hardness	Total Suspended Solids	Dissolved Copper	Dissolved Zinc	Total Copper	Total Zinc
11/30/04	0.052	0	**72**	7.3	4.8	20	13
12/13/04	4.7	6.3	**51**	**23**	19	17	**20**
12/30/04	0.006	0	NC	6.2	6.0	1.7	15

Bold value indicates relative percent difference exceeded less than 20 percent criteria.
NC Not calculable due to one or both values being less than the reporting limit.

Sample SR167EE3 was identified as a field duplicate of sample SR167EE1 for the 11/30/04 sampling event. As shown in the table above , the RPD value for total suspended solids (TSS) (72 percent) exceeded the project criterion (less than 20 percent). The TSS results for both the sample and field duplicate were qualified as estimated (flagged J).

Sample SR167EE3 was identified as a field duplicate of sample SR167EE1 for the 12/13/04 sampling event. As shown in the table above, the RPD values for TSS (51 percent), dissolved copper (23 percent), and dissolved zinc (20 percent) exceeded the project criterion (less than 20 percent). The TSS results for both the sample and field duplicate were qualified as estimated (flagged J). Dissolved copper and dissolved zinc data were not qualified because the RPD exceedance was marginal (0 to 3 percent) and all other criteria were met.

Overall Assessment of Data Quality

Usability of the data is based on the guidance documents noted previously. Upon consideration of the information presented here, the data are acceptable as qualified.

Definition of Data Qualifiers

The following data qualifier definitions are taken from *USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review* (USEPA 2004).

U The analyte was analyzed for, but was not detected above the level of the reported sample quantitation limit.

J The result is an estimated quantity. The associated value is the approximate concentration of the analyte in the sample.

UJ The analyte was analyzed for, but was not detected. The reported quantitation limit is approximate and may be inaccurate or imprecise.

R The data are unusable. The sample results are rejected due to serious deficiencies in meeting Quality Control (QC) criteria. The analyte may or may not be present in the sample.

References

Taylor. 2002. SR 167 Ecology Embankment Water Quality Monitoring Project: Final Report. Prepared for Washington State Department of Transportation, by Taylor Associates, Inc., Seattle, Washington.

USEPA. 1983. Methods for chemical analysis of water and wastes. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio. (EPA-600/4-79-020).

USEPA. 2004a. Contract laboratory program national functional guidelines for inorganic data review. U.S. Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation (OSRTI), Washington, D.C. (EPA-540-R-04-004. October 2004.

USEPA. 2004b. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. SW-846. Third Edition including Updates I, II, IIA, IIB, III, IIIA, and IIIB. U.S. Environmental Protection Agency. November 2004. Obtained from agency website: <http://www.epa.gov/SW-846/main.htm>.

APPENDIX D

Summary Tables and Figures for Water Quality Data Statistical Analyses

Table D1. Statistical analysis of differences between influent and effluent concentrations and loads based on the results from a sign test.

Parameter	Sample Size (n)	Test Type	Null Hypothesis (H_O)	Alternate Hypothesis (H_A)	p-value[a]	Median Difference[b] (Influent-Effluent)
TSS Concentration	25	One-Tailed	Effluent ≥ Influent	Effluent < Influent	**p < 0.0001**	95.0 mg/L
TSS Load	9	One-Tailed	Effluent ≥ Influent	Effluent < Influent	**p = 0.0038**	3.55 kg
Total Phosphorus Concentration	25	One-Tailed	Effluent ≥ Influent	Effluent < Influent	**p < 0.0001**	0.153 mg/L
Total Phosphorus Load	9	One-Tailed	Effluent ≥ Influent	Effluent < Influent	**p = 0.0038**	4.34 g
SRP Concentrations	9	One-Tailed	Effluent ≥ Influent	Effluent < Influent	p = 0.9088	-0.013 mg/L
SRP Load	9	One-Tailed	Effluent ≥ Influent	Effluent < Influent	p = 0.5000	-0.297 g
Total Zinc Concentration	25	One-Tailed	Effluent ≥ Influent	Effluent < Influent	**p < 0.0001**	192 µg/L
Total Zinc Load	9	One-Tailed	Effluent ≥ Influent	Effluent < Influent	**p = 0.0038**	4.97 g
Dissolved Zinc Concentration	25	One-Tailed	Effluent ≥ Influent	Effluent < Influent	**p < 0.0001**	83 µg/L
Dissolved Zinc Load	9	One-Tailed	Effluent ≥ Influent	Effluent < Influent	**p = 0.0038**	3.55 g
Total Copper Concentration	13	One-Tailed	Effluent ≥ Influent	Effluent < Influent	**p = 0.0004**	56 µg/L
Dissolved Copper Concentration	13	One-Tailed	Effluent ≥ Influent	Effluent < Influent	**p = 0.0004**	5 µg/L
Turbidity	12	One-Tailed	Effluent ≥ Influent	Effluent < Influent	**p = 0.0007**	54.7 NTU
pH	12	Two-Tailed	Effluent = Influent	Effluent ≠ Influent	p = 0.1489	0.20
Hardness	25	Two-Tailed	Effluent = Influent	Effluent ≠ Influent	p = 1.0000	-0.2 mg/L as $CaCO_3$

[a] Values in **bold** indicate the null hypothesis is rejected at a significance level of 0.05.
[b] Median difference across all pairs of influent and effluent samples.
TSS: total suspended solids
SRP: soluble reactive phosphorus
mg/L: milligram/Liter
kg: kilogram
g: gram

Table D2. Results from Mann-Kendall tests to assess temporal trends in influent and effluent concentrations and associated removal efficiencies over the period from 2001 through 2005.

Parameter	n	Influent Concentration vs. Time	Effluent Concentration vs. Time	Method #1 Removal vs. Time
Total Suspended Solids	25	0.054	**-0.378**	**0.360**
Total Phosphorus	25	0.074	**-0.578**	**0.538**
Total Zinc	25	**0.364**	0.024	**0.340**
Dissolved Zinc	25	0.107	-0.044	0.080
Hardness		**0.377**	0.208	NA

Values in **bold** indicate the Kendall's tau correlation coefficient is significantly different from zero at $\alpha = 0.05$.
NA: not applicable

Table D3. Kendall's tau correlation coefficients from comparisons of storm event characteristics to influent and effluent total suspended solids concentrations, loads, and associated removal efficiency estimates.

	Storm Precipitation Depth (inch)	Storm Average Intensity (inch/hour)	Storm Peak Intensity (inch/hour)	Storm Antecedent Dry Period (hours)	Storm Duration (hours)
Influent TSS Concentration (mg/l)	**-0.338**	-0.138	-0.040	0.057	-0.185
Effluent TSS Concentration (mg/L)	0.067	0.095	**0.342**	-0.110	-0.027
Method #1 Removal	-0.254	-0.124	**-0.346**	0.052	-0.127
Influent TSS Load (kg)	0.343	0.222	0.057	0.000	0.229
Effluent TSS Load (kg)	0.229	0.222	**0.686**	0.333	0.057
Method #3 Removal	0.000	-0.222	**-0.514**	-0.333	0.171

Values in **bold** indicate the Kendall's tau correlation coefficient for the associated variables is significantly different from zero at $\alpha = 0.05$.
TSS: total suspended solids
mg/L: milligram/liter
g: gram

Table D4. Kendall's tau correlation coefficients from comparisons of storm event characteristics to influent and effluent total phosphorus concentrations, loads, and associated removal efficiency estimates.

	Storm Precipitation Depth (inch)	Storm Average Intensity (inch/hour)	Storm Peak Intensity (inch/hour)	Storm Antecedent Dry Period (hours)	Storm Duration (hours)
Influent TP Concentration (mg/l)	-0.193	0.133	-0.071	0.026	-0.285
Effluent TP Concentration (mg/L)	0.258	0.113	**0.370**	0.009	0.183
Method #1 Removal	**-0.311**	-0.004	-0.280	-0.083	-0.264
Influent TP Load (g)	0.457	0.278	0.000	0.167	**0.514**
Effluent TP Load (g)	**0.743**	**0.556**	0.400	0.444	0.400
Method #3 Removal	-0.400	**-0.500**	**-0.743**	-0.278	-0.114

Values in bold indicate the Kendall's tau correlation coefficient for the associated variables is significantly different from zero at $\alpha = 0.05$.
TP: total phosphorus
mg/L: milligram/liter
g: gram

Table D5. Kendall's tau correlation coefficients from comparisons of storm event characteristics to influent and effluent soluble reactive phosphorus concentrations, loads, and associated removal efficiency estimates.

	Storm Precipitation Depth (inch)	Storm Average Intensity (inch/hour)	Storm Peak Intensity (inch/hour)	Storm Antecedent Dry Period (hours)	Storm Duration (hours)
Influent SRP Concentration (mg/L)	-0.286	-0.444	-0.457	0.222	0.114
Effluent SRP Concentration (mg/L)	0.114	0.056	0.114	**0.500**	-0.114
Method #1 Removal	**-0.514**	**-0.611**	**-0.572**	-0.056	0.000
Influent SRP Load (g)	0.000	-0.167	-0.400	0.389	0.286
Effluent SRP Load (g)	**0.686**	**0.500**	0.343	0.500	0.343
Method #3 Removal	-0.400	**-0.611**	**-0.686**	-0.056	0.000

Values in bold indicate the Kendall's tau correlation coefficient for the associated variables is significantly different from zero at $\alpha = 0.05$.
SRP: soluble reactive phosphorus
mg/L: milligram/liter
g: gram

Table D6. Kendall's tau correlation coefficients from comparisons of storm event characteristics to influent and effluent total zinc concentrations, loads, and associated removal efficiency estimates.

	Storm Precipitation Depth (inch)	Storm Average Intensity (inch/hour)	Storm Peak Intensity (inch/hour)	Storm Antecedent Dry Period (hours)	Storm Duration (hours)
Influent Total Zinc Concentration (µg/l)	**-0.496**	-0.156	-0.253	0.091	**-0.308**
Effluent Total Zinc Concentration (µg/L)	-0.195	-0.009	-0.085	0.101	-0.248
Method #1 Removal	**-0.341**	-0.106	-0.160	-0.017	-0.215
Influent Total Zinc Load (g)	0.457	0.111	-0.171	0.111	**0.572**
Effluent Total Zinc Load (g)	**0.572**	0.444	0.343	**0.556**	**0.514**
Method #3 Removal	-0.057	-0.278	-0.457	-0.389	0.000

Values in bold indicate the Kendall's tau correlation coefficient for the associated variables is significantly different from zero at $\alpha = 0.05$.
µg/L: microgram/liter
g: gram

Table D7. Kendall's tau correlation coefficients from comparisons of storm event characteristics to influent and effluent dissolved zinc concentrations, loads, and associated removal efficiency estimates.

	Storm Precipitation Depth (inch)	Storm Average Intensity (inch/hour)	Storm Peak Intensity (inch/hour)	Storm Antecedent Dry Period (hours)	Storm Duration (hours)
Influent Dissolved Zinc Conc. (µg/l)	-0.247	**-0.421**	-0.282	0.254	0.058
Effluent Dissolved Zinc Conc. (µg/L)	-0.071	-0.089	-0.143	0.201	-0.066
Method #1 Removal	-0.009	-0.062	0.044	0.052	0.048
Influent Dissolved Zinc Load (g)	0.400	0.056	-0.171	0.167	**0.629**
Effluent Dissolved Zinc Load (g)	**0.572**	0.389	0.286	**0.611**	**0.572**
Method #3 Removal	-0.114	-0.222	**-0.514**	-0.444	-0.057

Values in bold indicate the Kendall's tau correlation coefficient for the associated variables is significantly different from zero at $\alpha = 0.05$.
µg/L: microgram/liter
g: gram

Table D8. Kendall's tau correlation coefficients from comparisons of storm event characteristics to influent and effluent total copper concentrations and associated removal efficiency estimates.

	Storm Precipitation Depth (inch)	Storm Average Intensity (inch/hour)	Storm Peak Intensity (inch/hour)	Storm Antecedent Dry Period (hours)	Storm Duration (hours)
Influent Total Copper Conc. (µg/l)	**-0.588**	0.081	0.013	0.219	-0.275
Effluent Total Copper Conc. (µg/L)	-0.106	0.055	0.013	-0.144	-0.172
Method #1 Removal	-0.275	-0.081	0.013	0.219	0.065

Values in bold indicate the Kendall's tau correlation coefficient for the associated variables is significantly different from zero at $\alpha = 0.05$.
µg/L: microgram/liter

Table D9. Kendall's tau correlation coefficients from comparisons of storm event characteristics to influent and effluent dissolved copper concentrations and associated removal efficiency estimates.

	Storm Precipitation Depth (inch)	Storm Average Intensity (inch/hour)	Storm Peak Intensity (inch/hour)	Storm Antecedent Dry Period (hours)	Storm Duration (hours)
Influent Dissolved Copper Conc. (μg/l)	-0.336	-0.306	**-0.531**	**0.702**	0.094
Effluent Dissolved Copper Conc. (μg/L)	-0.222	-0.271	-0.358	0.194	-0.013
Method #1 Removal	-0.065	-0.081	-0.146	0.400	0.065

Values in bold indicate the Kendall's tau correlation coefficient for the associated variables is significantly different from zero at $\alpha = 0.05$.
μg/L: microgram/liter

Table D10. Kendall's tau correlation coefficients from comparisons of storm event characteristics to influent and effluent turbidity levels and associated removal efficiency estimates.

	Storm Precipitation Depth (inch)	Storm Average Intensity (inch/hour)	Storm Peak Intensity (inch/hour)	Storm Antecedent Dry Period (hours)	Storm Duration (hours)
Influent Turbidity Level (NTU)	-0.229	-0.333	-0.229	-0.222	-0.171
Effluent Turbidity Level (NTU)	-0.229	-0.167	0.229	0.389	-0.114
Method #1 Removal	-0.114	-0.278	-0.343	**-0.500**	0.000

Values in bold indicate the Kendall's tau correlation coefficient for the associated variables is significantly different from zero at $\alpha = 0.05$.
NTU: Nephelometric Turbidity Unit

Table D11. Kendall's tau correlation coefficients from comparisons of storm event characteristics to influent and effluent pH levels.

	Storm Precipitation Depth (inch)	Storm Average Intensity (inch/hour)	Storm Peak Intensity (inch/hour)	Storm Antecedent Dry Period (hours)	Storm Duration (hours)
Influent pH Level	-0.059	0.000	-0.059	0.457	0.059
Effluent pH Level	-0.145	-0.197	-0.029	0.028	0.029

Values in bold indicate the Kendall's tau correlation coefficient for the associated variables is significantly different from zero at $\alpha = 0.05$.

Table D12. Kendall's tau correlation coefficients from comparisons of storm event characteristics to influent and effluent hardness concentrations.

	Storm Precipitation Depth (inch)	Storm Average Intensity (inch/hour)	Storm Peak Intensity (inch/hour)	Storm Antecedent Dry Period (hours)	Storm Duration (hours)
Influent Hardness Conc. (mg/L as $CaCO_3$)	**-0.469**	-0.120	**-0.396**	**0.335**	-0.299
Effluent Hardness Conc. (mg/L as $CaCO_3$)	**-0.445**	**-0.460**	**-0.469**	**0.459**	-0.088

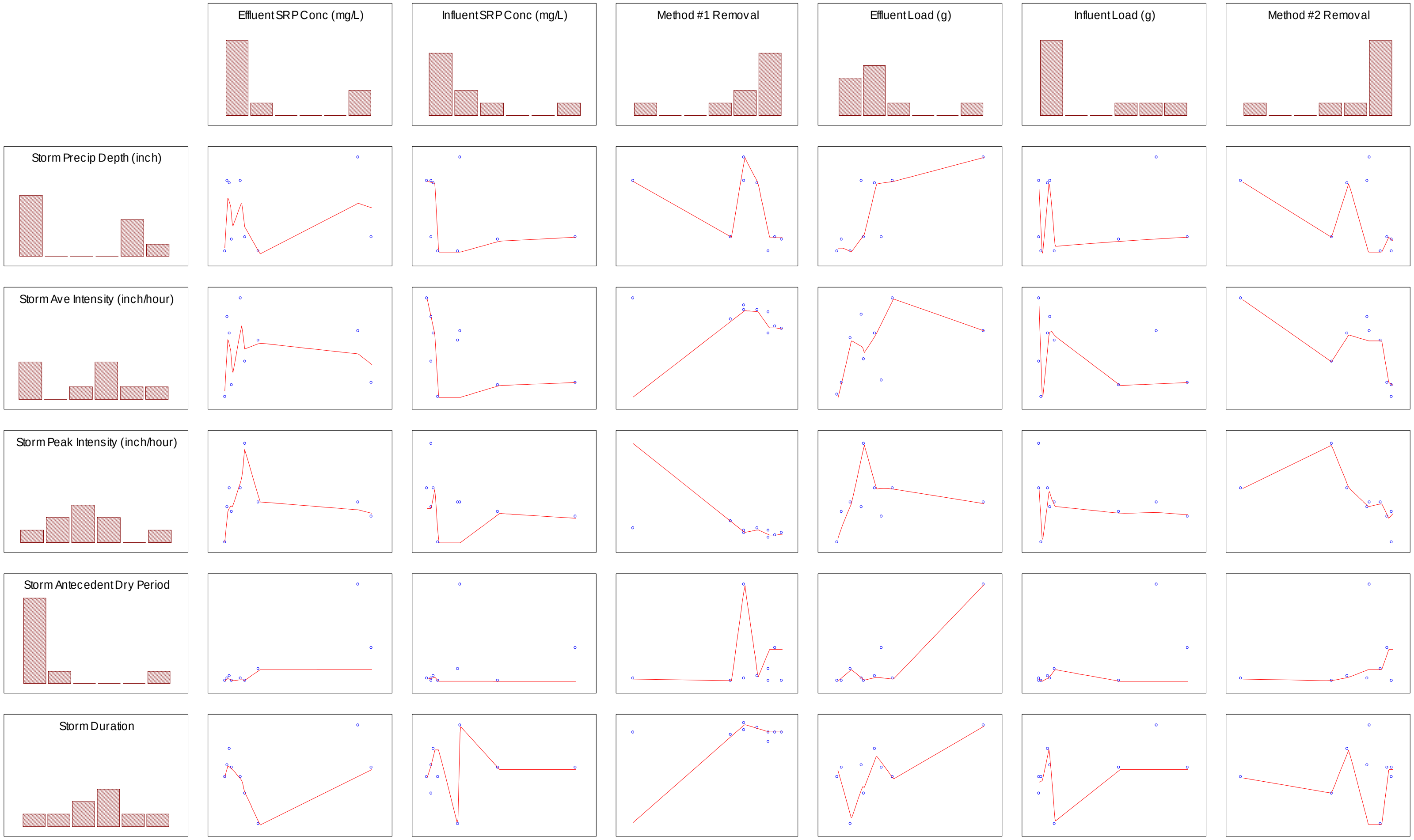
Values in bold indicate the Kendall's tau correlation coefficient for the associated variables is significantly different from zero at $\alpha = 0.05$.
mg/L: milligram/liter

Note: Lines in each plots represent a Locally Weighted Scatterplot Smooth (LOWESS) through the data

Figure D1. Matrix scatter plot comparing storm event characteristics to influent and effluent total suspended solids (TSS) concentrations, loads, and associated removal efficiency estimates.

Note: Lines in each plots represent a Locally Weighted Scatterplot Smooth (LOWESS) through the data

Figure D2. Matrix scatter plot comparing storm event characteristics to influent and effluent total phosphorus (TP) concentrations, loads, and associated removal efficiency estimates.



Note: Lines in each plots represent a Locally Weighted Scatterplot Smooth (LOWESS) through the data

Figure D3. Matrix scatter plot comparing storm event characteristics to influent and effluent soluble reactive phosphorus (SRP) concentrations, loads, and associated removal efficiency estimates.

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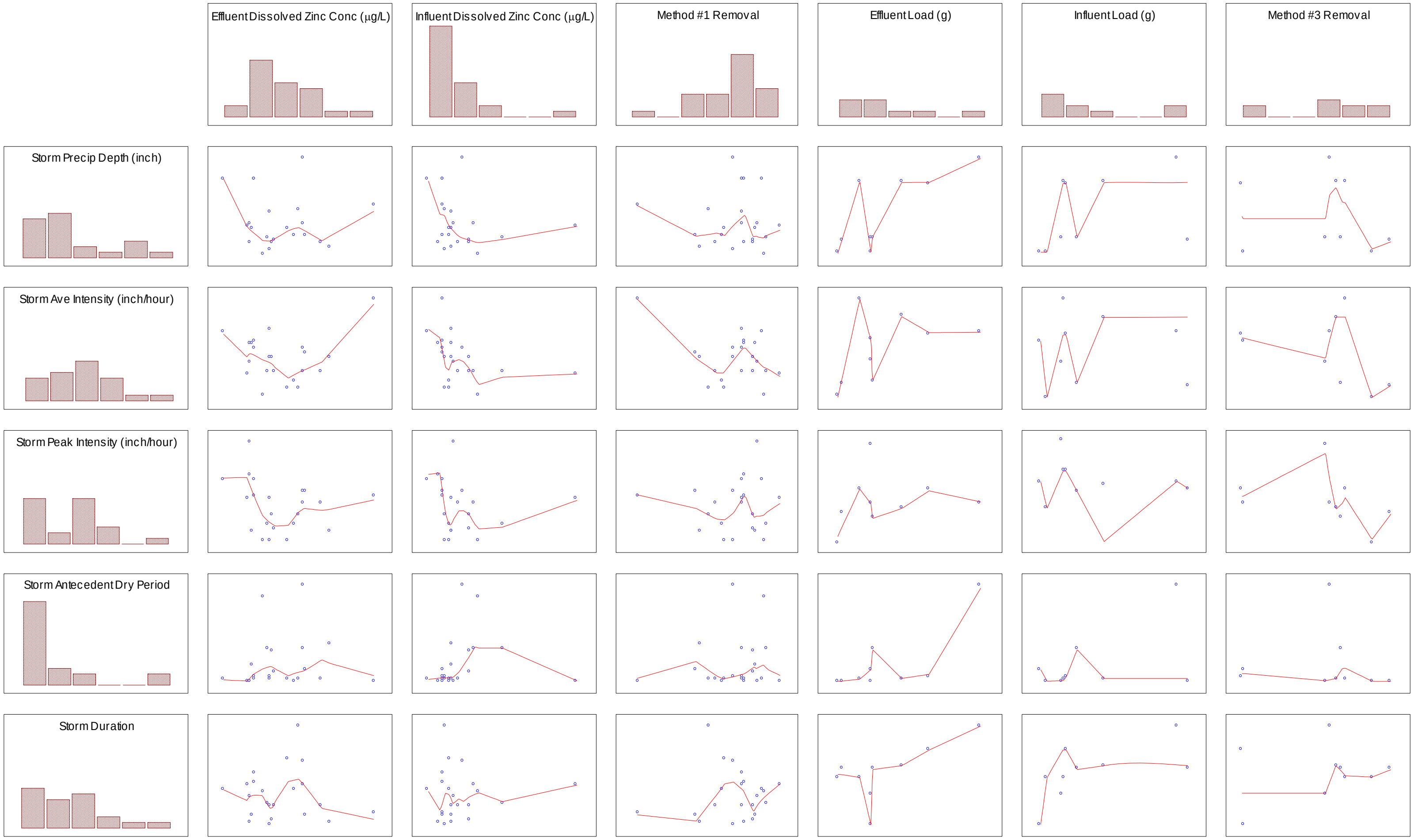
Note: Lines in each plots represent a Locally Weighted Scatterplot Smooth (LOWESS) through the data

Figure D4. Matrix scatter plot comparing storm event characteristics to influent and effluent total zinc concentrations, loads, and associated removal efficiency estimates.



Note: Lines in each plots represent a Locally Weighted Scatterplot Smooth (LOWESS) through the data

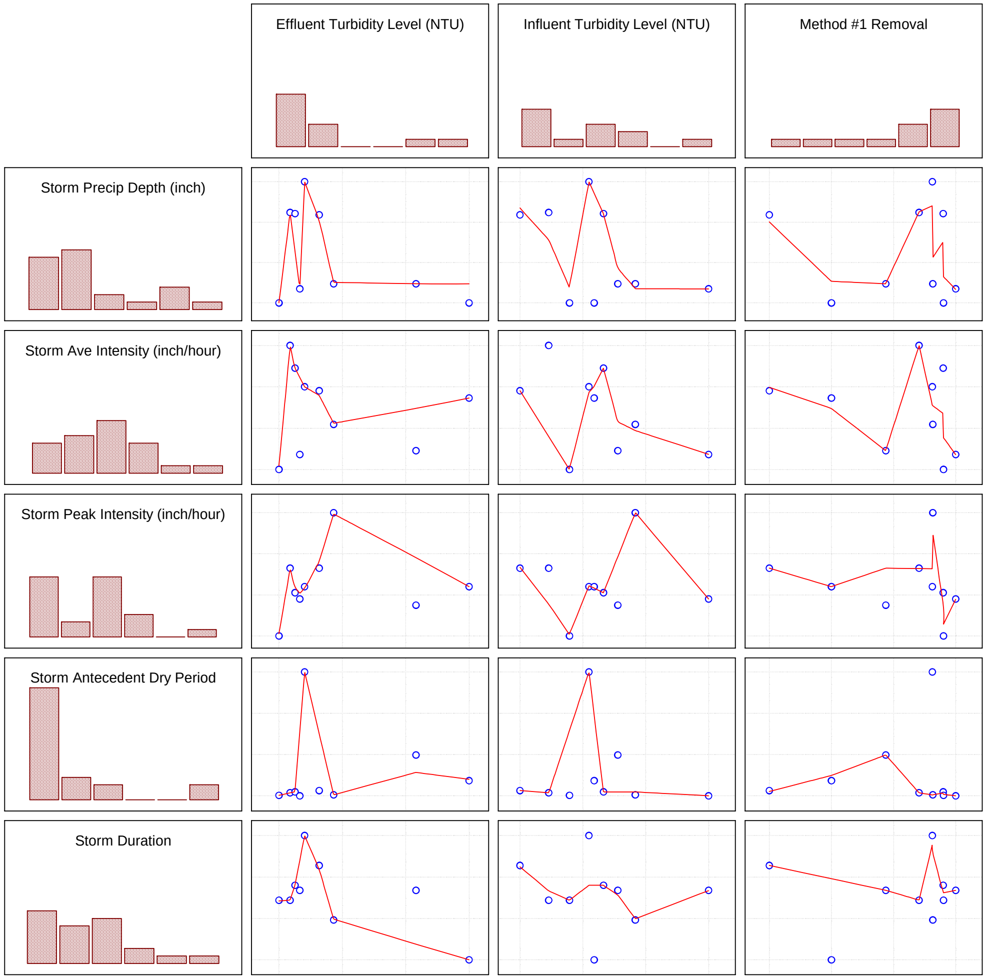
Figure D5. Matrix scatter plot comparing storm event characteristics to influent and effluent dissolved zinc concentrations, loads, and associated removal efficiency estimates.

Note: Lines in each plots represent a Locally Weighted Scatterplot Smooth (LOWESS) through the data

Figure D6. Matrix scatter plot comparing storm event characteristics to influent and effluent total copper concentrations and associated removal efficiency estimates.

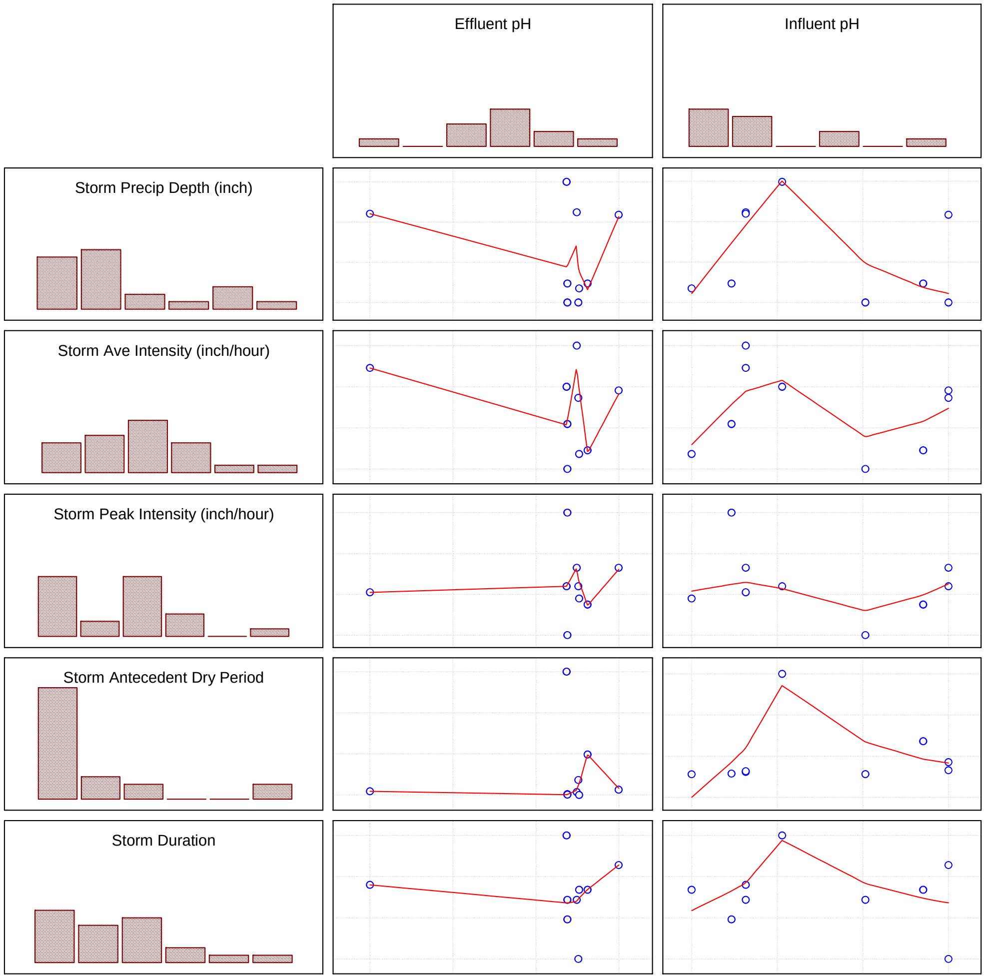
Note: Lines in each plots represent a Locally Weighted Scatterplot Smooth (LOWESS) through the data

Figure D7. Matrix scatter plot comparing storm event characteristics to influent and effluent dissolved copper concentrations and associated removal efficiency estimates.



Note: Lines in each plots represent a Locally Weighted Scatterplot Smooth (LOWESS) through the data

Figure D8. Matrix scatter plot comparing storm event characteristics to influent and effluent turbidity levels and associated removal efficiency estimates.



Note: Lines in each plots represent a Locally Weighted Scatterplot Smooth (LOWESS) through the data

Figure D9. Matrix scatter plot comparing storm event characteristics to influent and effluent pH levels.

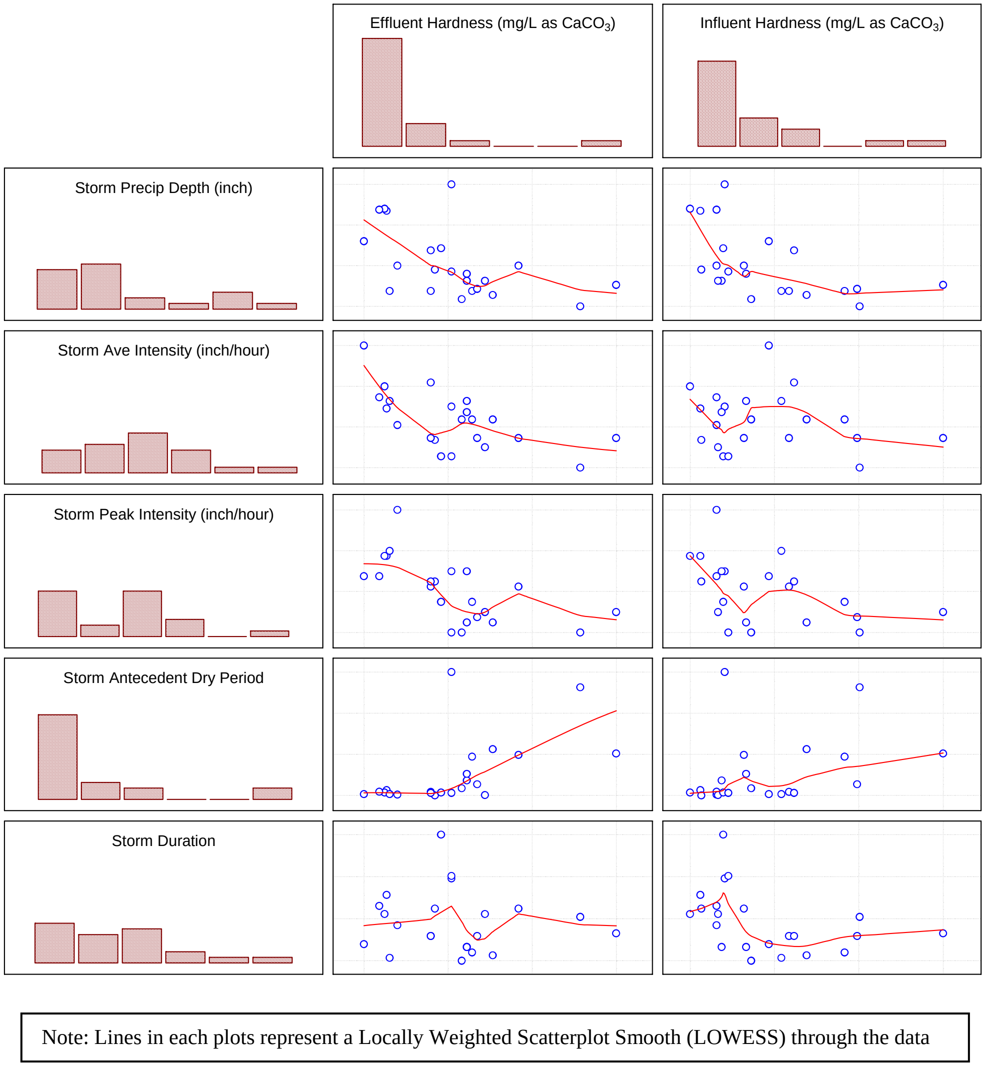
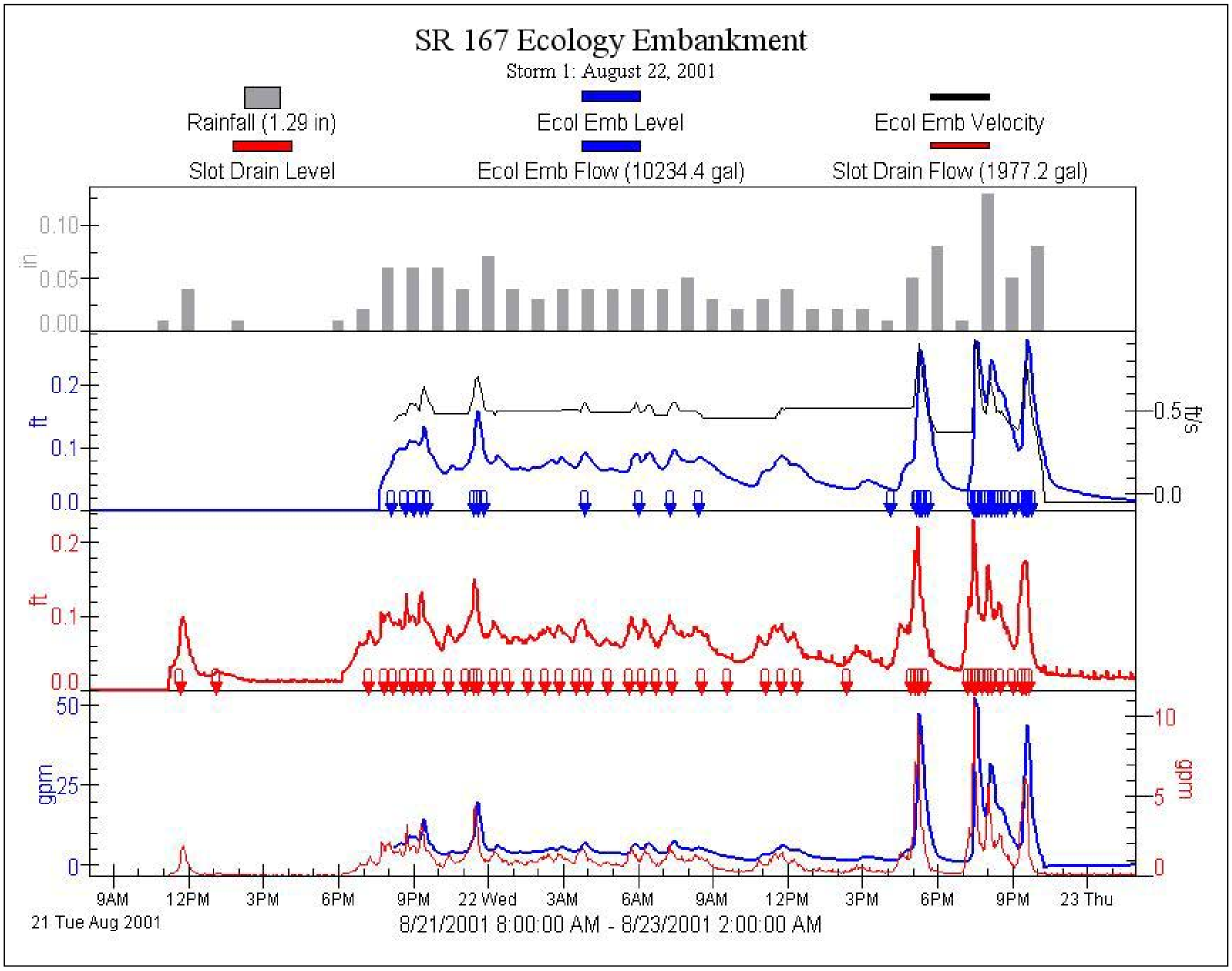


Figure D10. Matrix scatter plot comparing storm event characteristics to influent and effluent hardness concentrations.

APPENDIX E

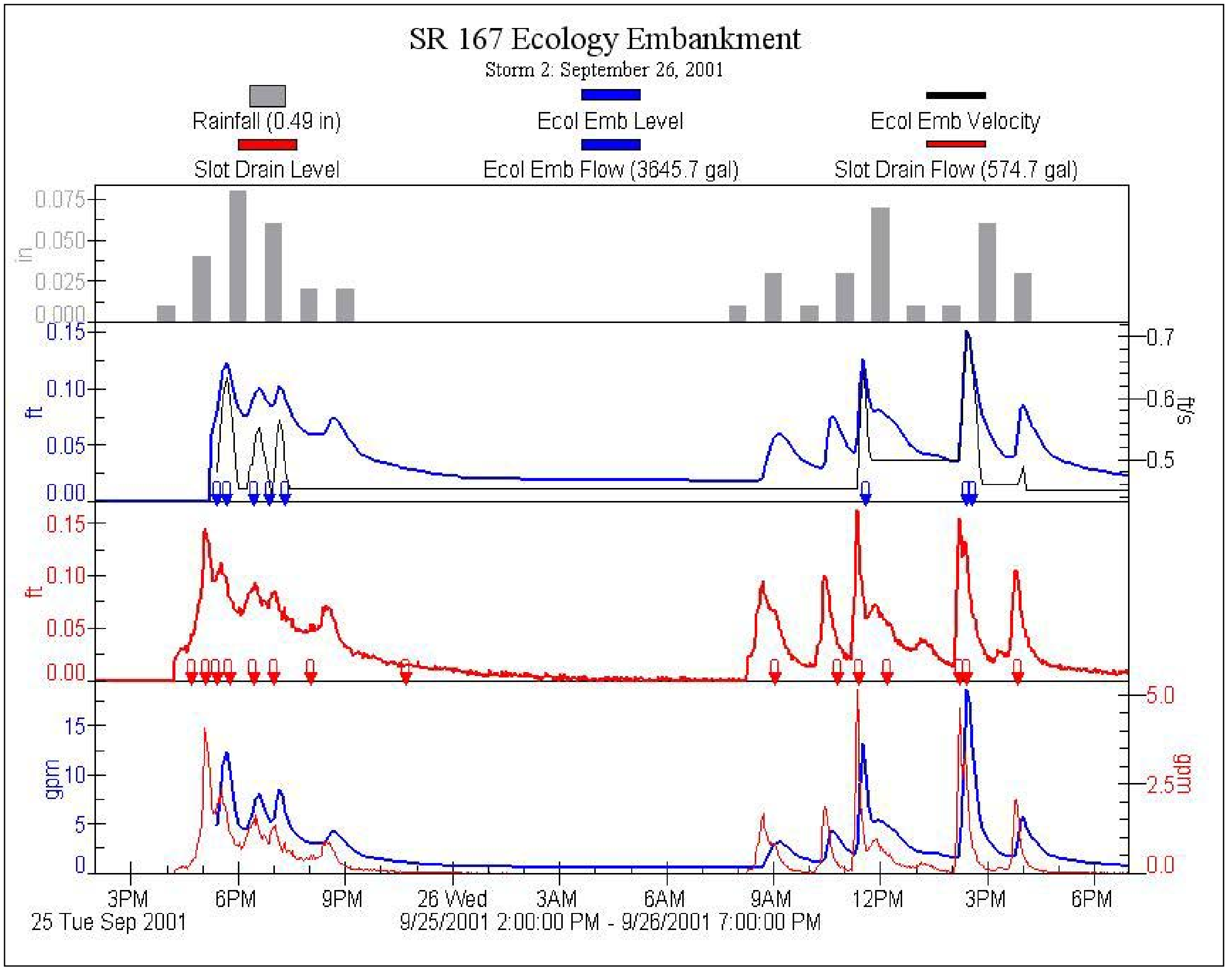
Hydrographs for Sampled Storm Events

Figure E1. Influent and effluent hydrographs and associated sample collection times for storm 1.



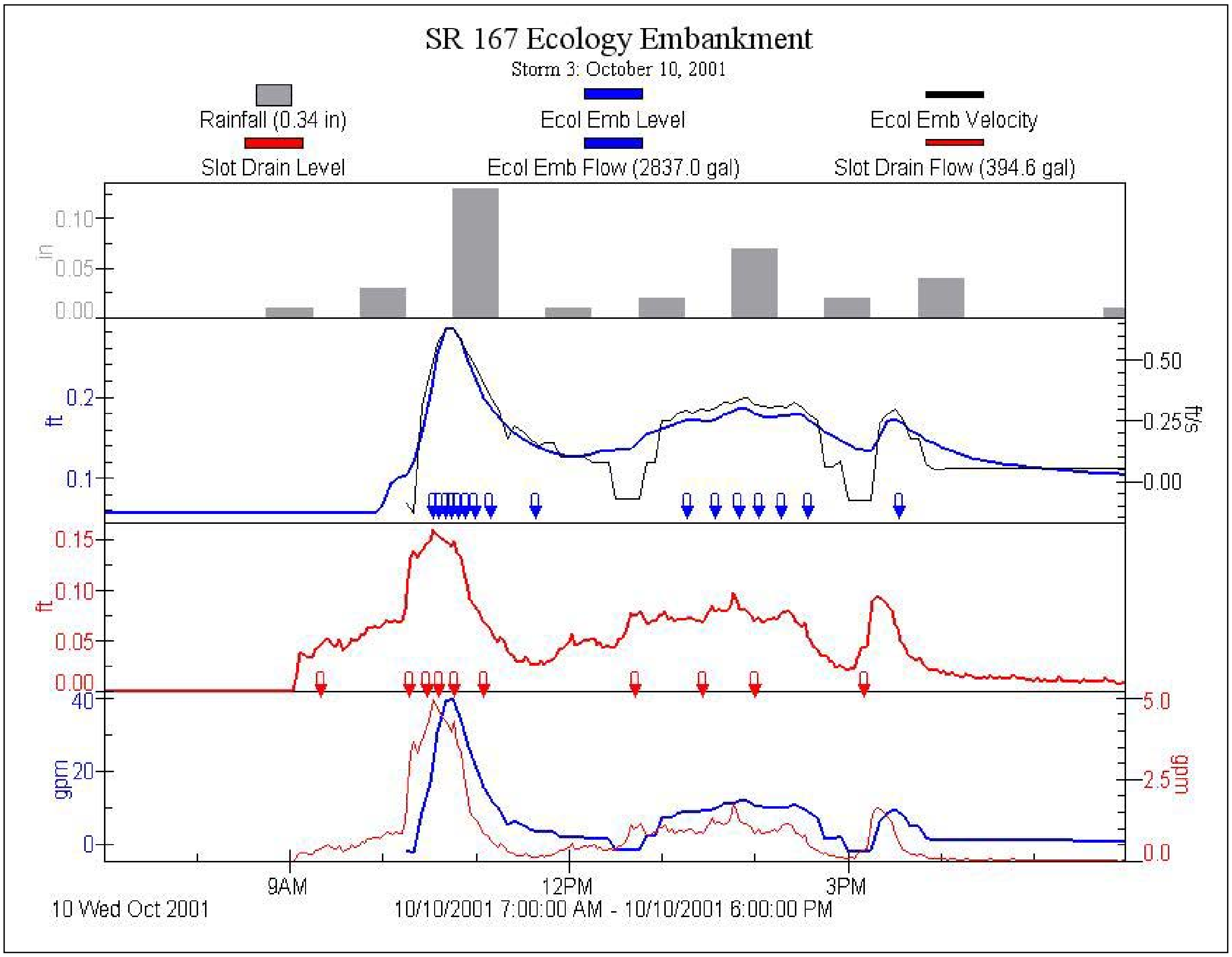
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by blue line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E2. Influent and effluent hydrographs and associated sample collection times for storm 2.



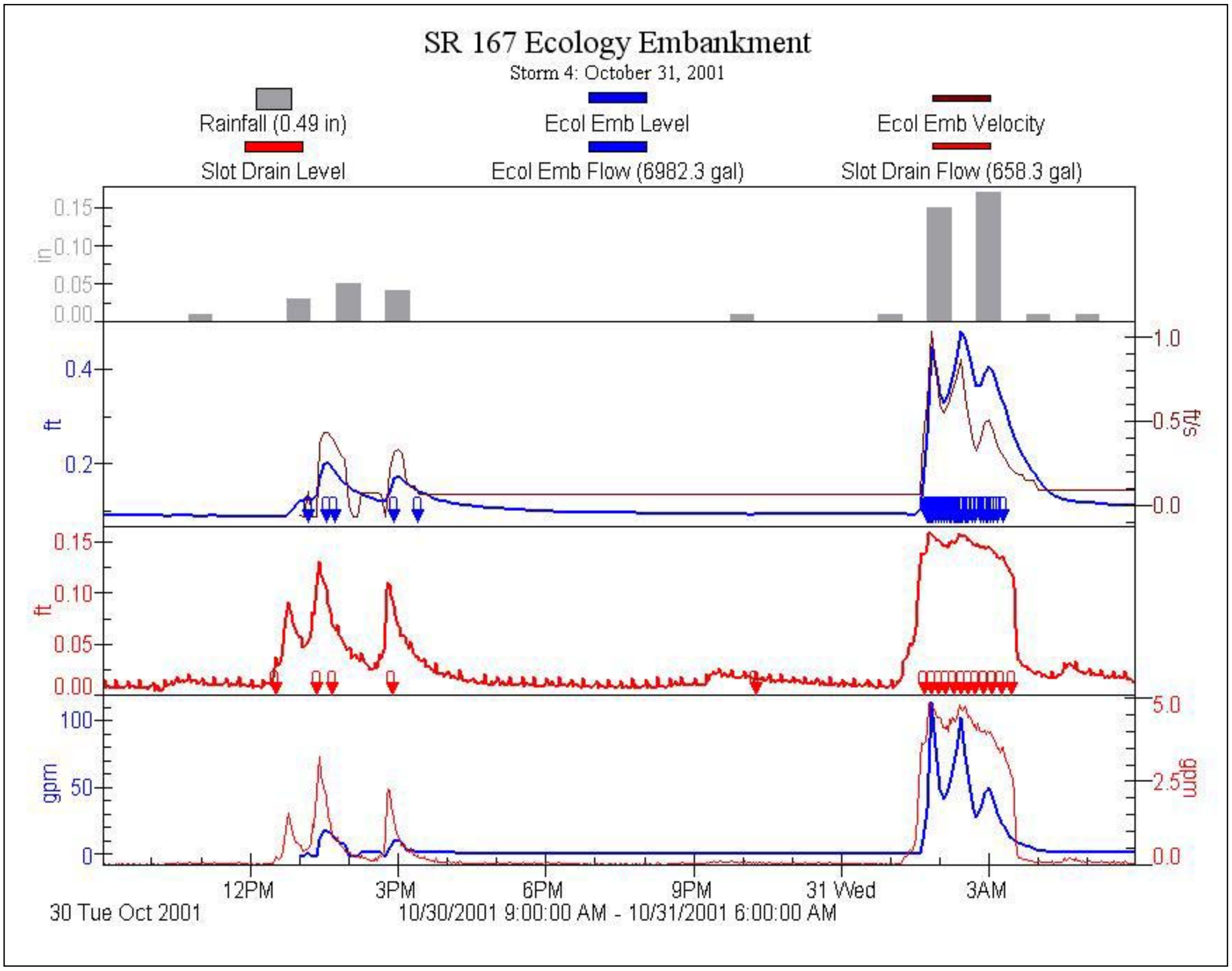
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by blue line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E3. Influent and effluent hydrographs and associated sample collection times for storm 3.



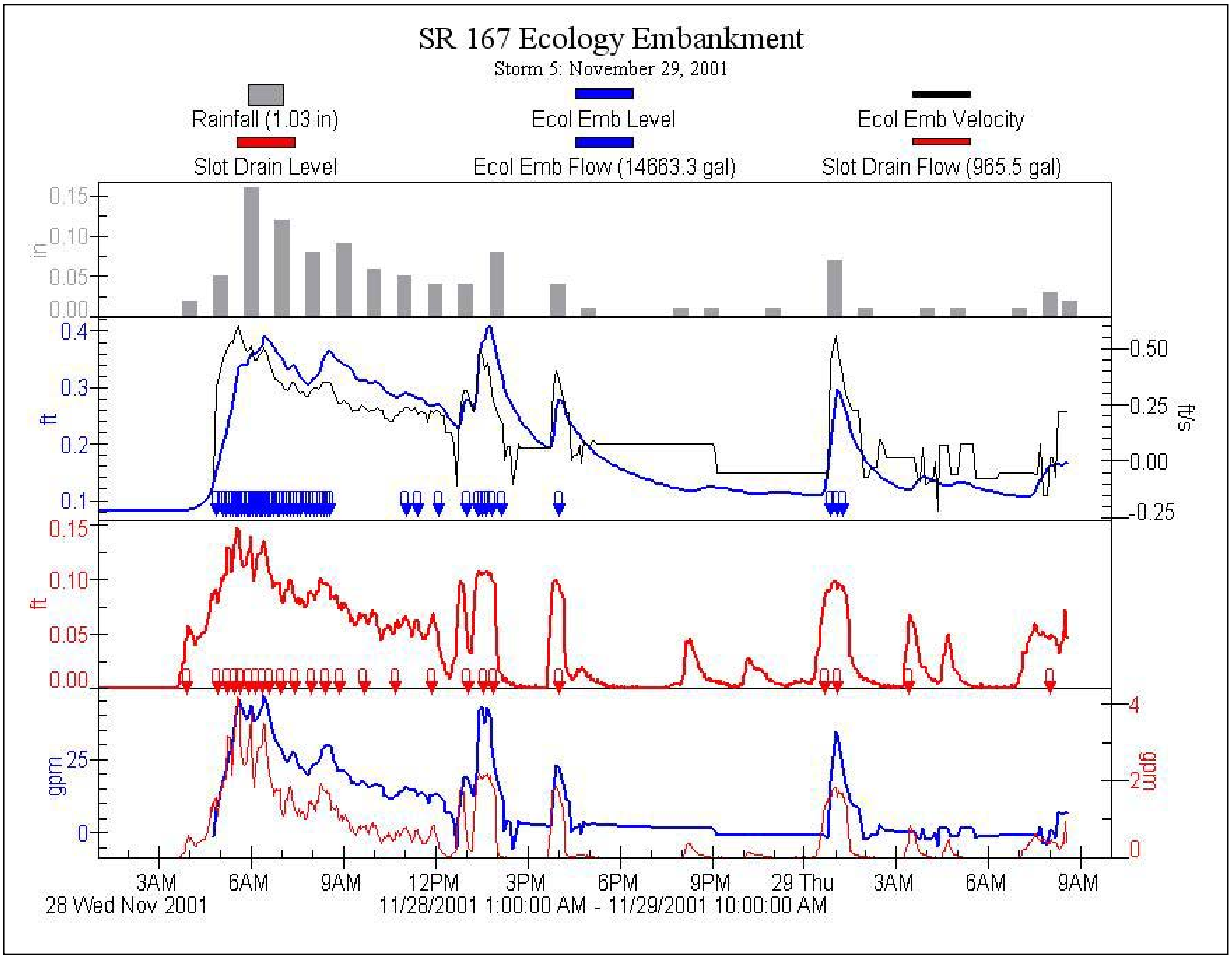
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by blue line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E4. Influent and effluent hydrographs and associated sample collection times for storm 4.



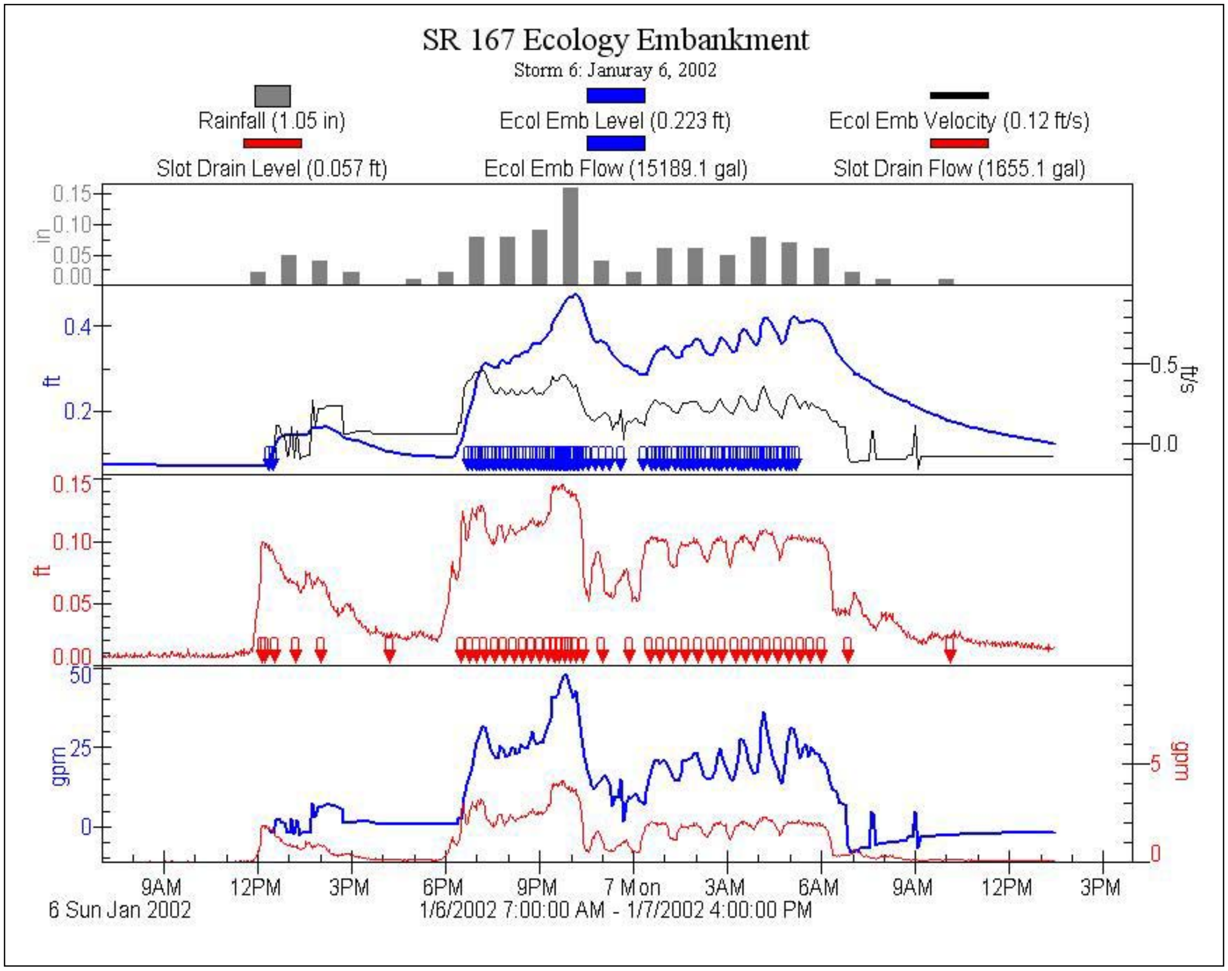
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by blue line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E5. Influent and effluent hydrographs and associated sample collection times for storm 5.



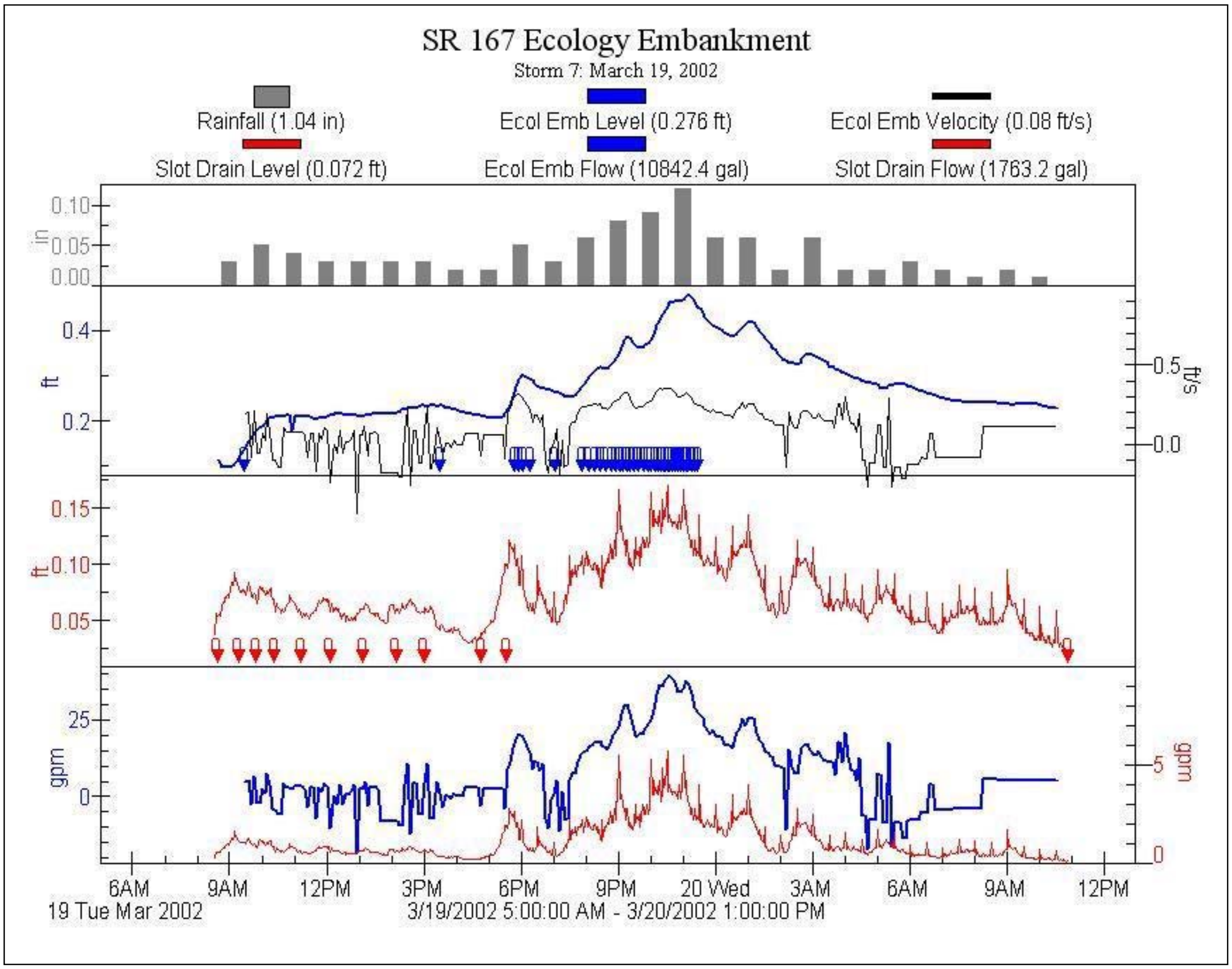
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by blue line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E6. Influent and effluent hydrographs and associated sample collection times for storm 6.



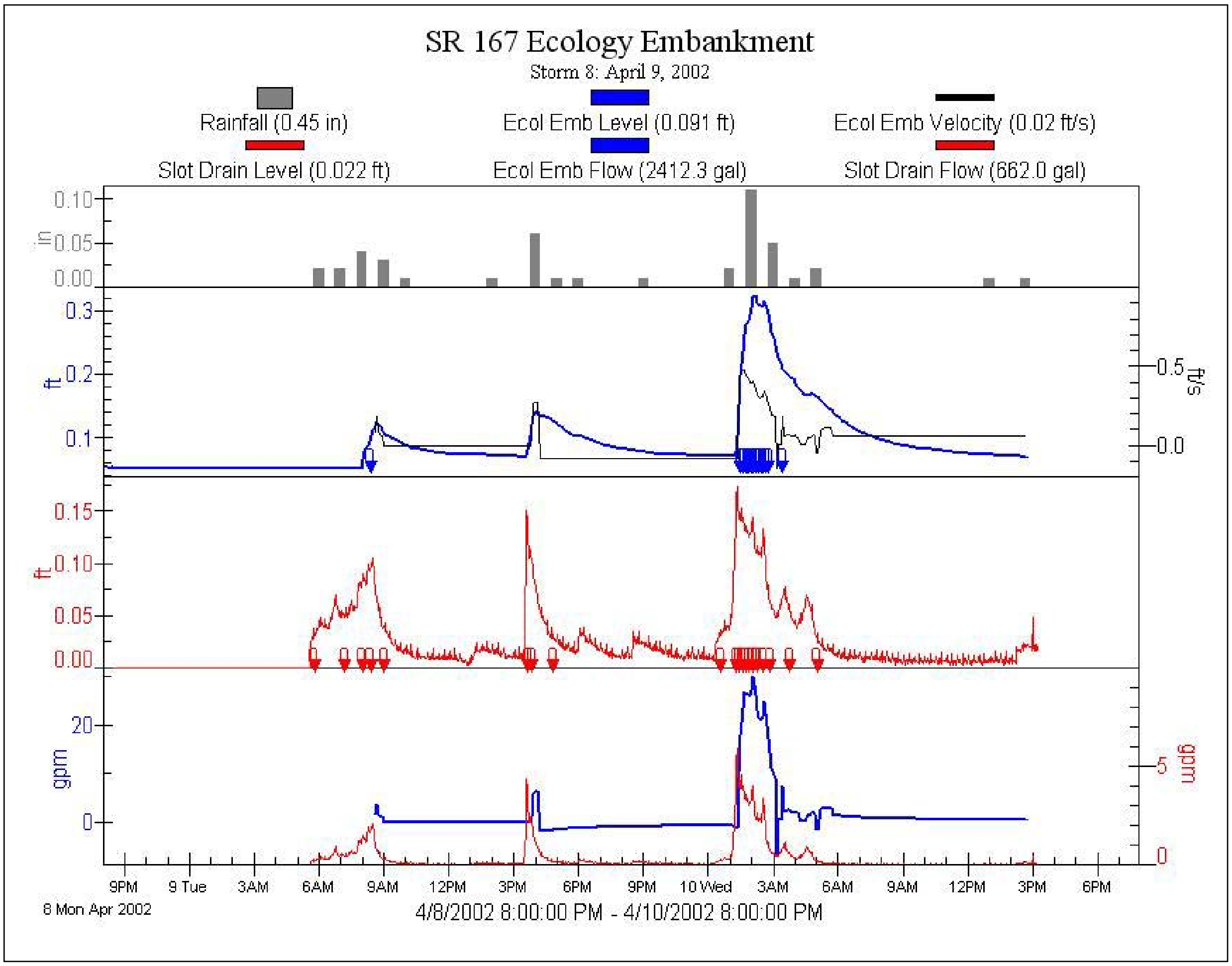
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by blue line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E7. Influent and effluent hydrographs and associated sample collection times for storm 7.



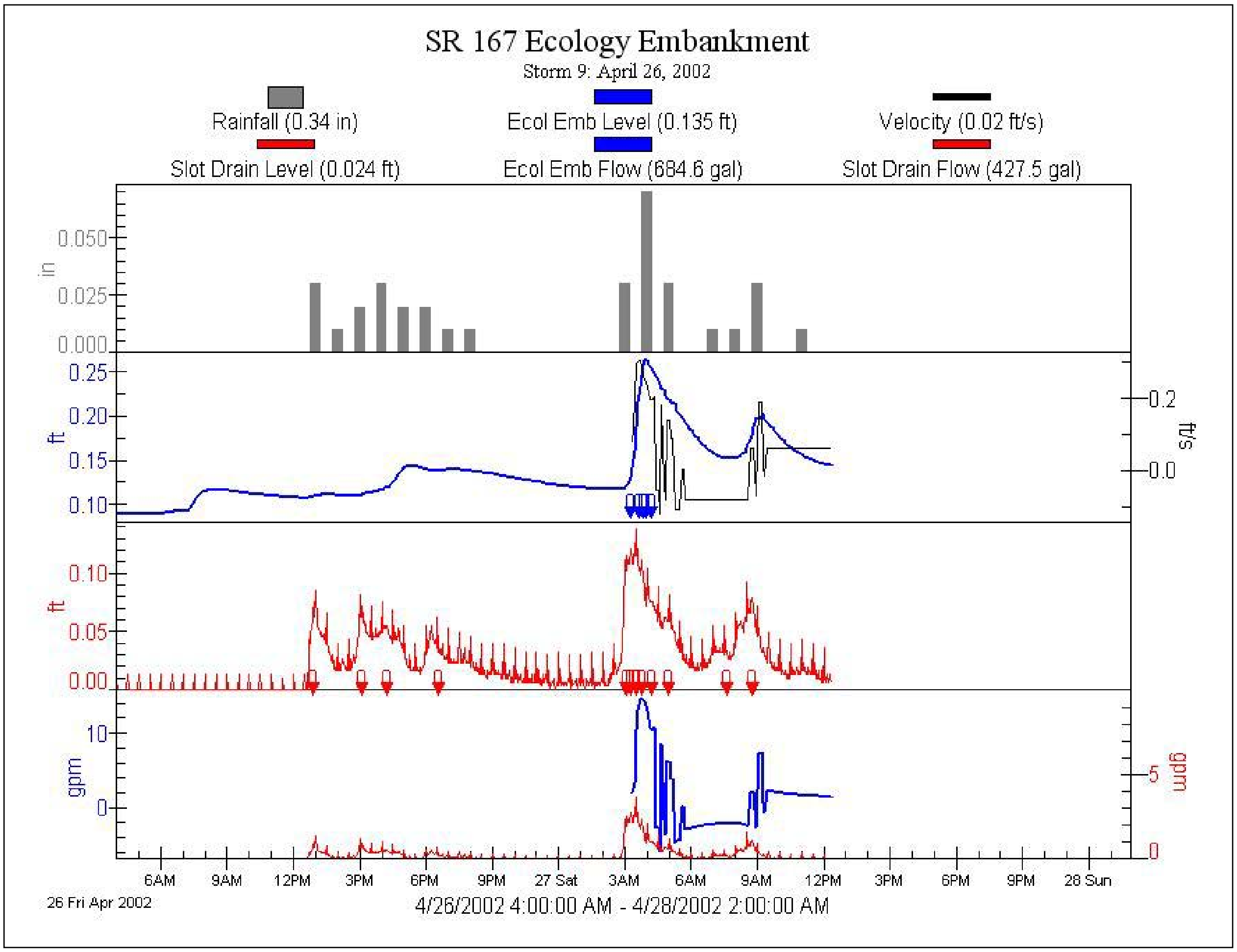
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by blue line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E8. Influent and effluent hydrographs and associated sample collection times for storm 8.



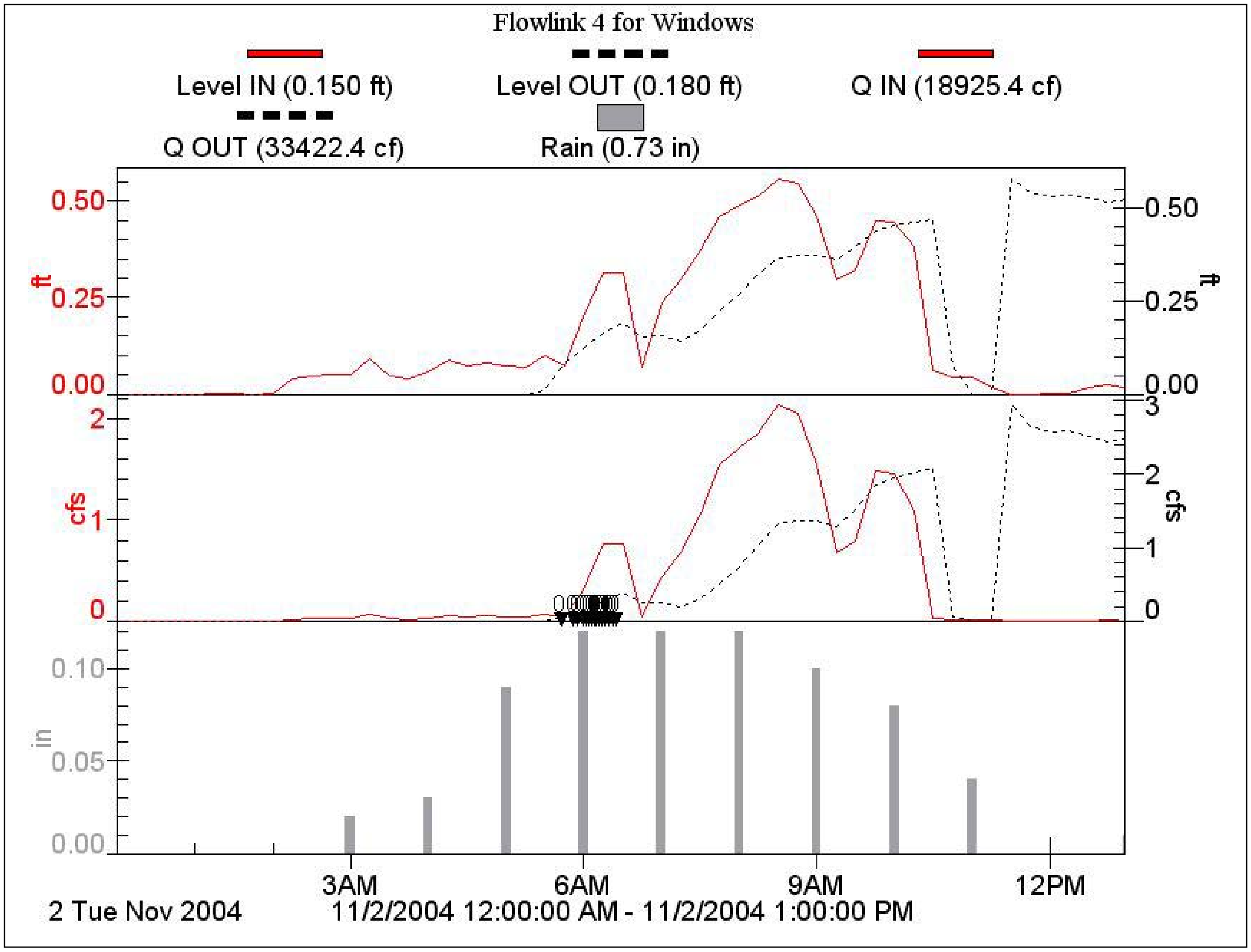
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by blue line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E9. Influent and effluent hydrographs and associated sample collection times for storm 9.



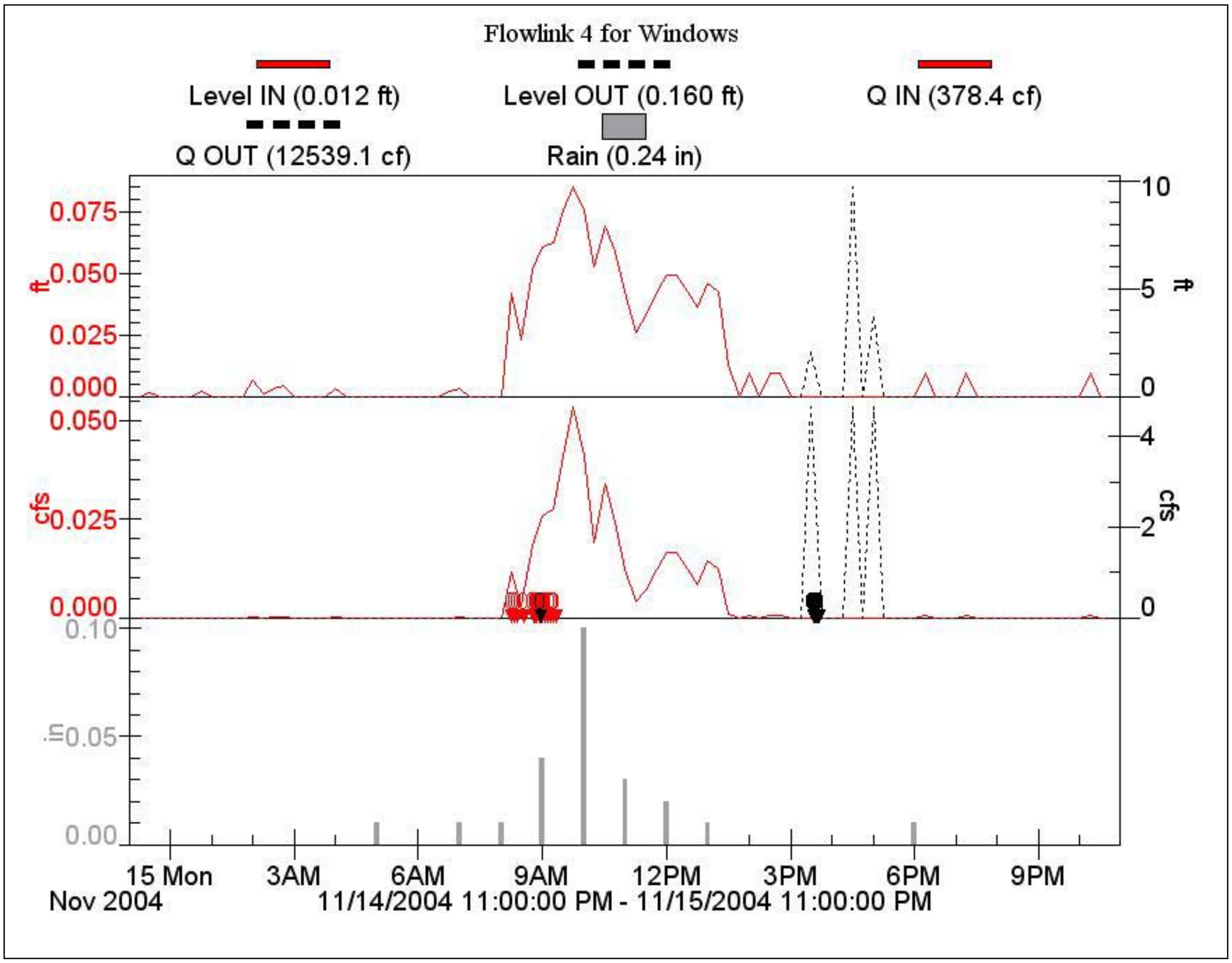
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by blue line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E10. Influent and effluent hydrographs and associated sample collection times for storm 13.



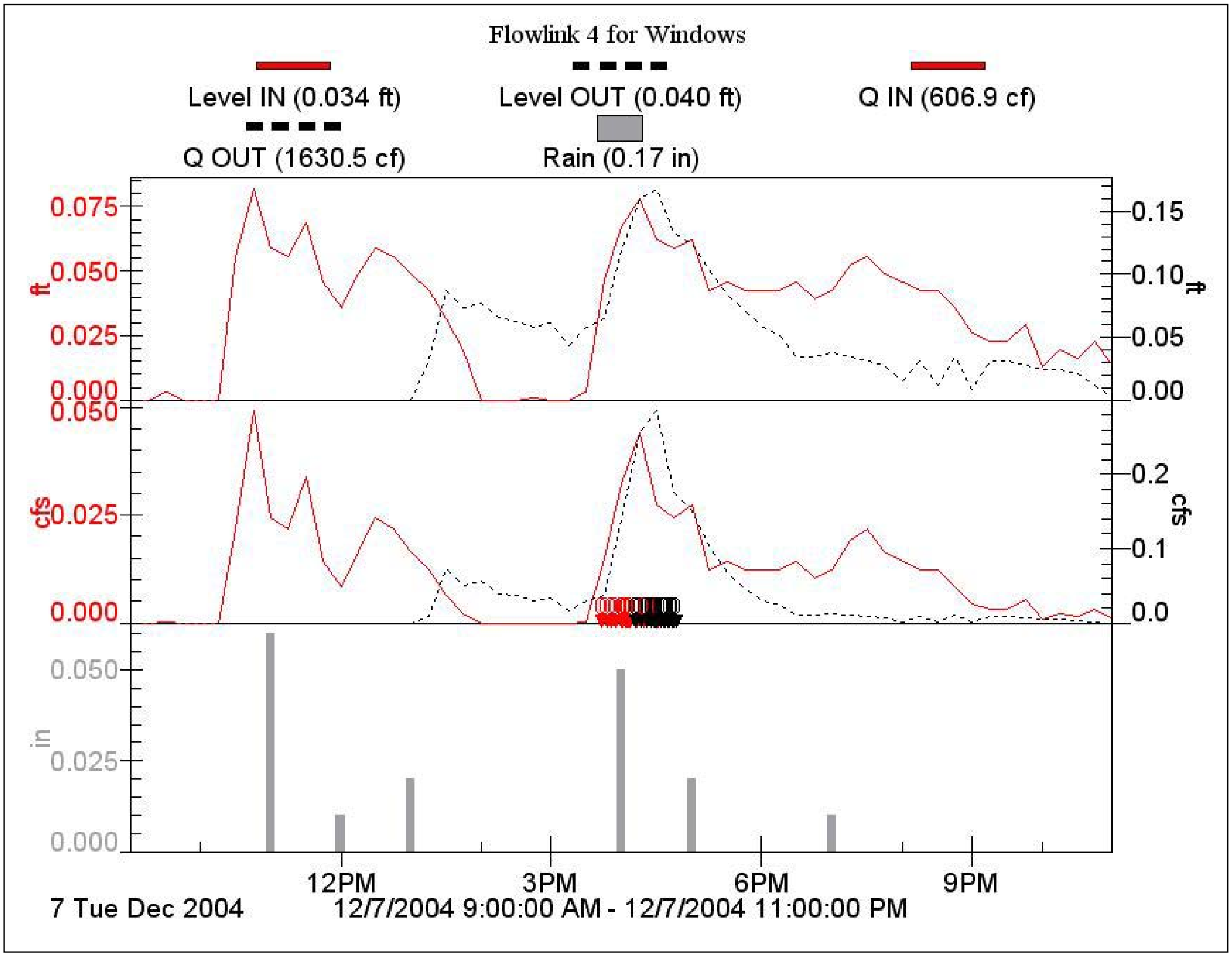
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph. Tetra Tech reported that inlet samples were taken but they do not appear on the Flowlink report.

Figure E11. Influent and effluent hydrographs and associated sample collection times for storm 14.



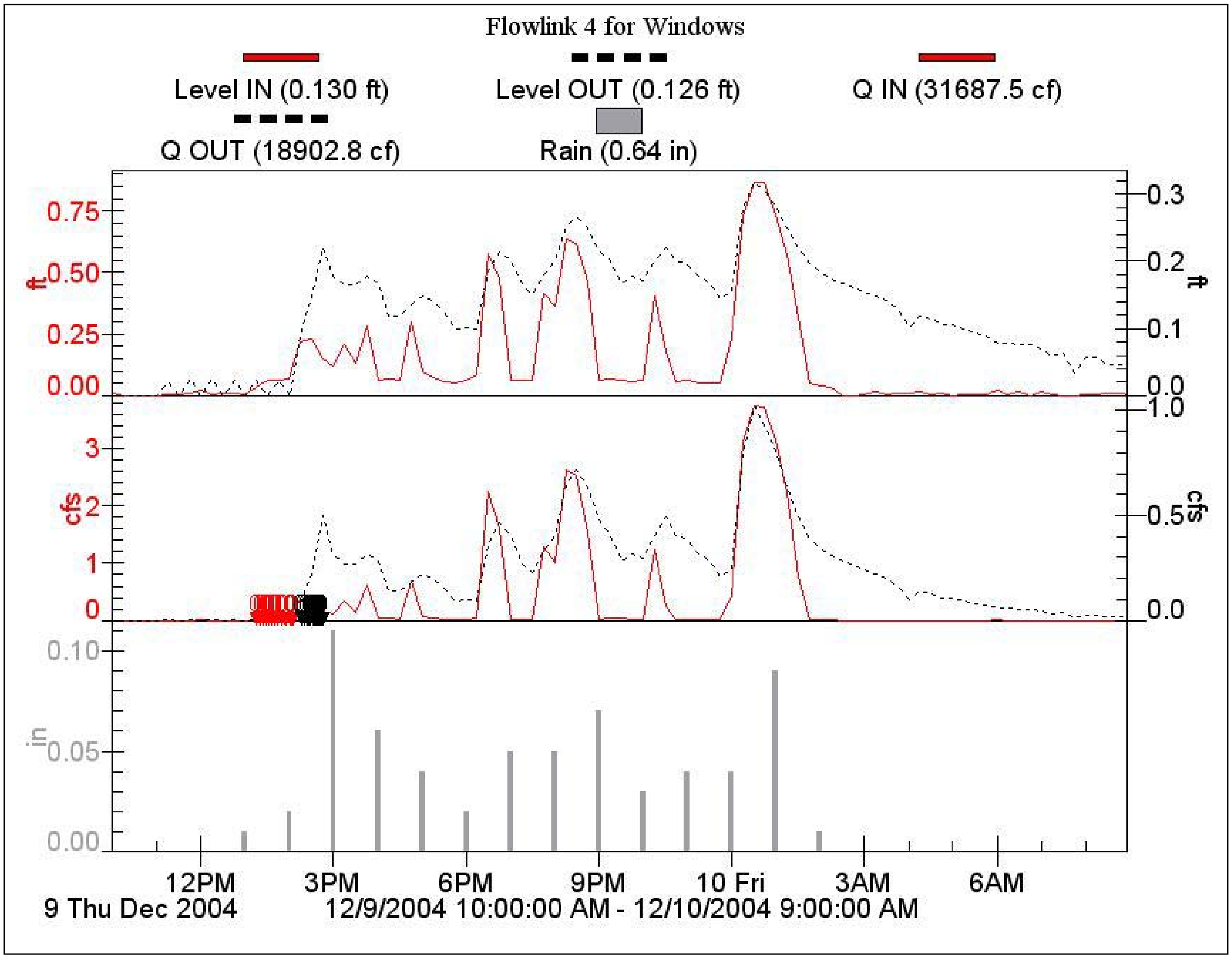
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E12. Influent and effluent hydrographs and associated sample collection times for storm 15.



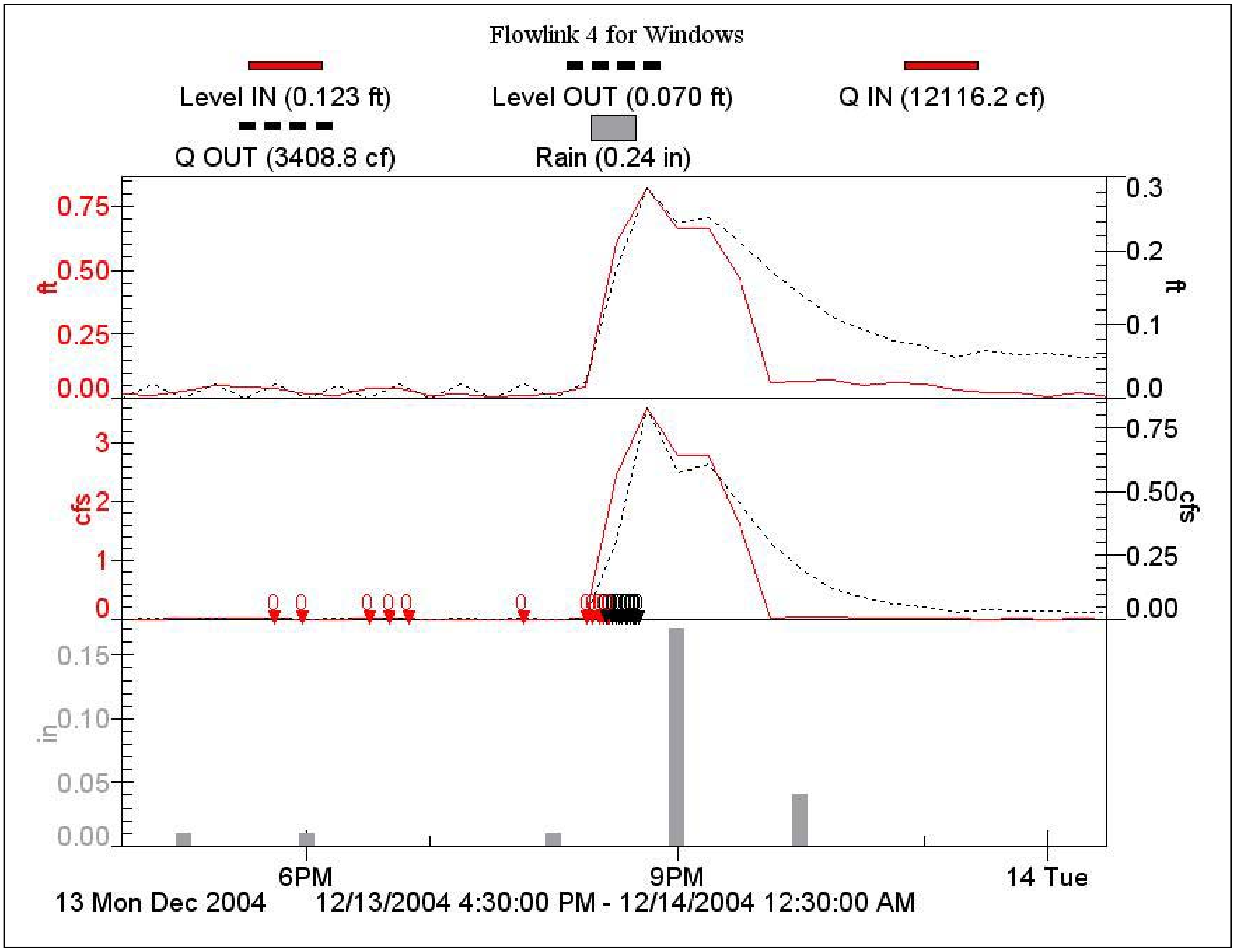
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E13. Influent and effluent hydrographs and associated sample collection times for storm 16.



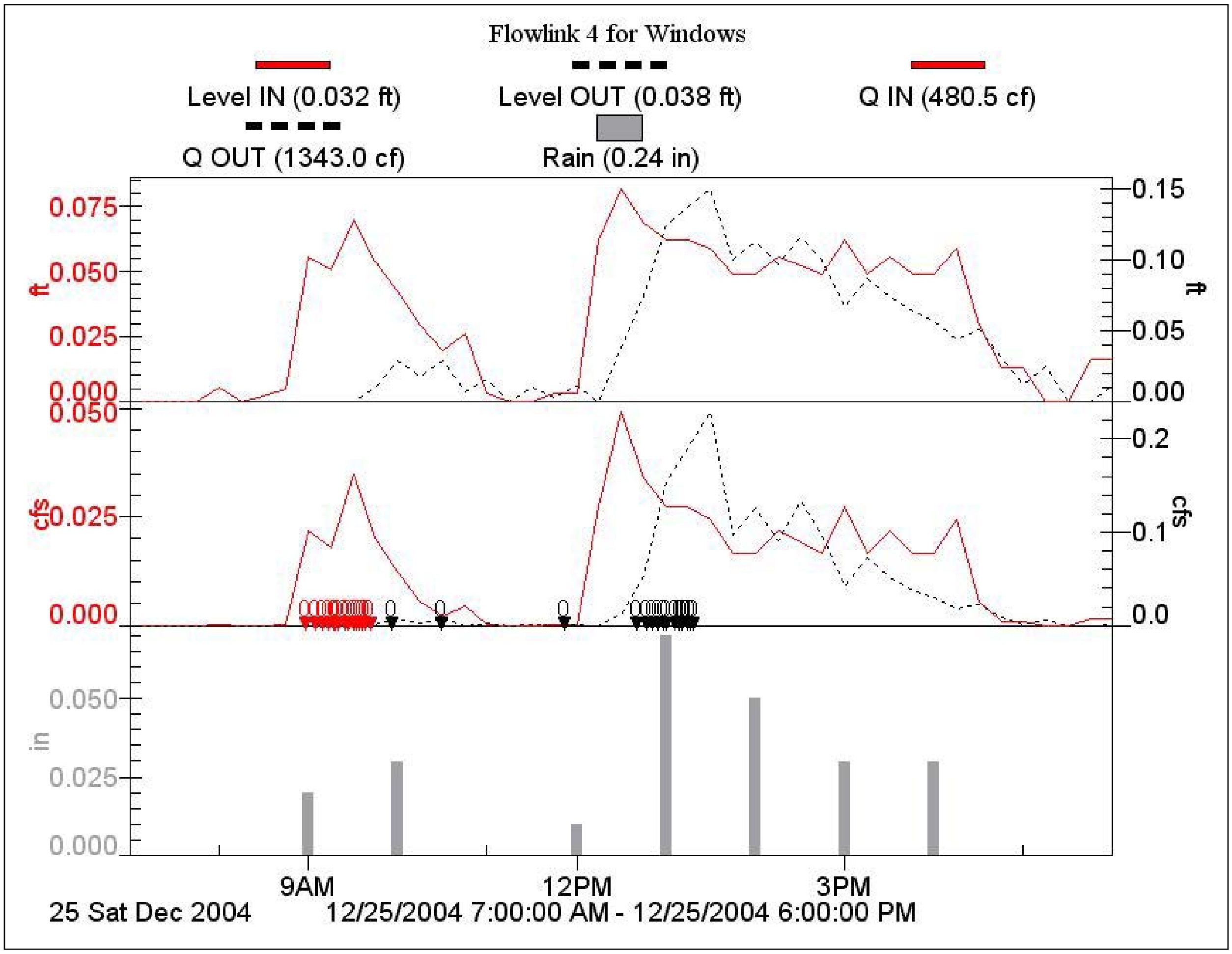
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E14. Influent and effluent hydrographs and associated sample collection times for storm 17.



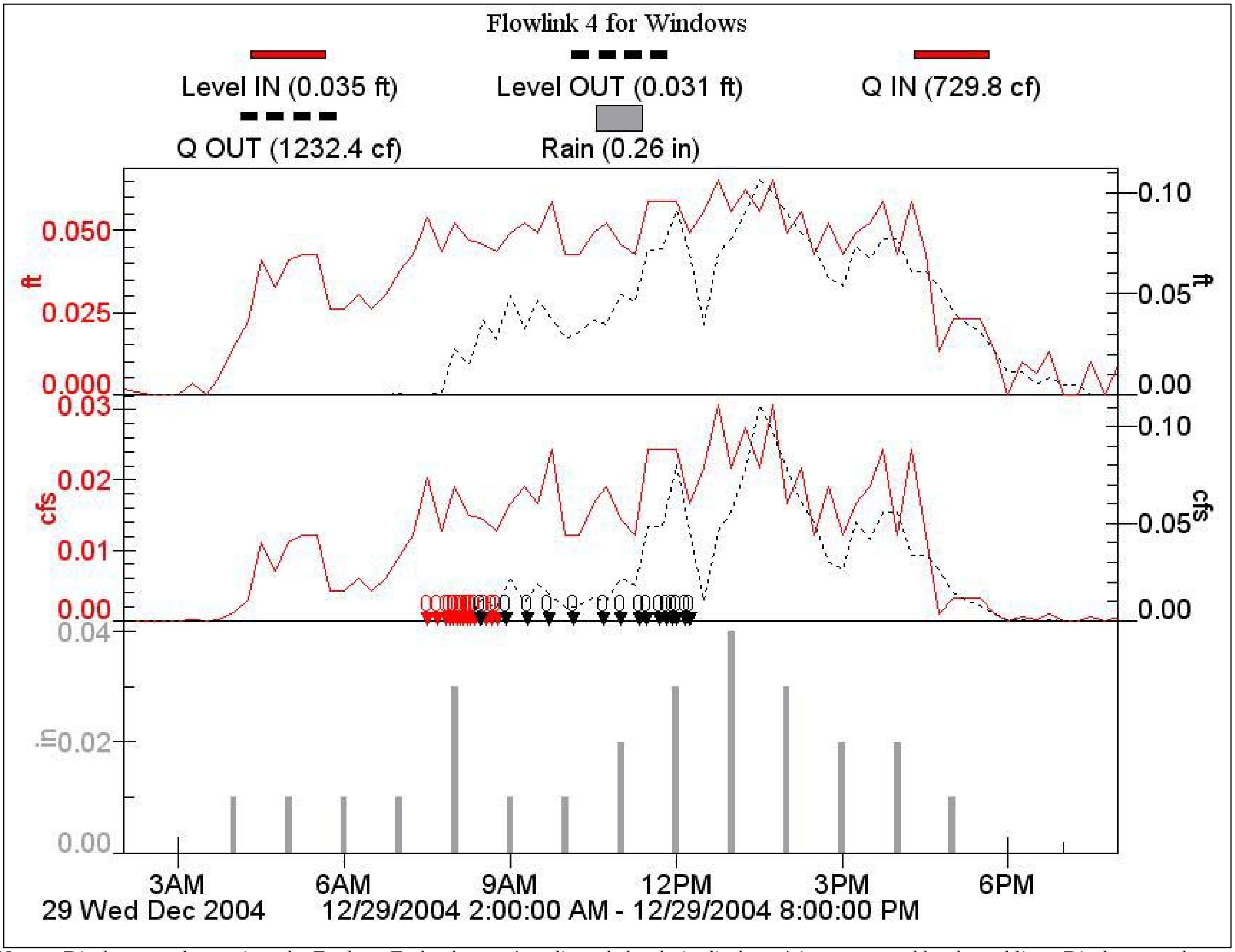
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E15. Influent and effluent hydrographs and associated sample collection times for storm 18.



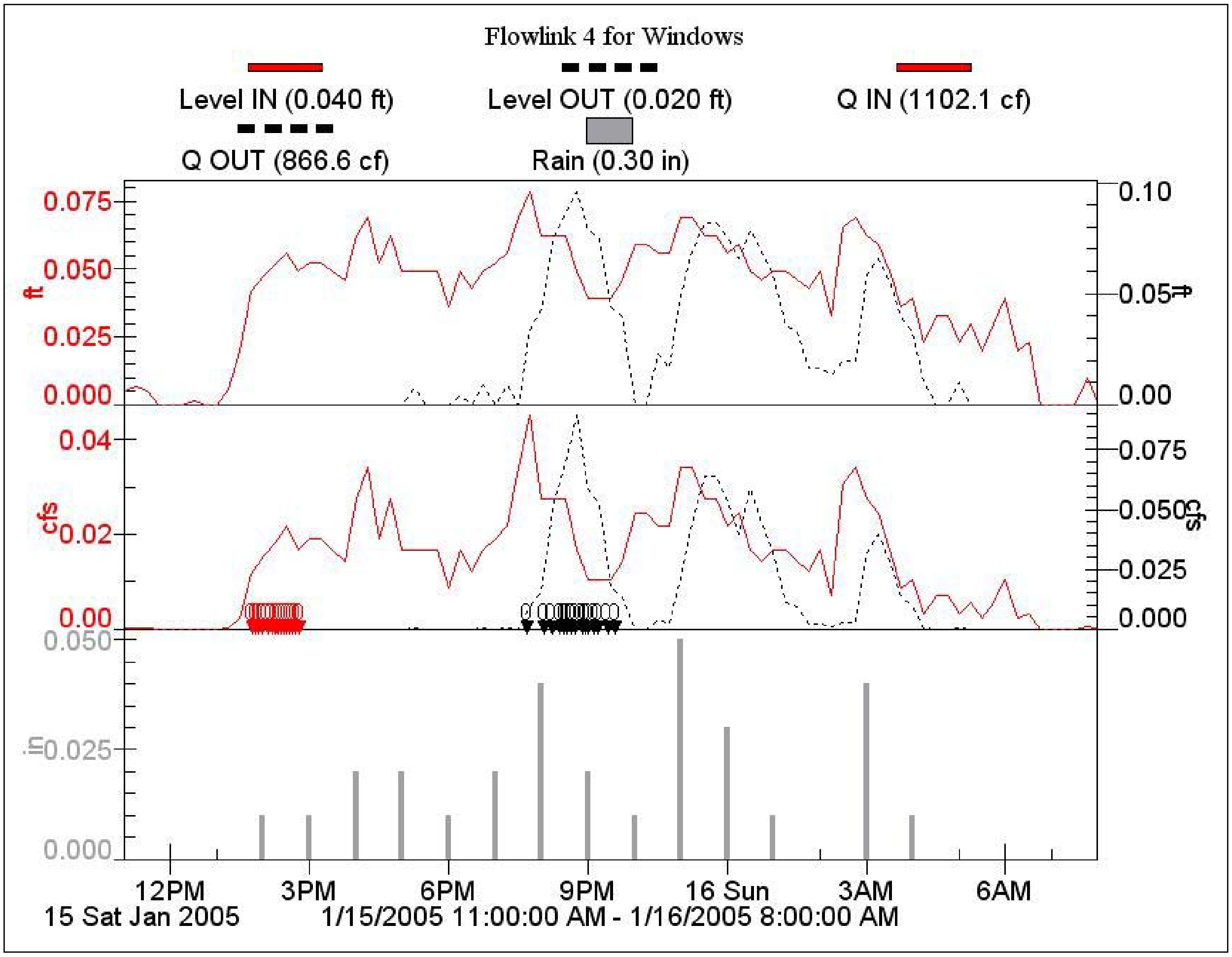
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E16. Influent and effluent hydrographs and associated sample collection times for storm 19.



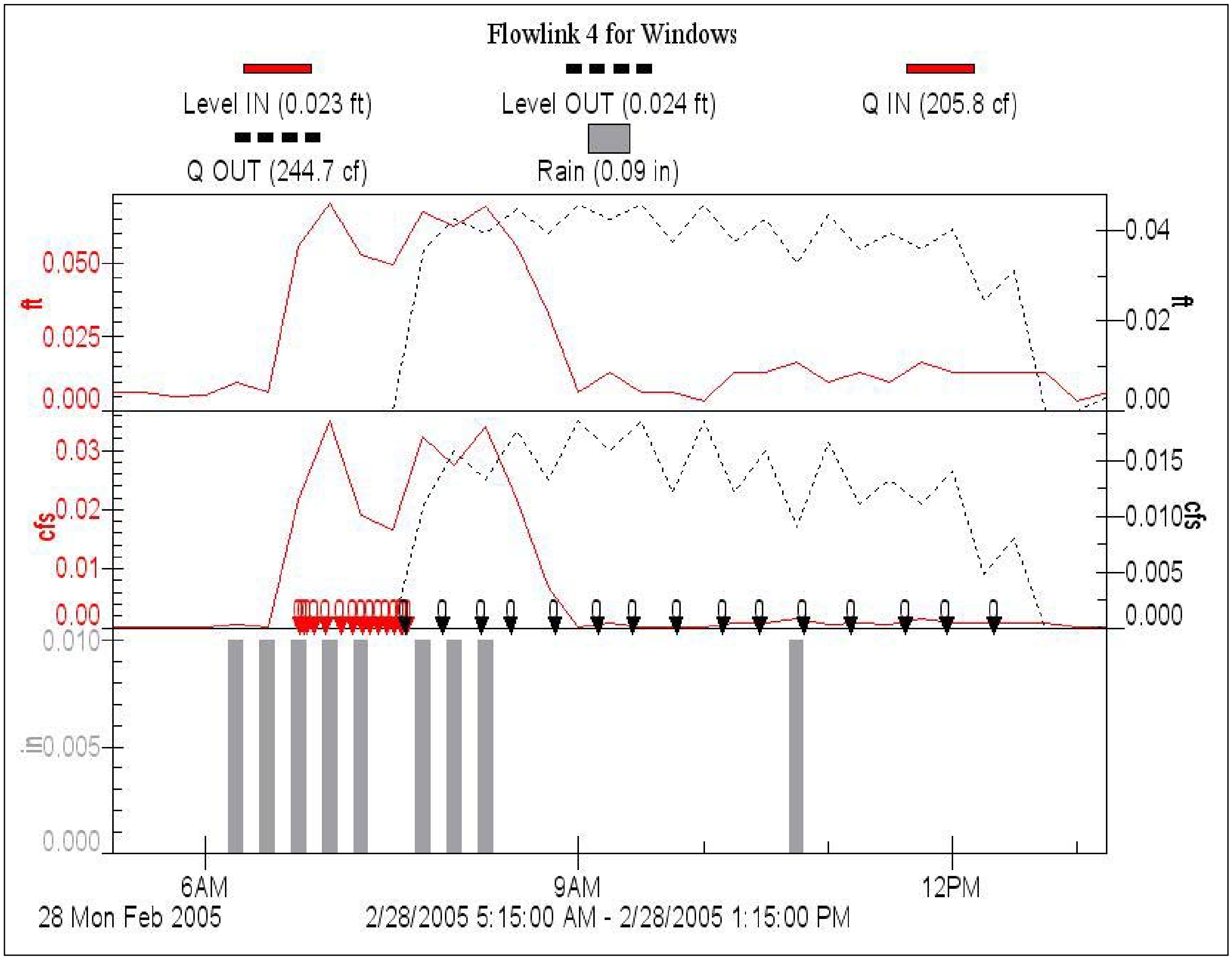
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E17. Influent and effluent hydrographs and associated sample collection times for storm 20.



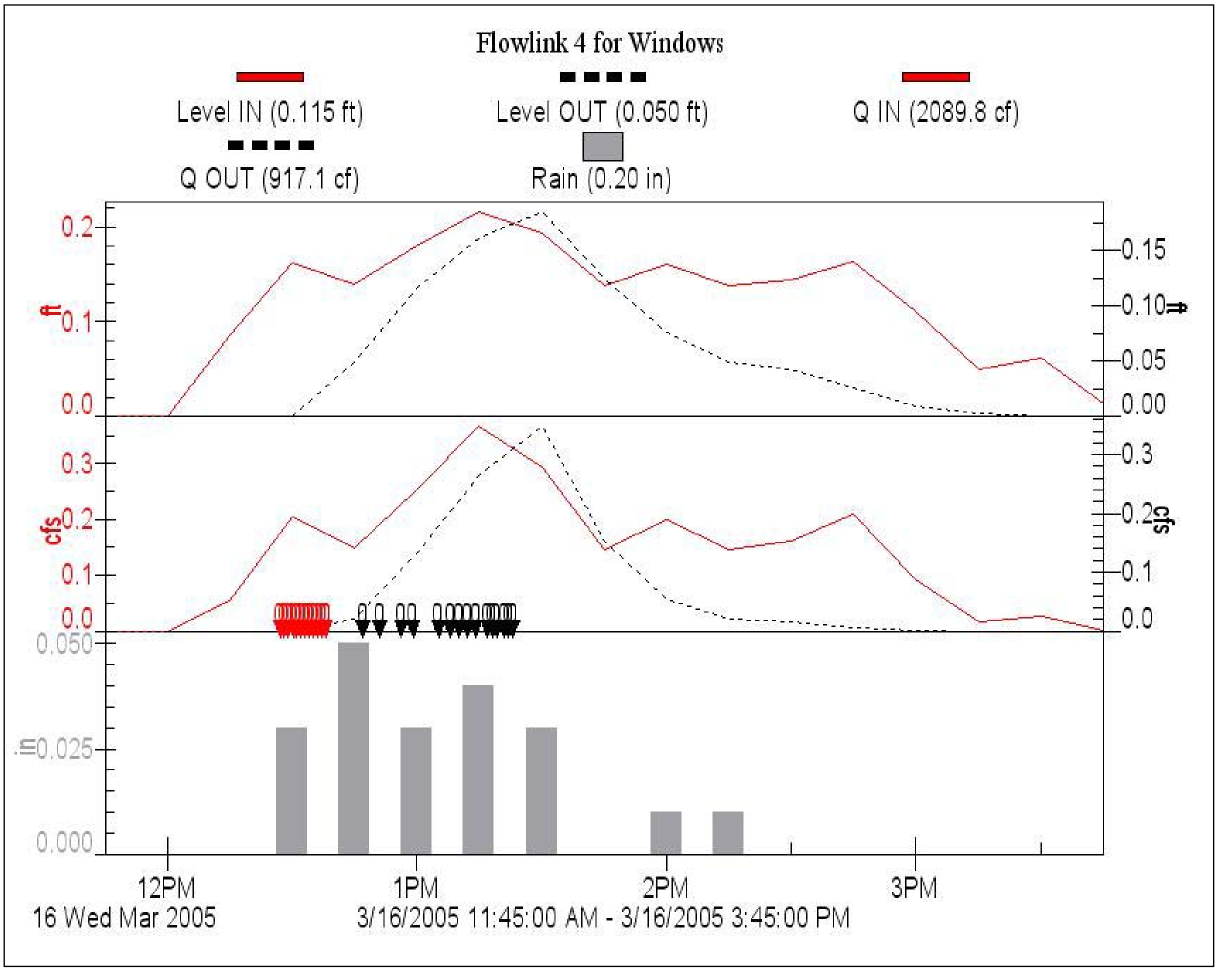
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E18. Influent and effluent hydrographs and associated sample collection times for storm 21.



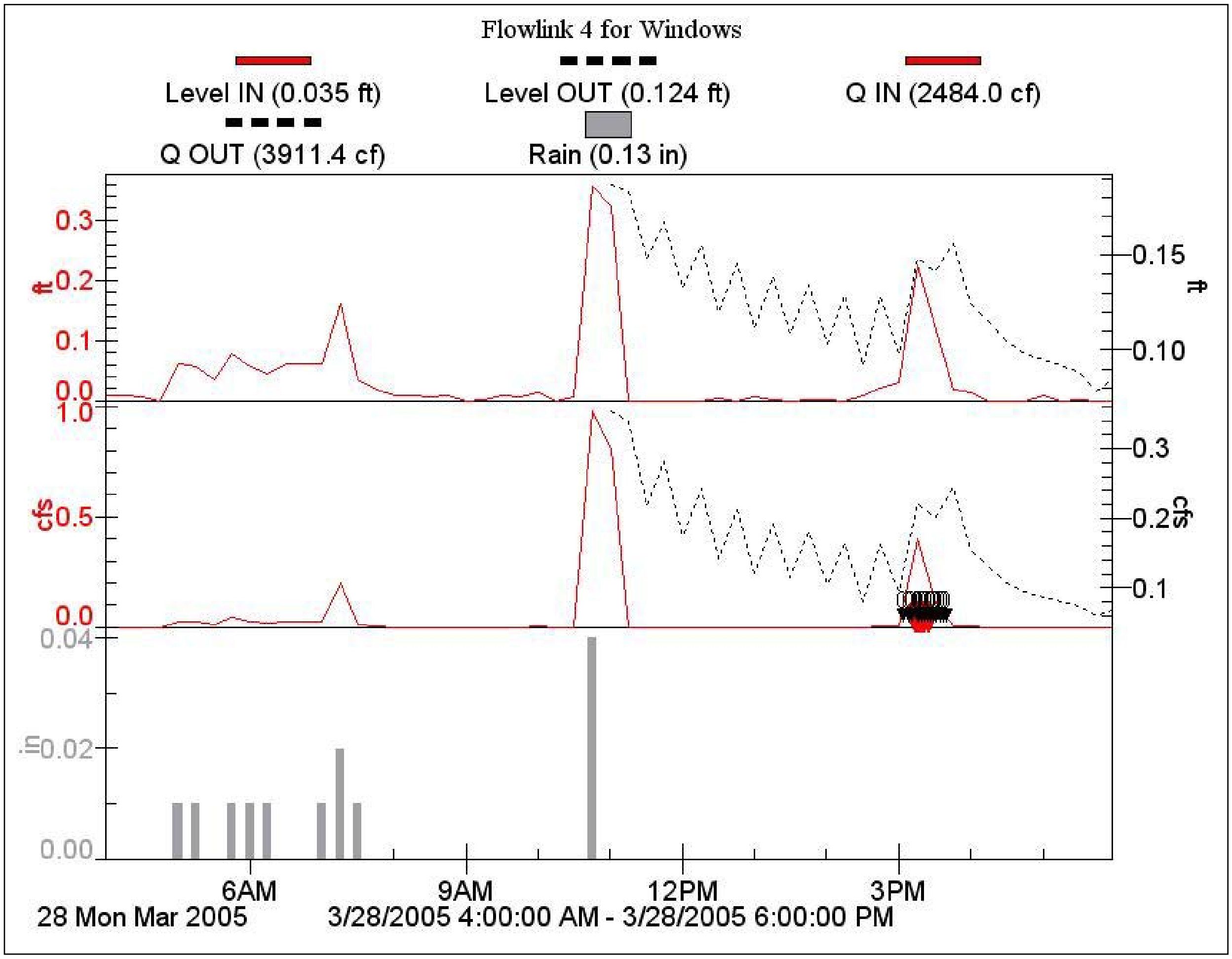
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E19. Influent and effluent hydrographs and associated sample collection times for storm 22.



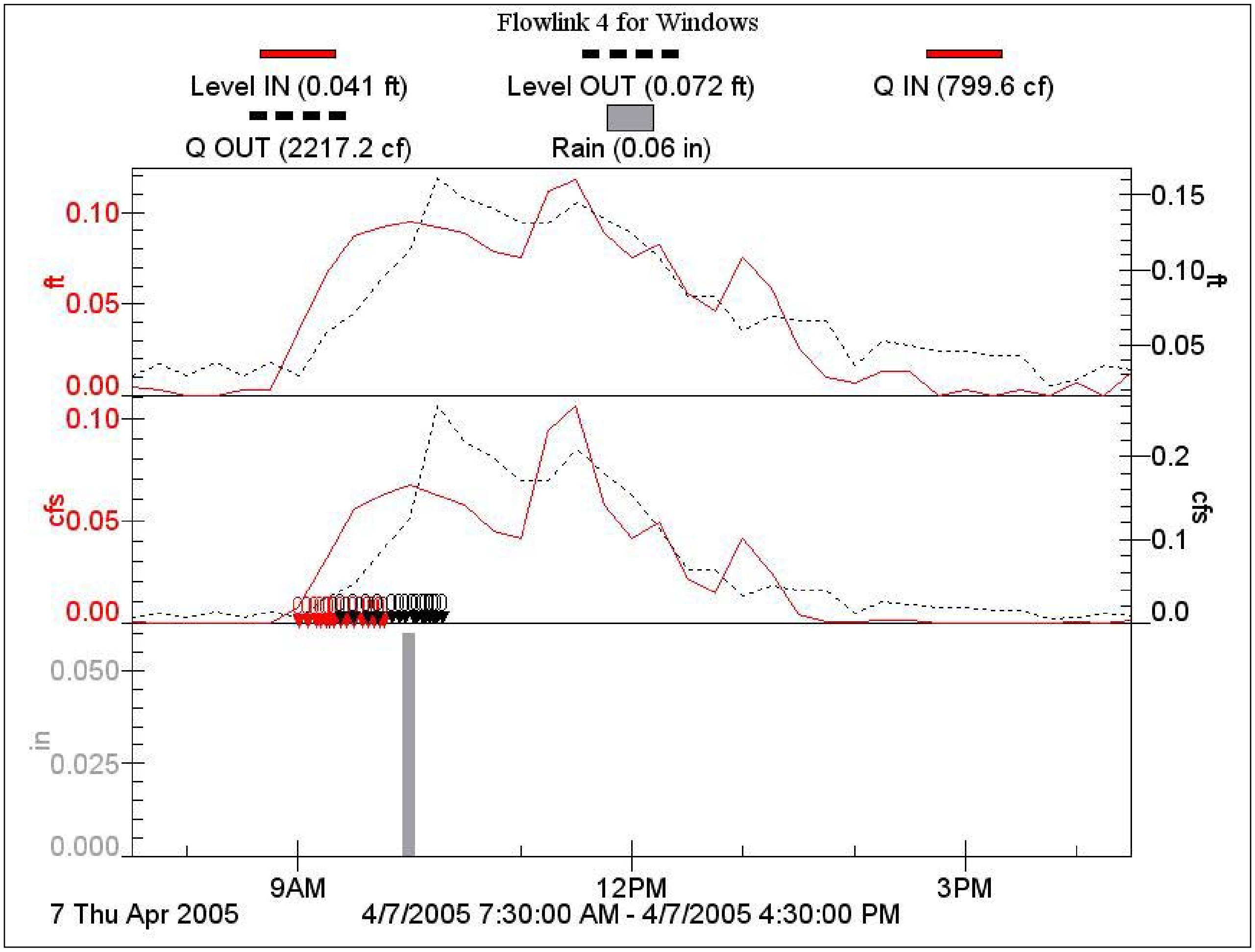
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph.

Figure E20. Influent and effluent hydrographs and associated sample collection times for storm 23.



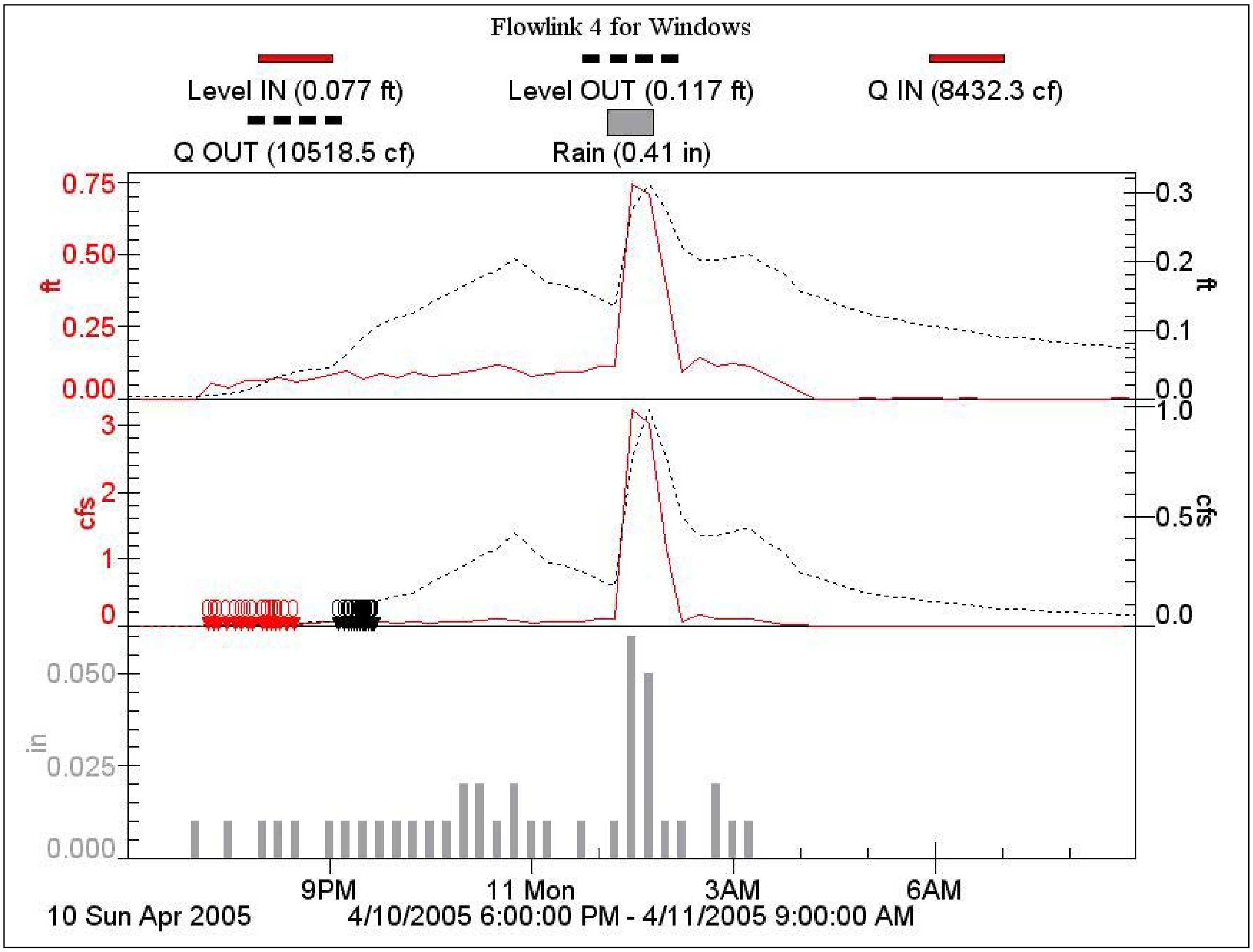
Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph. Note: there are apparent rain gauge errors as flow does not match rain for the sampled hydrograph.

Figure E21. Influent and effluent hydrographs and associated sample collection times for storm 24.



Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph. Note: rainfall does not match the hydrograph.

Figure E22. Influent and effluent hydrographs and associated sample collection times for storm 25.



Notes: Discharge and stage into the Ecology Embankment (unadjusted slot drain discharge) is represented by the red line. Discharge and stage exiting the Ecology Embankment is represented by the dashed black line. Sampling times are represented by triangles on the x-axis of the discharge graph.

APPENDIX F

Laboratory Report, Chain-of-Custody Records, and Quality Assurance Worksheets for Collected Water Quality Data

APPENDIX G

Dissolved Zinc and Copper Removal Efficiency Data from Basic Treatment Facilities

Table G1. Dissolved zinc removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Biofilter	Altadena (strip)	2/16/00	58	7.9	86.4%
Biofilter	Altadena (strip)	2/27/00	28	12	57.1%
Biofilter	Altadena (strip)	3/8/00	29	13	55.2%
Biofilter	Altadena (strip)	4/18/00	43.1	29.2	32.3%
Biofilter	Altadena (strip)	10/27/00	131	71	45.8%
Biofilter	Altadena (strip)	1/12/01	44	23	47.7%
Biofilter	Altadena (strip)	1/24/01	58	43	25.9%
Biofilter	Altadena (strip)	2/10/01	66	63	4.5%
Biofilter	Altadena (strip)	4/7/01	40	23	42.5%
Biofilter	Altadena (strip)	4/20/01	35	20	42.9%
Biofilter	Carlsbad Biofiltration Strip	2/20/00	100	29	71.0%
Biofilter	Carlsbad Biofiltration Strip	3/5/00	84	23	72.6%
Biofilter	Carlsbad Biofiltration Strip	4/17/00	160	49	69.4%
Biofilter	Carlsbad Biofiltration Strip	10/29/00	68	32	52.9%
Biofilter	Carlsbad Biofiltration Strip	1/26/01	94	38	59.6%
Biofilter	Carlsbad Biofiltration Strip	2/23/01	74	34	54.1%
Biofilter	Carlsbad Biofiltration Strip	3/6/01	83	20	75.9%
Biofilter	Cerritos MS	2/21/00	30.1	17.6	41.5%
Biofilter	Cerritos MS	2/27/00	58	35	39.7%
Biofilter	Cerritos MS	3/8/00	52.3	48.6	7.1%
Biofilter	Cerritos MS	4/18/00	105	50.3	52.1%
Biofilter	Cerritos MS	10/27/00	136	53	61.0%
Biofilter	Cerritos MS	1/12/01	94	21	77.7%
Biofilter	Cerritos MS	4/7/01	118	29	75.4%
Biofilter	I-5 North of Palomar Airport Road	2/20/00	23	41	-78.3%

Table G1 (continued). Dissolved zinc removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Biofilter	I-5 North of Palomar Airport Road	3/5/00	42	16	61.9%
Biofilter	I-5 North of Palomar Airport Road	4/17/00	83	26	68.7%
Biofilter	I-5 North of Palomar Airport Road	1/26/01	48	32	33.3%
Biofilter	I-5 North of Palomar Airport Road	2/12/01	33	31	6.1%
Biofilter	I-5 North of Palomar Airport Road	2/23/01	36	35	2.8%
Biofilter	I-5 North of Palomar Airport Road	3/6/01	33	34	-3.0%
Biofilter	I-5 North of Palomar Airport Road	4/7/01	130	72	44.6%
Biofilter	I-5 North of Palomar Airport Road	4/21/01	72	51	29.2%
Biofilter	I-5/I-605 Swale	2/20/00	26.6	6.2	76.7%
Biofilter	I-5/I-605 Swale	2/27/00	61	23.3	61.8%
Biofilter	I-5/I-605 Swale	3/8/00	69	33.2	51.9%
Biofilter	I-5/I-605 Swale	4/18/00	109	55.6	49.0%
Biofilter	I-5/I-605 Swale	10/27/00	113	42	62.8%
Biofilter	I-5/I-605 Swale	1/12/01	76	84	-10.5%
Biofilter	I-5/I-605 Swale	4/7/01	171	29	83.0%
Biofilter	I-605 / Del Amo	3/8/00	24.4	23.7	2.9%
Biofilter	I-605 / Del Amo	4/18/00	69.5	42.7	38.6%
Biofilter	I-605 / Del Amo	10/27/00	50	42	16.0%
Biofilter	I-605 / Del Amo	1/8/01	192	186	3.1%
Biofilter	I-605 / Del Amo	1/12/01	48	39	18.8%
Biofilter	I-605 / Del Amo	1/24/01	116	53	54.3%
Biofilter	I-605/SR-91 Strip	3/8/00	45	12.8	71.6%
Biofilter	I-605/SR-91 Strip	4/18/00	79	50.7	35.8%
Biofilter	I-605/SR-91 Strip	10/27/00	79	126	-59.5%

Table G1 (continued). Dissolved zinc removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Biofilter	I-605/SR-91 Strip	1/10/01	60	35	41.7%
Biofilter	I-605/SR-91 Strip	2/13/01	48	22	54.2%
Biofilter	I-605/SR-91 Strip	4/7/01	96	402	-318.8%
Biofilter	I-605/SR-91 Swale	3/8/00	72.9	20.5	71.9%
Biofilter	I-605/SR-91 Swale	4/18/00	141	45.4	67.8%
Biofilter	I-605/SR-91 Swale	10/27/00	173	82	52.6%
Biofilter	I-605/SR-91 Swale	1/10/01	75	44	41.3%
Biofilter	SR-78 / Melrose Dr	1/10/01	100	31	69.0%
Biofilter	SR-78 / Melrose Dr	1/26/01	130	29	77.7%
Biofilter	SR-78 / Melrose Dr	2/12/01	110	22	80.0%
Biofilter	SR-78 / Melrose Dr	2/23/01	120	20	83.3%
Detention Basin	I-15/SR-78 EDB	1/25/00	38	105	-176.3%
Detention Basin	I-15/SR-78 EDB	2/16/00	100	31	69.0%
Detention Basin	I-15/SR-78 EDB	2/20/00	48	27	43.8%
Detention Basin	I-15/SR-78 EDB	3/5/00	42	32	23.8%
Detention Basin	I-15/SR-78 EDB	4/17/00	26	34	-30.8%
Detention Basin	I-15/SR-78 EDB	10/29/00	28	36	-28.6%
Detention Basin	I-15/SR-78 EDB	1/8/01	49	65	-32.7%
Detention Basin	I-15/SR-78 EDB	1/10/01	21	33	-57.1%
Detention Basin	I-15/SR-78 EDB	1/26/01	20	36	-80.0%
Detention Basin	I-15/SR-78 EDB	2/10/01	21	21	0.0%
Detention Basin	I-15/SR-78 EDB	2/12/01	20	41	-105.0%
Detention Basin	I-15/SR-78 EDB	3/6/01	22	32	-45.5%
Detention Basin	I-15/SR-78 EDB	4/7/01	50	69	-38.0%

Table G1 (continued). Dissolved zinc removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Detention Basin	I-15/SR-78 EDB	4/21/01	51	47	7.8%
Detention Basin	I-5 / I-605 EDB	4/6/99	72	68	5.6%
Detention Basin	I-5 / I-605 EDB	4/11/99	40	53	-32.5%
Detention Basin	I-5 / I-605 EDB	2/20/00	44.4	36.1	18.7%
Detention Basin	I-5 / I-605 EDB	2/27/00	57.8	47.3	18.2%
Detention Basin	I-5 / I-605 EDB	3/8/00	42.9	11.95	72.1%
Detention Basin	I-5 / I-605 EDB	4/17/00	65	15	76.9%
Detention Basin	I-5 / I-605 EDB	10/27/00	128	62	51.6%
Detention Basin	I-5 / I-605 EDB	1/12/01	54	23	57.4%
Detention Basin	I-5 / I-605 EDB	2/14/01	47	46	2.1%
Detention Basin	I-5 / I-605 EDB	3/7/01	40	32	20.0%
Detention Basin	I-5 / I-605 EDB	4/8/01	77	58	24.7%
Detention Basin	I-5 / SR-56	1/25/00	21	23	-9.5%
Detention Basin	I-5 / SR-56	2/16/00	22	17	22.7%
Detention Basin	I-5 / SR-56	2/20/00	29	18	37.9%
Detention Basin	I-5 / SR-56	10/26/00	21	30	-42.9%
Detention Basin	I-5 / SR-56	2/23/01	29	22	24.1%
Detention Basin	I-5 / SR-56	4/7/01	22	25	-13.6%
Detention Basin	I-5 / SR-56	4/21/01	23	19	17.4%
Detention Basin	I-5/Manchester (east)	2/16/00	74	76	-2.7%
Detention Basin	I-5/Manchester (east)	2/20/00	110	60	45.5%
Detention Basin	I-5/Manchester (east)	3/5/00	67	63	6.0%
Detention Basin	I-5/Manchester (east)	4/17/00	100	91	9.0%
Detention Basin	I-5/Manchester (east)	10/26/00	120	110	8.3%

Table G1 (continued). Dissolved zinc removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Detention Basin	I-5/Manchester (east)	10/29/00	100	100	0.0%
Detention Basin	I-5/Manchester (east)	1/8/01	140	82	41.4%
Detention Basin	I-5/Manchester (east)	1/10/01	73	83	-13.7%
Detention Basin	I-5/Manchester (east)	1/26/01	63	73	-15.9%
Detention Basin	I-5/Manchester (east)	2/12/01	62	44	29.0%
Detention Basin	I-5/Manchester (east)	2/23/01	100	140	-40.0%
Detention Basin	I-5/Manchester (east)	3/6/01	45	73	-62.2%
Detention Basin	I-5/Manchester (east)	4/7/01	170	190	-11.8%
Detention Basin	I-5/Manchester (east)	4/21/01	130	140	-7.7%
Detention Basin	I-605 / SR-91 EDB	3/25/99	130	130	0.0%
Detention Basin	I-605 / SR-91 EDB	4/6/99	73	88	-20.5%
Detention Basin	I-605 / SR-91 EDB	4/11/99	56	43	23.2%
Detention Basin	I-605 / SR-91 EDB	2/27/00	263	175	33.5%
Detention Basin	I-605 / SR-91 EDB	3/8/00	176	75.6	57.0%
Detention Basin	I-605 / SR-91 EDB	4/17/00	79	79	0.0%
Detention Basin	I-605 / SR-91 EDB	10/27/00	56	59	-5.4%
Detention Basin	I-605 / SR-91 EDB	1/25/01	244	141	42.2%
Detention Basin	I-605 / SR-91 EDB	2/14/01	135	62	54.1%
Detention Basin	I-605 / SR-91 EDB	3/6/01	176	116	34.1%
Detention Basin	I-605 / SR-91 EDB	4/7/01	193	95	50.8%
Media Filter	Eastern Regional MS	4/6/99	37	6	83.8%
Media Filter	Eastern Regional MS	2/20/00	33.7	7.55	77.6%
Media Filter	Eastern Regional MS	2/27/00	37.1	20.4	45.0%
Media Filter	Eastern Regional MS	3/8/00	39.9	0.5	98.7%

Table G1 (continued). **Dissolved zinc removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.**

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Media Filter	Eastern Regional MS	4/17/00	35	19	45.7%
Media Filter	Eastern Regional MS	1/12/01	29	21	27.6%
Media Filter	Eastern Regional MS	1/25/01	102	77	24.5%
Media Filter	Eastern Regional MS	2/14/01	54	23	57.4%
Media Filter	Eastern Regional MS	3/6/01	47	43	8.5%
Media Filter	Eastern Regional MS	4/7/01	76	41	46.1%
Media Filter	Escondido MS	1/25/00	210	16	92.4%
Media Filter	Escondido MS	2/16/00	110	4.5	95.9%
Media Filter	Escondido MS	2/20/00	97	6.2	93.6%
Media Filter	Escondido MS	3/5/00	170	0.5	99.7%
Media Filter	Escondido MS	4/17/00	170	46	72.9%
Media Filter	Escondido MS	10/29/00	230	44	80.9%
Media Filter	Escondido MS	1/26/01	210	15	92.9%
Media Filter	Escondido MS	2/10/01	160	8.9	94.4%
Media Filter	Escondido MS	2/12/01	160	8	95.0%
Media Filter	Escondido MS	2/25/01	260	8.8	96.6%
Media Filter	Escondido MS	3/6/01	230	9.5	95.9%
Media Filter	Foothill MS (Sand Filter)	4/6/99	110	21	80.9%
Media Filter	Foothill MS (Sand Filter)	4/11/99	120	21	82.5%
Media Filter	Foothill MS (Sand Filter)	2/20/00	151	22.6	85.0%
Media Filter	Foothill MS (Sand Filter)	2/27/00	155	34.4	77.8%
Media Filter	Foothill MS (Sand Filter)	3/8/00	157	87.4	44.3%
Media Filter	Foothill MS (Sand Filter)	4/17/00	220	110	50.0%
Media Filter	Foothill MS (Sand Filter)	1/25/01	160	48	70.0%

Table G1 (continued). Dissolved zinc removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Media Filter	Foothill MS (Sand Filter)	2/10/01	159	55	65.4%
Media Filter	Foothill MS (Sand Filter)	3/6/01	96	87	9.4%
Media Filter	Foothill MS (Sand Filter)	4/7/01	134	42	68.7%
Media Filter	Foothill MS (Sand Filter)	4/21/01	113	50	55.8%
Media Filter	I-5/SR-78 P&R	1/25/00	200	29	85.5%
Media Filter	I-5/SR-78 P&R	2/16/00	49	24	51.0%
Media Filter	I-5/SR-78 P&R	2/20/00	27	5.8	78.5%
Media Filter	I-5/SR-78 P&R	3/8/00	35	6.5	81.4%
Media Filter	I-5/SR-78 P&R	4/17/00	220	35	84.1%
Media Filter	I-5/SR-78 P&R	10/26/00	210	44	79.0%
Media Filter	I-5/SR-78 P&R	10/29/00	57	15	73.7%
Media Filter	I-5/SR-78 P&R	1/8/01	230	82	64.3%
Media Filter	I-5/SR-78 P&R	1/10/01	35	59	-68.6%
Media Filter	I-5/SR-78 P&R	1/26/01	59	21	64.4%
Media Filter	I-5/SR-78 P&R	2/10/01	78	27	65.4%
Media Filter	I-5/SR-78 P&R	2/12/01	27	10	63.0%
Media Filter	I-5/SR-78 P&R	2/23/01	52	23	55.8%
Media Filter	I-5/SR-78 P&R	3/6/01	80	26	67.5%
Media Filter	I-5/SR-78 P&R	4/7/01	200	83	58.5%
Media Filter	I-5/SR-78 P&R	4/21/01	170	88	48.2%
Media Filter	La Costa P&R	1/25/00	220	2.25	99.0%
Media Filter	La Costa P&R	2/16/00	64	3.2	95.0%
Media Filter	La Costa P&R	2/20/00	25	1.6	93.6%
Media Filter	La Costa P&R	3/5/00	23	3	87.0%

Table G1 (continued). Dissolved zinc removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Media Filter	La Costa P&R	4/17/00	81	9.8	87.9%
Media Filter	La Costa P&R	10/26/00	85	8.1	90.5%
Media Filter	La Costa P&R	1/8/01	120	17	85.8%
Media Filter	La Costa P&R	1/26/01	21	6	71.4%
Media Filter	La Costa P&R	2/23/01	28	7.6	72.9%
Media Filter	La Costa P&R	4/7/01	100	18	82.0%
Media Filter	La Costa P&R	4/21/01	170	22	87.1%
Media Filter	Lakewood P&R	2/20/00	41.6	19	54.3%
Media Filter	Lakewood P&R	2/27/00	81.3	17.4	78.6%
Media Filter	Lakewood P&R	1/10/01	53	38	28.3%
Media Filter	Lakewood P&R	2/12/01	59	28	52.5%
Media Filter	Lakewood RP SF Vault (95)	5/13/95	130	30	76.9%
Media Filter	Lakewood RP SF Vault (95)	5/23/95	50	30	40.0%
Media Filter	Termination P&R	2/20/00	27.2	17.1	37.1%
Media Filter	Termination P&R	2/27/00	55.5	20.2	63.6%
Media Filter	Termination P&R	4/17/00	130	57	56.2%
Media Filter	Termination P&R	10/27/00	72	98	-36.1%
Media Filter	Termination P&R	1/24/01	81	115	-42.0%
Media Filter	Termination P&R	2/11/01	60	54	10.0%
Media Filter	Termination P&R	3/7/01	27	45	-66.7%
Media Filter	Termination P&R	4/7/01	135	53	60.7%
Media Filter	Via Verde P&R	2/20/00	23.4	5.3	77.4%
Media Filter	Via Verde P&R	2/27/00	33.3	2.2	93.4%
Media Filter	Via Verde P&R	4/17/00	44	8	81.8%

Table G1 (continued). Dissolved zinc removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Media Filter	Via Verde P&R	10/27/00	118	28	76.3%
Media Filter	Via Verde P&R	1/11/01	47	15	68.1%
Media Filter	Via Verde P&R	4/7/01	57	9.5	83.3%
Media Filter	Via Verde P&R	4/21/01	87	13	85.1%
Retention Pond	I-5 / La Costa (east)	1/25/00	120	40	66.7%
Retention Pond	I-5 / La Costa (east)	2/16/00	96	34	64.6%
Retention Pond	I-5 / La Costa (east)	2/20/00	28	33	-17.9%
Retention Pond	I-5 / La Costa (east)	3/5/00	44	38	13.6%
Retention Pond	I-5 / La Costa (east)	4/17/00	43	85	-97.7%
Retention Pond	I-5 / La Costa (east)	1/8/01	120	16	86.7%
Retention Pond	I-5 / La Costa (east)	1/10/01	23	18	21.7%
Retention Pond	I-5 / La Costa (east)	1/26/01	22	14	36.4%
Retention Pond	I-5 / La Costa (east)	2/12/01	23	32	-39.1%
Retention Pond	I-5 / La Costa (east)	2/25/01	34	30	11.8%
Retention Pond	I-5 / La Costa (east)	3/6/01	30	13	56.7%
Retention Pond	I-5 / La Costa (east)	4/7/01	62	41	33.9%
Retention Pond	I-5 / La Costa (east)	4/21/01	74	30	59.5%
Retention Pond	Lakewood RP Vault (97-98)	4/24/97	40	30	25.0%
Retention Pond	Lakewood RP Vault (97-98)	5/15/97	200	120	40.0%
Retention Pond	Lakewood RP Vault (97-98)	5/22/97	80	20	75.0%
Retention Pond	Lakewood RP Vault (97-98)	7/28/97	60	40	33.3%
Retention Pond	Lakewood RP Vault (97-98)	7/29/97	20	20	0.0%
Retention Pond	Lakewood RP Vault (97-98)	5/24/98	50	80	-60.0%
Retention Pond	Lakewood RP Vault (97-98)	6/5/98	30	60	-100.0%

Table G1 (continued). **Dissolved zinc removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.**

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Retention Pond	Lakewood RP Vault (97-98)	6/15/98	80	70	12.5%
Retention Pond	Lakewood RP Vault (97-98)	6/22/98	130	20	84.6%
Retention Pond	Lakewood RP Vault (97-98)	7/9/98	80	80	0.0%
Retention Pond	Lakewood RP Vault (97-98)	7/22/98	70	40	42.9%
Retention Pond	Lakewood RP Vault (97-98)	7/25/98	30	20	33.3%
Retention Pond	Lakewood RP Vault (97-98)	7/30/98	50	30	40.0%
Retention Pond	Lakewood RP Vault (97-98)	8/10/98	40	30	25.0%
Retention Pond	Lakewood RP Vault (97-98)	9/1/98	220	120	45.5%
Retention Pond	Lakewood RP SF Vault (95)	5/13/95	20	130	-550.0%
Retention Pond	Lakewood RP SF Vault (95)	5/16/95	20	30	-50.0%
Retention Pond	Lakewood RP SF Vault (95)	5/23/95	50	50	0.0%
		Median:	67.5	32.5	45.8%
		Minimum:	20	0.5	-550.0%
		Maximum:	263	402	99.7%

Data source: ASCE 2006

Table G2. Dissolved copper removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Biofilter	Altadena (strip)	2/16/2000	4.7	1.35	71.30%
Biofilter	Altadena (strip)	2/27/2000	4.6	1.7	63.00%
Biofilter	Altadena (strip)	4/18/2000	4.8	4.8	0.00%
Biofilter	Altadena (strip)	10/27/2000	12	12	0.00%
Biofilter	Altadena (strip)	1/12/2001	3.3	2.9	12.10%
Biofilter	Altadena (strip)	1/24/2001	6.1	5.3	13.10%
Biofilter	Altadena (strip)	2/10/2001	8.4	7.9	6.00%
Biofilter	Carlsbad Biofiltration Strip	1/26/2001	19	1.9	90.00%
Biofilter	Carlsbad Biofiltration Strip	2/23/2001	13	3.9	70.00%
Biofilter	Cerritos MS	2/21/2000	4.1	4.1	0.00%
Biofilter	Cerritos MS	2/27/2000	17.8	15.6	12.40%
Biofilter	Cerritos MS	3/8/2000	11.1	11.7	-5.40%
Biofilter	Cerritos MS	1/12/2001	11	8	27.30%
Biofilter	I-5 North of Palomar Airport Road	2/20/2000	7.2	9.7	-34.70%
Biofilter	I-5 North of Palomar Airport Road	3/5/2000	8.6	5.1	40.70%
Biofilter	I-5 North of Palomar Airport Road	4/17/2000	19	11	42.10%
Biofilter	I-5 North of Palomar Airport Road	1/26/2001	11	9.6	12.70%
Biofilter	I-5 North of Palomar Airport Road	2/12/2001	7.3	5.9	19.20%
Biofilter	I-5 North of Palomar Airport Road	2/23/2001	13	13	0.00%
Biofilter	I-5 North of Palomar Airport Road	3/6/2001	7.3	7.3	0.00%
Biofilter	I-5 North of Palomar Airport Road	4/21/2001	15	13	13.30%
Biofilter	I-5/I-605 Swale	2/20/2000	3.1	1.3	58.10%
Biofilter	I-5/I-605 Swale	2/27/2000	12.2	9.3	23.80%
Biofilter	I-5/I-605 Swale	3/8/2000	13.4	9.5	29.10%
Biofilter	I-5/I-605 Swale	4/18/2000	17.1	15	12.30%

Table G2 (continued). Dissolved copper removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Biofilter	I-5/I-605 Swale	10/27/2000	15	9.9	34.00%
Biofilter	I-5/I-605 Swale	1/12/2001	6.5	12	-84.60%
Biofilter	I-605 / Del Amo	3/8/2000	9.4	8.5	9.60%
Biofilter	I-605 / Del Amo	4/18/2000	18.9	17.2	9.00%
Biofilter	I-605 / Del Amo	10/27/2000	16	15	6.30%
Biofilter	I-605 / Del Amo	1/12/2001	8.9	9	-1.10%
Biofilter	I-605/SR-91 Strip	3/8/2000	11.2	6.4	42.90%
Biofilter	I-605/SR-91 Strip	10/27/2000	12	14	-16.70%
Biofilter	I-605/SR-91 Strip	1/10/2001	11	10	9.10%
Biofilter	I-605/SR-91 Strip	2/13/2001	9.2	6.9	25.00%
Biofilter	I-605/SR-91 Strip	4/7/2001	18	24	-33.30%
Biofilter	I-605/SR-91 Swale	3/8/2000	10.8	11.5	-6.50%
Biofilter	I-605/SR-91 Swale	4/18/2000	19	16	15.80%
Biofilter	I-605/SR-91 Swale	10/27/2000	16	18	-12.50%
Biofilter	I-605/SR-91 Swale	1/10/2001	7.4	17	-129.70%
Biofilter	SR-78 / Melrose Dr	1/10/2001	11	7.4	32.70%
Biofilter	SR-78 / Melrose Dr	1/26/2001	11	4.3	60.90%
Biofilter	SR-78 / Melrose Dr	2/12/2001	10	4.5	55.00%
Biofilter	SR-78 / Melrose Dr	2/23/2001	8.6	3.6	58.10%
Biofilter	SR-78 / Melrose Dr	4/7/2001	18	6.7	62.80%
Detention Basin	I-15/SR-78 EDB	2/16/2000	15	11	26.70%
Detention Basin	I-15/SR-78 EDB	2/20/2000	8.8	7	20.50%
Detention Basin	I-15/SR-78 EDB	3/5/2000	6.2	7	-12.90%
Detention Basin	I-15/SR-78 EDB	4/17/2000	12	12	0.00%

Table G2 (continued). Dissolved copper removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Detention Basin	I-15/SR-78 EDB	10/29/2000	11	12	-9.10%
Detention Basin	I-15/SR-78 EDB	1/10/2001	9.1	9.7	-6.60%
Detention Basin	I-15/SR-78 EDB	1/26/2001	7.7	8.4	-9.10%
Detention Basin	I-15/SR-78 EDB	2/10/2001	10	9.3	7.00%
Detention Basin	I-15/SR-78 EDB	2/12/2001	6.2	8.1	-30.60%
Detention Basin	I-15/SR-78 EDB	2/23/2001	7.1	7.7	-8.50%
Detention Basin	I-15/SR-78 EDB	3/6/2001	6.4	7.1	-10.90%
Detention Basin	I-15/SR-78 EDB	4/7/2001	12	14	-16.70%
Detention Basin	I-15/SR-78 EDB	4/21/2001	13	11	15.40%
Detention Basin	I-5 / I-605 EDB	4/6/1999	17	19	-11.80%
Detention Basin	I-5 / I-605 EDB	4/11/1999	8.7	8.1	6.90%
Detention Basin	I-5 / I-605 EDB	2/20/2000	4.32	4.85	-12.30%
Detention Basin	I-5 / I-605 EDB	2/27/2000	8.49	9.06	-6.70%
Detention Basin	I-5 / I-605 EDB	3/8/2000	6.42	8.35	-30.10%
Detention Basin	I-5 / I-605 EDB	4/17/2000	9.4	5.8	38.30%
Detention Basin	I-5 / I-605 EDB	10/27/2000	16	9.5	40.60%
Detention Basin	I-5 / I-605 EDB	1/12/2001	4.9	5.1	-4.10%
Detention Basin	I-5 / I-605 EDB	1/25/2001	9.4	2.6	72.30%
Detention Basin	I-5 / I-605 EDB	2/14/2001	8.2	5.2	36.60%
Detention Basin	I-5 / I-605 EDB	3/7/2001	7.6	8	-5.30%
Detention Basin	I-5 / I-605 EDB	4/8/2001	13	12	7.70%
Detention Basin	I-5 / SR-56	1/25/2000	20	26	-30.00%
Detention Basin	I-5 / SR-56	2/16/2000	12	11	8.30%
Detention Basin	I-5 / SR-56	2/20/2000	9.2	7	23.90%

Table G2 (continued). Dissolved copper removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Detention Basin	I-5 / SR-56	3/5/2000	3.8	5.6	-47.40%
Detention Basin	I-5 / SR-56	4/17/2000	7.9	12	-51.90%
Detention Basin	I-5 / SR-56	10/26/2000	11	13	-18.20%
Detention Basin	I-5 / SR-56	1/10/2001	5.5	5.3	3.60%
Detention Basin	I-5 / SR-56	1/26/2001	7.2	5.7	20.80%
Detention Basin	I-5 / SR-56	2/23/2001	8	6.5	18.80%
Detention Basin	I-5 / SR-56	3/6/2001	3.9	3.9	0.00%
Detention Basin	I-5 / SR-56	4/7/2001	12	12	0.00%
Detention Basin	I-5 / SR-56	4/21/2001	14	16	-14.30%
Detention Basin	I-5/Manchester (east)	2/16/2000	16	15	6.30%
Detention Basin	I-5/Manchester (east)	2/20/2000	14	12	14.30%
Detention Basin	I-5/Manchester (east)	3/5/2000	8.6	10	-16.30%
Detention Basin	I-5/Manchester (east)	10/29/2000	16	19	-18.80%
Detention Basin	I-5/Manchester (east)	1/10/2001	11	13	-18.20%
Detention Basin	I-5/Manchester (east)	1/26/2001	13	13	0.00%
Detention Basin	I-5/Manchester (east)	2/12/2001	8.9	4.8	46.10%
Detention Basin	I-5/Manchester (east)	2/23/2001	14	12	14.30%
Detention Basin	I-5/Manchester (east)	3/6/2001	7.9	12	-51.90%
Detention Basin	I-605 / SR-91 EDB	3/25/1999	15	14	6.70%
Detention Basin	I-605 / SR-91 EDB	4/6/1999	13	12	7.70%
Detention Basin	I-605 / SR-91 EDB	4/11/1999	7.4	6.7	9.50%
Detention Basin	I-605 / SR-91 EDB	2/27/2000	14.5	24.3	-67.60%
Detention Basin	I-605 / SR-91 EDB	3/8/2000	14.5	10.3	29.00%
Detention Basin	I-605 / SR-91 EDB	4/17/2000	14	16	-14.30%

Table G2 (continued). Dissolved copper removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Detention Basin	I-605 / SR-91 EDB	10/27/2000	9.1	12	-31.90%
Detention Basin	I-605 / SR-91 EDB	2/14/2001	9.8	7.4	24.50%
Detention Basin	I-605 / SR-91 EDB	3/6/2001	10	21	-110.00%
Detention Basin	Lexington Hills - Detention Pond	5/26/2000	4.26	5.35	-25.60%
Detention Basin	Lexington Hills - Detention Pond	5/13/2002	9.65	8.84	8.40%
Detention Basin	Lexington Hills - Detention Pond	6/17/2002	3.31	4.08	-23.30%
Media Filter	Eastern Regional MS	4/6/1999	10	7.8	22.00%
Media Filter	Eastern Regional MS	2/20/2000	5	3.74	25.20%
Media Filter	Eastern Regional MS	2/27/2000	8.02	7.51	6.40%
Media Filter	Eastern Regional MS	3/8/2000	3.29	3.03	7.90%
Media Filter	Eastern Regional MS	4/17/2000	7.3	6.9	5.50%
Media Filter	Eastern Regional MS	1/12/2001	4.8	4.7	2.10%
Media Filter	Eastern Regional MS	1/25/2001	17	19	-11.80%
Media Filter	Eastern Regional MS	2/14/2001	5.4	3.6	33.30%
Media Filter	Eastern Regional MS	3/6/2001	6.2	6.6	-6.50%
Media Filter	Eastern Regional MS	4/7/2001	5	6.3	-26.00%
Media Filter	Escondido MS	2/16/2000	3.5	3	14.30%
Media Filter	Escondido MS	4/17/2000	5.5	7	-27.30%
Media Filter	Escondido MS	10/29/2000	8.5	4.6	45.90%
Media Filter	Escondido MS	1/26/2001	10	2	80.00%
Media Filter	Escondido MS	2/10/2001	7.9	4	49.40%
Media Filter	Escondido MS	3/6/2001	3.7	2	45.90%
Media Filter	Escondido MS	4/7/2001	7.6	5.6	26.30%
Media Filter	Escondido MS	4/21/2001	9.1	4.6	49.50%

Table G2 (continued). Dissolved copper removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Media Filter	Foothill MS (Sand Filter)	4/6/1999	19	14	26.30%
Media Filter	Foothill MS (Sand Filter)	2/20/2000	5.36	4.15	22.60%
Media Filter	Foothill MS (Sand Filter)	2/27/2000	4.49	5.52	-22.90%
Media Filter	Foothill MS (Sand Filter)	3/8/2000	18	7	61.10%
Media Filter	Foothill MS (Sand Filter)	4/17/2000	6.8	7.3	-7.40%
Media Filter	Foothill MS (Sand Filter)	10/27/2000	14	30	-114.30%
Media Filter	Foothill MS (Sand Filter)	1/25/2001	9.2	11	-19.60%
Media Filter	Foothill MS (Sand Filter)	2/10/2001	8.8	12	-36.40%
Media Filter	Foothill MS (Sand Filter)	3/6/2001	4	5.8	-45.00%
Media Filter	Foothill MS (Sand Filter)	4/7/2001	6.6	8.8	-33.30%
Media Filter	Foothill MS (Sand Filter)	4/21/2001	5.6	7.8	-39.30%
Media Filter	I-5/SR-78 P&R	2/16/2000	12	10	16.70%
Media Filter	I-5/SR-78 P&R	2/20/2000	5.9	4	32.20%
Media Filter	I-5/SR-78 P&R	3/8/2000	5.2	5	3.80%
Media Filter	I-5/SR-78 P&R	4/17/2000	18	20	-11.10%
Media Filter	I-5/SR-78 P&R	10/26/2000	16	13	18.80%
Media Filter	I-5/SR-78 P&R	10/29/2000	4.6	4.8	-4.30%
Media Filter	I-5/SR-78 P&R	1/10/2001	3.6	11	-205.60%
Media Filter	I-5/SR-78 P&R	1/26/2001	4.7	3.5	25.50%
Media Filter	I-5/SR-78 P&R	2/10/2001	7.3	5.9	19.20%
Media Filter	I-5/SR-78 P&R	2/23/2001	3.1	3.4	-9.70%
Media Filter	I-5/SR-78 P&R	3/6/2001	11	4.6	58.20%
Media Filter	I-5/SR-78 P&R	4/7/2001	12	12	0.00%
Media Filter	I-5/SR-78 P&R	4/21/2001	12	10	16.70%

Table G2 (continued). Dissolved copper removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Media Filter	La Costa P&R	2/16/2000	9.3	6.5	30.10%
Media Filter	La Costa P&R	2/20/2000	3.8	2.4	36.80%
Media Filter	La Costa P&R	4/17/2000	8.4	10	-19.00%
Media Filter	La Costa P&R	10/26/2000	8.4	6.9	17.90%
Media Filter	La Costa P&R	1/8/2001	18	15	16.70%
Media Filter	La Costa P&R	1/10/2001	3.6	3.2	11.10%
Media Filter	La Costa P&R	2/23/2001	3.2	2.7	15.60%
Media Filter	La Costa P&R	3/6/2001	3	2.6	13.30%
Media Filter	La Costa P&R	4/7/2001	9.2	9.5	-3.30%
Media Filter	La Costa P&R	4/21/2001	18	8.8	51.10%
Media Filter	Lakewood P&R	2/27/2000	5.37	3	44.10%
Media Filter	Lakewood P&R	1/10/2001	5.5	10	-81.80%
Media Filter	Lakewood P&R	2/12/2001	4.8	4.1	14.60%
Media Filter	Lakewood RP SF Vault (95)	5/16/1995	11	7	36.40%
Media Filter	Lakewood RP SF Vault (95)	5/23/1995	14	18	-28.60%
Media Filter	Termination P&R	2/20/2000	3.94	3.56	9.60%
Media Filter	Termination P&R	2/27/2000	6.9	6.33	8.30%
Media Filter	Termination P&R	4/17/2000	16	13	18.80%
Media Filter	Termination P&R	10/27/2000	7.4	22	-197.30%
Media Filter	Termination P&R	1/24/2001	14	10	28.60%
Media Filter	Termination P&R	2/11/2001	9.2	9.1	1.10%
Media Filter	Termination P&R	3/7/2001	4.5	6.6	-46.70%
Media Filter	Termination P&R	4/7/2001	14	12	14.30%
Media Filter	Via Verde P&R	4/17/2000	3.6	4.6	-27.80%

Table G2 (continued). Dissolved copper removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Media Filter	Via Verde P&R	10/27/2000	6.9	13	-88.40%
Media Filter	Via Verde P&R	4/7/2001	3	3.1	-3.30%
Media Filter	Via Verde P&R	4/21/2001	6	1.7	71.70%
Retention Pond	I-5 / La Costa (east)	2/20/2000	11	12	-9.10%
Retention Pond	I-5 / La Costa (east)	3/5/2000	8	12	-50.00%
Retention Pond	I-5 / La Costa (east)	4/17/2000	17	27	-58.80%
Retention Pond	I-5 / La Costa (east)	1/10/2001	14	4.6	67.10%
Retention Pond	I-5 / La Costa (east)	2/12/2001	6.5	11	-69.20%
Retention Pond	I-5 / La Costa (east)	2/25/2001	8.4	5.7	32.10%
Retention Pond	I-5 / La Costa (east)	3/6/2001	7.5	2.2	70.70%
Retention Pond	I-5 / La Costa (east)	4/21/2001	20	2.8	86.00%
Retention Pond	Lakewood RP Vault (97-98)	5/22/1997	12	4	66.70%
Retention Pond	Lakewood RP Vault (97-98)	7/28/1997	13	8	38.50%
Retention Pond	Lakewood RP Vault (97-98)	7/29/1997	3	3	0.00%
Retention Pond	Lakewood RP Vault (97-98)	8/2/1997	14	4	71.40%
Retention Pond	Lakewood RP Vault (97-98)	5/24/1998	8	11	-37.50%
Retention Pond	Lakewood RP Vault (97-98)	6/5/1998	12	10	16.70%
Retention Pond	Lakewood RP Vault (97-98)	6/15/1998	20	7	65.00%
Retention Pond	Lakewood RP Vault (97-98)	7/9/1998	12	4	66.70%
Retention Pond	Lakewood RP Vault (97-98)	7/22/1998	11	6	45.50%
Retention Pond	Lakewood RP Vault (97-98)	7/25/1998	4	3	25.00%
Retention Pond	Lakewood RP Vault (97-98)	7/30/1998	8	4	50.00%
Retention Pond	Lakewood RP Vault (97-98)	8/10/1998	5	4	20.00%
Retention Pond	Lakewood RP SF Vault (95)	5/13/1995	19	22	-15.80%

Table G2 (continued). Dissolved copper removal efficiency data for basic treatment facilities that were obtained through the International Stormwater Best Management Practices Database.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Retention Pond	Lakewood RP SF Vault (95)	5/16/1995	9	11	-22.20%
Retention Pond	Lakewood RP SF Vault (95)	5/23/1995	8	14	-75.00%
		Median:	9.1	7.9	8.3%
		Minimum:	3	1.3	-205.6%
		Maximum:	20	30	90.0%

Data source: ASCE 2006

Table G3. Dissolved zinc removal efficiency data for basic treatment facilities that were obtained through WSDOT's NPDES permit monitoring program over the period from 2003 through 2005.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Dry Pond	Dry Pond I-5 MP 188	12/5/2003	31	22	29.00%
Dry Pond	Dry Pond I-5 MP 188	12/13/2003	44	21	52.30%
Dry Pond	Dry Pond I-5 MP 188	12/16/2003	49	21	57.10%
Dry Pond	Dry Pond I-5 MP 188	1/8/2004	95	21	77.90%
Dry Pond	Dry Pond I-5 MP 188	1/15/2004	39	32	17.90%
Dry Pond	Dry Pond I-5 MP 188	1/26/2004	28	24	14.30%
Dry Pond	Dry Pond I-5 MP 188	2/5/2004	37	20	45.90%
Dry Pond	Dry Pond I-5 MP 188	3/4/2004	33	16	51.50%
Dry Pond	Dry Pond I-5 MP 188	3/10/2004	20	12	40.00%
Vault	Chambered Vault SR 525 MP 4.1	10/25/2004	24	22	8.30%
Vault	Chambered Vault SR 525 MP 4.1	11/1/2004	30	22	26.70%
Vault	Chambered Vault SR 525 MP 4.1	12/30/2004	25	34	-36.00%
Vault	Chambered Vault SR 525 MP 4.1	3/28/2005	34	28	17.60%
Vault	Chambered Vault SR 525 MP 4.1	4/8/2005	42	31	26.20%
Vault	Chambered Vault SR 525 MP 4.1	5/16/2005	37	30	18.90%
Vault	Chambered Vault SR 525 MP 4.1	5/18/2005	32	23	28.10%
Vault	Closed Vault SR 405 MP 26	12/16/2003	20	18	10.00%
Vault	Closed Vault SR 405 MP 26	1/8/2004	38	47	-23.70%
Vault	Open Vault SR 405 MP 29.5	3/4/2004	46	39	15.20%
Vault	Open Vault SR 405 MP 29.5	11/24/2004	94	53	43.60%
Vault	Open Vault SR 405 MP 29.5	11/30/2004	71	38	46.50%
Vault	Open Vault SR 405 MP 29.5	12/6/2004	60	46	23.30%
Vault	Open Vault SR 405 MP 29.5	12/9/2004	60	39	35.00%
Vault	Open Vault SR 405 MP 29.5	12/10/2004	68	43	36.80%
Vault	Open Vault SR 405 MP 29.5	12/30/2004	100	49	51.00%

Table G3 (continued). Dissolved zinc removal efficiency data for basic treatment facilities that were obtained through WSDOT's NPDES permit monitoring program over the period from 2003 through 2005.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Vault	Open Vault SR 405 MP 29.5	2/4/2005	31	50	-61.30%
Vault	Open Vault SR 405 MP 29.5	3/21/2005	63	28	55.60%
Vault	Open Vault SR 405 MP 29.5	3/28/2005	30	25	16.70%
Vault	Open Vault SR 405 MP 29.5	3/29/2005	45	31	31.10%
Vault	Open Vault SR 405 MP 29.5	4/8/2005	53	38	28.30%
Vault	Open Vault SR 405 MP 29.5	4/11/2005	28	29	-3.60%
Vault	Open Vault SR 405 MP 29.5	5/18/2005	50	28	44.00%
Wet Pond	Wet Pond I-5 MP 96	11/17/2003	64	41	35.90%
Wet Pond	Wet Pond I-5 MP 96	11/25/2003	64	44	31.30%
Wet Pond	Wet Pond I-5 MP 96	11/28/2003	44	38	13.60%
Wet Pond	Wet Pond I-5 MP 96	12/5/2003	61	36	41.00%
Wet Pond	Wet Pond I-5 MP 96	12/13/2003	57	30	47.40%
Wet Pond	Wet Pond I-5 MP 96	1/23/2004	63	40	36.50%
Wet Pond	Wet Pond I-5 MP 96	1/28/2004	54	28	48.10%
Wet Pond	Wet Pond I-5 MP 96	11/26/2004	56	37	33.90%
Wet Pond	Wet Pond I-5 MP 96	12/9/2004	86	33	62.20%
		Median:	45	31	31.3%
		Minimum:	20	12	-61.3%
		Maximum:	100	53	77.9%

Data source: WSDOT 2006a
NPDES: National Point Source Elimination System

Table G4. Dissolved copper removal efficiency data for basic treatment facilities that were obtained through WSDOT's NPDES permit monitoring program over the period from 2003 through 2005.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Dry Pond	Dry Pond I-5 MP 188	12/5/2003	3.3	2.5	24.2%
Dry Pond	Dry Pond I-5 MP 188	12/13/2003	4.0	2.8	30.0%
Dry Pond	Dry Pond I-5 MP 188	12/16/2003	4.1	2.7	34.1%
Dry Pond	Dry Pond I-5 MP 188	1/8/2004	7.5	2.9	61.3%
Dry Pond	Dry Pond I-5 MP 188	1/15/2004	6.9	2.5	63.8%
Dry Pond	Dry Pond I-5 MP 188	1/26/2004	3.6	2.8	22.2%
Dry Pond	Dry Pond I-5 MP 188	2/5/2004	3.9	2.2	43.6%
Dry Pond	Dry Pond I-5 MP 188	3/4/2004	4.6	3.1	32.6%
Dry Pond	Dry Pond I-5 MP 188	3/10/2004	5.7	3.2	43.9%
Vault	Chambered Vault SR 525 MP 4.1	10/25/2004	4.3	2.9	32.6%
Vault	Chambered Vault SR 525 MP 4.1	11/1/2004	3.1	1.9	38.7%
Vault	Chambered Vault SR 525 MP 4.1	3/28/2005	11	0.58	94.7%
Vault	Chambered Vault SR 525 MP 4.1	4/8/2005	8.5	6.3	25.9%
Vault	Chambered Vault SR 525 MP 4.1	5/16/2005	9.1	2.8	69.2%
Vault	Chambered Vault SR 525 MP 4.1	5/18/2005	6.6	3.9	40.9%
Vault	Closed Vault SR 405 MP 26	12/16/2003	3.2	3.8	-18.8%
Vault	Closed Vault SR 405 MP 26	1/8/2004	3.8	3.7	2.6%
Vault	Closed Vault SR 405 MP 26	1/15/2004	3.5	2.8	20.0%
Vault	Closed Vault SR 405 MP 26	1/26/2004	4.4	5.0	-13.6%
Vault	Open Vault SR 405 MP 29.5	3/4/2004	8.5	6.9	18.8%
Vault	Open Vault SR 405 MP 29.5	11/24/2004	10	7.3	27.0%
Vault	Open Vault SR 405 MP 29.5	11/30/2004	8.6	8.2	4.7%
Vault	Open Vault SR 405 MP 29.5	12/6/2004	5.7	6.3	-10.5%
Vault	Open Vault SR 405 MP 29.5	12/9/2004	5.9	6.0	-1.7%
Vault	Open Vault SR 405 MP 29.5	12/10/2004	8.3	6.9	16.9%

Table G4 (continued). Dissolved copper removal efficiency data for basic treatment facilities that were obtained through WSDOT's NPDES permit monitoring program over the period from 2003 through 2005.

BMP Type	Test Site Name	Sampling Date	Influent Concentration (µg/L)	Effluent Concentration (µg/L)	Method #1 Removal
Vault	Open Vault SR 405 MP 29.5	12/30/2004	14	5.7	59.3%
Vault	Open Vault SR 405 MP 29.5	2/4/2005	8.3	9.1	-9.6%
Vault	Open Vault SR 405 MP 29.5	3/21/2005	17	8.7	48.8%
Vault	Open Vault SR 405 MP 29.5	3/28/2005	8.0	8.4	-5.0%
Vault	Open Vault SR 405 MP 29.5	3/29/2005	9.2	7.3	20.7%
Vault	Open Vault SR 405 MP 29.5	4/8/2005	12	7.3	39.2%
Vault	Open Vault SR 405 MP 29.5	4/11/2005	5.7	7.2	-26.3%
Vault	Open Vault SR 405 MP 29.5	5/18/2005	13	7.6	41.5%
Wet Pond	Wet Pond I-5 MP 96	11/17/2003	3.6	4.7	-30.6%
Wet Pond	Wet Pond I-5 MP 96	11/25/2003	3.9	3.6	7.7%
Wet Pond	Wet Pond I-5 MP 96	11/28/2003	4.2	3.4	19.0%
Wet Pond	Wet Pond I-5 MP 96	12/5/2003	3.5	2.7	22.9%
Wet Pond	Wet Pond I-5 MP 96	1/23/2004	5.0	3.8	24.0%
Wet Pond	Wet Pond I-5 MP 96	1/28/2004	3.5	3.2	8.6%
Wet Pond	Wet Pond I-5 MP 96	12/9/2004	3.80	3.75	1.3%
		Median:	5.7	3.775	23.4%
		Minimum:	3.1	0.58	-30.6%
		Maximum:	17	9.1	94.7%

Data source: WSDOT 2006a
NPDES: National Point Source Elimination System