Lake Okeechobee Tributary Sediment Removal Demonstration Project

SFWMD Contract No. C-11205

Final Report

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Submitted to:

South Florida Water Management District
Dr. Rodolfo (Odi) Villapando
Project Manager

Prepared by:

Environmental Research & Design, Inc.
3419 Trentwood Blvd., Suite 102
Orlando, FL 32812
Dr. Harvey H. Harper, P.E.
Project Director

EXECUTIVE SUMMARY

Lettuce Creek is within Nubbin Slough Basin, northeast of Lake Okeechobee, and discharges to the lake through the L-63S Canal. Historical water quality monitoring, conducted by the South Florida Water Management District (District), suggests that Lettuce Creek may be a significant source of sediment and particulate loading to the L-63S Canal, particularly under high flow conditions.

From 2000-2004, a demonstration project was conducted in Lettuce Creek, just upstream of the point of discharge into the L-63S Canal, to evaluate the phosphorus reduction benefits which can be realized by removal of tributary sediment loads. Two sediment removal technologies were evaluated during this study, including Continuous Deflective Separation (CDS) and Tributary Sediment Trap (TST). Construction and installation of the CDS and TST units was conducted from February-April 2002. The units were constructed side-by-side, adjacent to Lettuce Creek, with a single 30-inch CMP intake pipe extending into Lettuce Creek. A series of structures and valves were also installed to split and regulate the flow discharging through the two units. Efficiency testing for the CDS and TST units was conducted from October 2002-November 2003 at inflow rates of 1, 5, and 11 cfs.

Flow rates in Lettuce Creek from November 1, 2002-December 1, 2003 were highly variable, depending primarily upon rainfall conditions. The vast majority of flow rates observed in Lettuce Creek were approximately 10 cfs or less. However, short-term increases in discharge rates to approximately 100 cfs were observed on two separate occasions and 475 cfs on one occasion.

Bulk water samples were collected from Lettuce Creek during low flow and high flow conditions to evaluate the characteristics of sediment particles contained in water samples from the creek. Under low flow conditions, approximately 50% of the sediment particles had a diameter of less than 11 μm. These particles are primarily organic in nature and characterized by an elevated phosphorus concentration and an extremely low settling velocity ($\sim 10^{-6}$ m/s). Under high flow conditions, approximately one-third of the particle sizes are less than 11 μm, with an additional one-third comprised of fine sand in the 100-140 μm range. This fine sand consists primarily of inert particles with a low phosphorus content and relatively rapid settling velocity. Increases in flow rates in Lettuce Creek were found to be positively correlated with orthophosphorus and total phosphorus concentrations, although no significant correlations were observed between flow rate and TSS, turbidity, or nitrogen species.

Concentrations of phosphorus species in Lettuce Creek were found to be highly variable, with measured concentrations of organic phosphorus, particulate phosphorus, and total phosphorus covering several orders of magnitude between minimum and maximum values. On an average basis, approximately 61% of the mean total phosphorus concentration of 898 μg/l is comprised of dissolved orthophosphorus, with 16% comprised of dissolved organic phosphorus, and 23% contributed by particulate phosphorus.

No significant removal of phosphorus species or TSS was observed in the CDS unit during operation at 1, 5, or 11 cfs. During operation at 1 cfs, the mass of total phosphorus increased by approximately 4% during migration through the CDS unit, with a net increase of 3% during operation at 5 cfs and a net reduction of 5% during operation at 11 cfs. Similar removal efficiencies were also observed in the TST unit. During operation at 1 cfs, the input mass of total phosphorus increased by approximately 1%, with a 1% removal at 5 cfs and a 1% increase at 11 cfs.

During a 207-day period of operation, the CDS unit collected 766.2 kg of dry solids which contained 0.14% total phosphorus and 0.44% total nitrogen. On an average basis, the CDS unit exhibited a mean TSS removal of 0.76 mg/l, with a mean total phosphorus removal of 1.1 μg/l and a mean total nitrogen removal of 3.4 μg/l. Over a 193-day operational period, the TST unit removed 408.8 kg of dry solids which contained 0.14% total phosphorus and 0.14% total nitrogen. On an average basis, the TST unit removed 0.57 mg/l of TSS, 0.79 μg/l of total phosphorus, and 0.77 μg/l of total nitrogen.

Based on calculated 20-year present worth costs, which includes construction plus O&M, the 20-year life-cycle cost for mass removal in the CDS unit is approximately $5.30/kg of dry solids, $3670/kg of total phosphorus, and $1199/kg of total nitrogen. The 20-year life-cycle cost for mass removal in the TST unit is approximately $6.21/kg of dry solids, $4511/kg of total phosphorus, and $4597/kg of total nitrogen.

Alum coagulation of the inflow to the CDS and TST units substantially enhanced removal of total phosphorus and TSS, with removals in excess of 90% for each parameter. Based on calculated 20-year present worth costs, which include construction plus O&M, the 20-year life-cycle cost for removal of TSS in the CDS and TST units ranges from $42.10-42.53/kg. The 20-year life-cycle cost for mass removal of total phosphorus ranges from $595-603/kg for the two units. These costs are substantially lower than the estimated mass removal costs for the unmodified units. However, alum coagulation would be much more cost-effective and efficient if a simple settling pond were to be used for collection of the floc rather than relying on the CDS or TST unit.

The inability of the solids separation units to remove phosphorus or suspended solids from Lettuce Creek inflow is attributed to three factors. First, only approximately 23% of the total phosphorus in Lettuce Creek exists in a particulate form. The vast majority of total phosphorus is dissolved and cannot be removed in the CDS and TST units. Second, the small diameter particles discharging into Lettuce Creek are too small to be removed effectively by solids separation technologies. Although each of the two units is capable of removing sand and larger particles, particulate phosphorus in Lettuce Creek is associated with particles which can easily pass through the CDS and TST units. Third, a substantial number of fish accumulated within the two units due to the open connection with Lettuce Creek. Although numerous attempts were made to control and remove the fish populations, inputs of waste products from both dead and living fish are thought to have contributed to the poor removal efficiencies.

ACKNOWLEDGEMENTS

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Ms. Kim Shugar	Florida Department of Environmental Protection

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SECTION 1

INTRODUCTION

1.1 Background

Lake Okeechobee is a critical water source for south Florida. The lake serves multiple purposes for the region, including drinking water supply; flood control; agricultural water supply; habitat for fish, birds, and other wildlife; urban and industrial water supply; and water supply for the Everglades. Over the past three decades, eutrophication of the lake has accelerated, largely due to excessive nonpoint source loadings from tributary basins north of the lake.

In 1987, the Florida Legislature delegated the South Florida Water Management District (District) to "design and implement a program to protect the water quality of Lake Okeechobee" (S. 373.4595, Florida Statutes) as part of the Surface Water Improvement and Management (SWIM) Act. The SWIM Act required that the program be designed to lower phosphorus loading to the lake by a specific amount. Since the implementation of the SWIM Plan, phosphorus loading to the lake has been significantly reduced through multiple phosphorus management practice programs. However, the overall pollution load reduction goal has not yet been achieved. The SWIM plan update of 1993 identified tributary sediment as a potential source of phosphorus to the lake that should be controlled.

A study was conducted in 1997 by the District and Mock, Roos & Associates, Inc. under Contract No. C-6770 titled, "Sediment Removal Feasibility Study." The purpose of that study was to determine the phosphorus content and transport potential of sediment from various tributaries in the north Lake Okeechobee watershed that convey stormwater runoff to the lake and to analyze feasible management alternatives for source removal and control. The study concluded that sediment removal will reduce phosphorus loads to Lake Okeechobee. The total phosphorus reduction achieved by sediment removal will be limited by the fraction of particulate phosphorus in the tributary bed load, estimated to be approximately 25%. It was estimated that between 5-25% of the particulate phosphorus entering the lake could be attenuated by direct sediment removal. The information from the study led to the development of the demonstration project addressed in this report. This project is designed to demonstrate the phosphorus reduction benefits which can be realized by tributary sediment removal. Before expanding sediment removal to other tributaries, this activity must be demonstrated to be technically feasible and economically viable.

In 2000, the District selected two sediment removal technologies, Continuous Deflective Separation (CDS) and Tributary Sediment Trap (TST), to be evaluated by this project. According to available literature (SFWMD, 1999), these technologies: (1) are effective in reducing particulate phosphorus loading; (2) can be applied in open channel flow conditions and have a high treatment capacity; (3) are on the lower end of cost for treatment facilities; and (4) can be easily maintained.

The CDS unit is a patented process designed for the removal of gross pollutants. It was developed in Australia by CDS Technologies, Ltd. and is manufactured in the United States by CDS Technologies, Inc. Inflow enters into the center chamber of the CDS unit and must pass through a screen to an outer chamber prior to discharging downstream. Gross pollutants are trapped in a sump area located below the separation screen.

The proposed Tributary Sediment Trap (TST) is recommended by the Guidebook of Sediment Control BMPs (SFWMD, 1999). The principle of sediment removal using a sediment trap is similar to a settling basin. However, instead of excavating an earthen basin, a deepened and widened settling chamber is used. Water velocities are suddenly slowed by an increase in cross-sectional area and/or one or more internal baffles, allowing sediment to settle in the bottom of the trap.

During July 2000, the District developed a Statement of Work for evaluation of the effectiveness of sediment removal technologies for removing particulate phosphorus in tributary inflow into Lake Okeechobee. A copy of the original Statement of Work for the project, titled "Lake Okeechobee Tributary Sediment Removal Demonstration Project," is given in Appendix A.

During September 2000, the District contracted with Environmental Research & Design, Inc. (ERD), under Contract No. C-11205, to perform the professional services outlined in the Statement of Work for this project.

1.2 Site Description

Routine water quality monitoring, conducted by the District, suggested that Lettuce Creek may be a significant source of sediment and particulate phosphorus loading to the L-63S Canal, particularly under high flow conditions. In addition, Lettuce Creek drains a large agricultural area which is thought to contribute significant phosphorus loadings into the creek. As a result, Lettuce Creek was selected by the District as a logical location for evaluation of the two sediment removal technologies. Lettuce Creek is within the Lake Okeechobee Surface Water Improvement and Management (SWIM) planning area. Lettuce Creek is within the Nubbin Slough basin northeast of the lake and is one of the major sources of phosphorus loading discharging into Lake Okeechobee. The site was selected according to the following criteria: (1) continuous flow conditions throughout much of the year; (2) no upstream water control structures; (3) relatively high sediment phosphorus content and particulate phosphorus concentrations; (4) erosive soil in upstream portions of the watershed; (5) relatively high sediment transport rate; (6) diversified land uses in the watershed; (7) a long period of historical record; and (8) high average water column phosphorus concentrations. The demonstration project is conducted at the site where Lettuce Creek discharges to the South Florida Water Management District (District) system. The tributary discharges to Lake Okeechobee through the L-63S canal.

A general site location map for the Lettuce Creek site is given in Figure 1-1. The project site on Lettuce Creek at L-63S canal is located in Section 13, Township 38S and Range 36E. Lettuce Creek is located northeast of Lake Okeechobee, approximately 10 miles southeast of the City of Okeechobee. Lettuce Creek drains a large area of agricultural land, dominated primarily by cattle grazing and dairy activities.

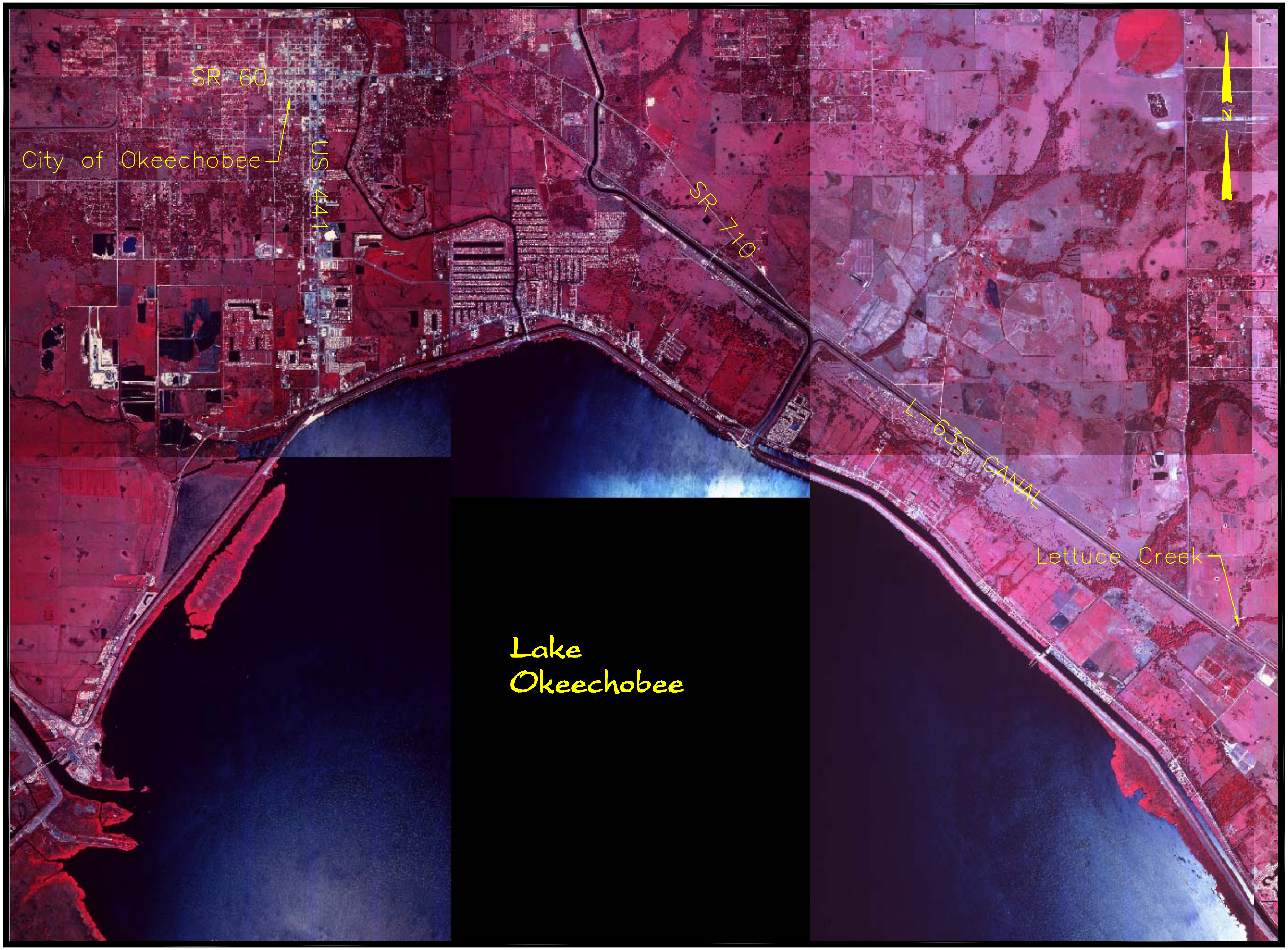


Figure 1-1. General Site Location Map.

A detailed site location map is given in Figure 1-2. The major tributary of Lettuce Creek passes under SR 710 and the CSX railroad prior to discharging into the L-63S Canal. The project site selected for installation of the CDS and TST units is located southeast of Lettuce Creek between the CSX railroad and the L-63S Canal.

Historically, Lettuce Creek discharged directly into Lake Okeechobee through a forested wetland system. However construction of the L-63S Canal intercepted the Lettuce Creek tributary, which now discharges into the L-63S Canal. As indicated on Figure 1-1, flow in the L-63S Canal travels in a northwest direction, discharging into Nubbin Slough, and ultimately Lake Okeechobee.

A photograph of Lettuce Creek between the CSX railroad and the L-63S Canal is given in Figure 1-3, taken during low flow conditions within the creek. A pile of rock rubble can be seen in the foreground of the picture which was installed by the District as an energy dissipater to slow the flow within the creek and allow sedimentation of particulate matter to occur upstream of the rock rubble. This rock rubble is exposed under low flow conditions, but is covered with several feet of water under high flow conditions.

Discharges from Lettuce Creek into the L-63S Canal are regulated by nine separate riser structures constructed out of 72-inch CMPs. A photograph of the water control riser structure is given in Figure 1-4. The riser structures are connected to nine separate 72-inch CMPs which discharge into the L-63S Canal. In general, water level within Lettuce Creek is maintained at approximately 2-3 ft higher than water surface elevations in the L-63 S Canal.

Water flow rates in Lettuce Creek are highly variable, depending primarily upon antecedent rainfall conditions. During periods of low rainfall, flow rates through Lettuce Creek decrease substantially, with water surface elevations decreasing below the riser boards in the outfall structure during extended dry periods. This condition can be seen in Figure 1-4. However, during periods of extended or heavy rainfall conditions, flow rates in Lettuce Creek increase substantially, frequently exceeding 500 cfs during rainy conditions.

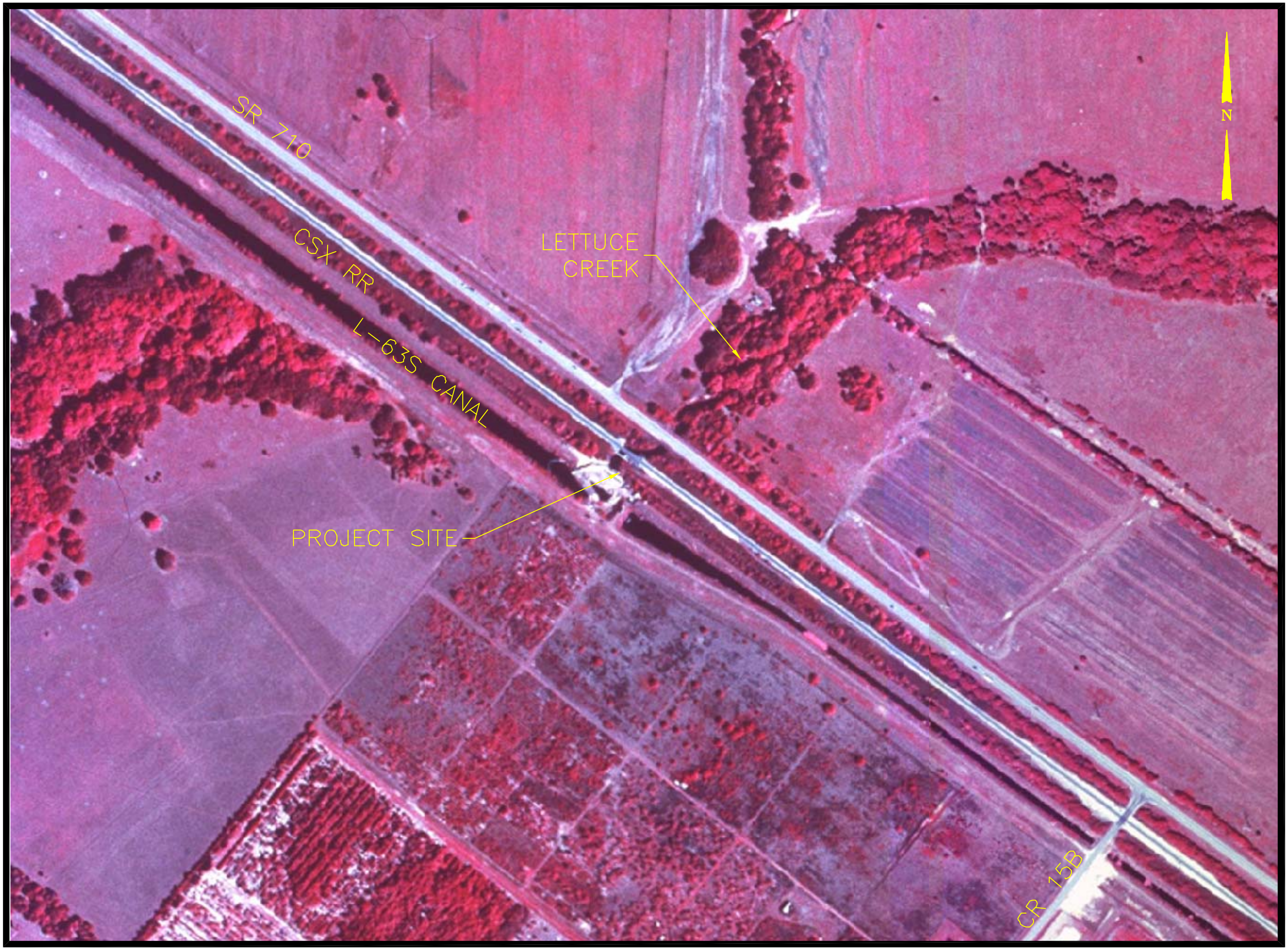


Figure 1-2. Site Location Details.

Figure 1-3. Lettuce Creek Between the CSX Railroad and the L-63S Canal.

Figure 1-4. Photograph of Water Control Riser Structure.

1.3 Project Objectives

The Lake Okeechobee Tributary Sediment Removal Demonstration Project is designed to evaluate technologies to reduce the amount of phosphorus discharged from upland basins to Lake Okeechobee. This project will provide critical information regarding the potential benefits of controlling phosphorus loads through tributary sediment removal. The short-term benefit of the demonstration project will be the removal of a source of phosphorus that potentially may degrade the water quality of Lake Okeechobee. Long-term success of the project will be determined by evaluation of sediment removal and water quality. Data from this project will provide an understanding of phosphorus movement through the tributary system and sediment removal mechanisms. Total cost, including project maintenance fees and cost per unit of phosphorus removed, will be analyzed for each technology to determine if these technologies are technically and economically effective methods to reduce phosphorus loading to the lake.

The Lake Okeechobee Tributary Sediment Removal Demonstration Project has three primary objectives. The first objective is to determine if particulate phosphorus loading to Lake Okeechobee from the Lettuce Creek drainage basin can be reduced using either of two pre-selected sediment removal technologies. The two sediment removal units were constructed side-by-side on Lettuce Creek, with identical portions of the creek flow diverted into each unit. The mass of particulate phosphorus entering and leaving each of the two units was monitored under a wide variety of operating conditions to evaluate the annual mass and percent reduction of particulate phosphorus from the Lettuce Creek drainage basin to the L-63S Canal and Lake Okeechobee.

The second objective of this project is to demonstrate the feasibility of sediment removal in a tributary as a method of reducing phosphorus loading to Lake Okeechobee. Each of the two sediment removal technologies are capable of removing specific types of particulate matter based on the physical characteristics of the particles, such as particle size, density, and shape. Each of these different particle types have a corresponding characteristic phosphorus concentration. The ability of the two systems to attenuate phosphorus is a function of the particle types removed by the systems and the phosphorus concentrations associated with each particle type. Sediment characteristics and phosphorus concentrations are evaluated on water flowing through the tributary under a variety of flow conditions. This information is used to determine the conditions under which phosphorus particles become mobilized in the tributary and the associated particle characteristics. Sediments collected in the two units will also be evaluated to determine the characteristics of the sediments which can be removed by the units. The phosphorus load captured in the units will be compared with the phosphorus load entering each unit to evaluate the degree of phosphorus reduction achieved by sediment removal.

The third objective of the sediment removal project is to perform a detailed assessment of the effectiveness of the two technologies and their economic viability. The effectiveness of the two technologies were evaluated over a 12-month monitoring period. Sediment and phosphorus inputs and outputs from each system were quantified using automatic stormwater samplers and flow monitors attached to the inflow and outflow from each unit. The effectiveness of each system is quantified using both a concentration-based and mass balance approach. The economic viability of each technology is evaluated by comparing the present worth cost (20-year) per kilogram of sediment and phosphorus removed by each system.

1.4 Project History

Work efforts for the Lake Okeechobee Tributary Sediment Removal Demonstration Project (Contract No. C-11205) are divided into three separate phases. Phase I is titled "Project Design" and includes development of a Project Work Plan, basic data collection, computation for engineering design, engineering design, project permitting, and preparation of a Quality Assurance Project Plan (QAPP). Phase II is titled "Construction, Installation, and Calibration of Monitoring Instruments" and consists of construction of the CDS and TST units, inflow piping and manholes, outflow piping and manholes, and other related appurtenances. Phase II also includes installation and calibration of all equipment needed to perform the performance efficiency monitoring for the installed CDS and TST units. Detailed reports outlining Phase I and Phase II activities have previously been submitted to the District.

Phase III is titled "Post-Construction Monitoring and Effectiveness Evaluation" and includes all work efforts necessary to assess the effectiveness of the CDS and TST units for removal of particulate phosphorus from the Lettuce Creek tributary to Lake Okeechobee. Although Phase I and Phase II activities are described, as necessary, in this report to provide background information for the project, the Phase III work efforts are the primary emphasis of this report.

A summary of project history for the Lake Okeechobee Tributary Sediment Removal Demonstration Project is given in Table 1-1. Final Phase I activities were completed on January 14, 2002. Construction of the CDS and TST units was performed during February-April 2002, with installation and calibration of monitoring equipment completed by the end of April 2002. The final Phase II report was submitted on May 6, 2002. Although the monitoring network had been installed, monitoring at the site was delayed from May-October 2002 by equipment vandalism and construction activities to replace the adjacent CSX bridge. Field monitoring at the site was initiated in October 2002 and was continued until November 2003. Quarterly reports were submitted on a routine basis during the monitoring program and provided a detailed outline of all activities performed during each quarterly period, along with a presentation and discussion of all collected data. Each of the quarterly reports submitted as part of this project are included in Appendix B.

1.5 Report Organization

This report is divided into seven separate sections for presentation of the work efforts, results, and conclusions of this project. Section 1 contains an introduction to the report, and includes a description of the Lettuce Creek site, project objectives, and project history. Section 2 includes a general discussion of the operation of CDS and TST units and includes details of the design and construction activities performed for this project. A discussion of the monitoring network installed at the site is given in Section 3. Section 4 includes a discussion of initial characterization studies for both surface water and sediments. A detailed discussion of the performance efficiency of the CDS and TST units for removal of particulate phosphorus in Lettuce

TABLE 1-1

PROJECT HISTORY FOR THE LAKE OKEECHOBEE TRIBUTARY SEDIMENT REMOVAL DEMONSTRATION PROJECT

DATE	ACTIVITY
September 2000	Contract executed between District and ERD
September-December 2000	Development of Project Work Plan; Work Plan submitted on December 13, 2000
January-July 2001	Perform design of CDS and TST structures; Final Design Report submitted on July 11, 2001
June 2001	Develop Quality Assurance Project Plan
June-August 2001	Installation of hydrologic monitoring network
August-October 2001	Basic data collection for water and sediment characteristics; Develop Monitoring Network Design; Final Monitoring Network Design Report submitted on October 4, 2001
November 2001-January 2002	Develop Final Phase I Report; Final Phase I Report submitted on January 14, 2002
June 2001-January 2002	Prepare and submit project permits; ACOE Permit issued on August 18, 2001; CSX Agreement for right-of-way use executed on January 17, 2002
February-April 2002	Construction of CDS and TST units; Final Completion Inspection on April 3, 2002
April 2002	Installation and calibration of monitoring equipment
April-May 2002	Prepare Phase II Report; Final Phase II Report submitted on May 6, 2002
May-October 2002	Monitoring delayed by equipment vandalism and construction activities to replace CSX bridge
October 2002-November 2003	Efficiency testing for CDS and TST units; Quarterly Reports submitted on May 30, 2003, July 31, 2003, January 12, 2004, and February 27, 2004
December 2003-March 2004	Final data analysis
April-May 2004	Final Report preparation

Creek is given in Section 5. The results of testing performed using alum to enhance the removal efficiency of the CDS and TST units are given in Section 6. Conclusions and recommendations from the monitoring program are outlined in Section 7.

1.6 Units of Measurement

In general, all scientific data, measurements, and descriptions given in this report related to chemical concentrations and mass are given in metric units. Engineering calculations related to the design and construction documents utilize English units due to their popularity and common use for these elements. References to elevations, such as water stage and flow rates, are also given in English units.

SECTION 2

OPERATION AND DESIGN DETAILS FOR THE CDS AND TST UNITS

During development of the Scope of Services for the Lake Okeechobee Tributary Sediment Removal Demonstration Project, the District selected two sediment removal technologies for evaluation and possible implementation on a number of tributaries to Lake Okeechobee. The two technologies selected for this project include the Continuous Deflective Separation (CDS) unit and the Tributary Sediment Trap (TST). The District directly specified the CDS unit to be used, Model PSW50_50, with a peak design flow rate of 11 ft^3/sec (cfs). Although the District did not specify dimensions for the TST, the selected unit is sized to treat an equivalent peak design flow rate of 11 cfs. A general description of operational characteristics for the CDS and TST units is given in the following sections.

2.1 General Description of CDS and TST Units

A literature review of available information on sediment removal technologies was performed by ERD to assist in evaluating the feasibility of these technologies for the proposed site and to obtain information necessary for completion of the design of the CDS and TST units. A relatively small amount of information is currently available regarding sediment and gross pollutant removal technologies, with much of the existing information developed by manufacturers of the various units. A complete listing of references obtained by ERD during the literature review is given in Appendix C.

2.1.1 CDS Units

The Continuous Deflective Separation (CDS) technology was developed in Australia by CDS Technologies, Ltd. to remove gross pollutants from stormwater runoff and combined sewer overflows. CDS units have been installed in Australia for the removal of gross pollutants since the early 1990s. The CDS patented process is manufactured and sold in the United States by CDS Technologies, Inc., and CDS units have been sold and installed in the United States since the mid-1990s.

A schematic diagram of the CDS unit is provided in Figure 2-1. Water enters the interior of the chamber and moves in a circular pattern across a separation screen. The water then passes through the separation screen and discharges from the unit in an opposing direction. Settleable materials accumulate in a concrete sump area located beneath the separation screen. CDS manufactures 12 basic models, treating flow rates from 1.1-300 cfs. A summary of standard unit capacities and physical features of CDS units is provided in Table 2-1. The treatment capacities provided in Table 2-1 are based on removing gross pollutants at the specified design headloss. These treatment capacities are not based on achieving a specific total suspended solids removal efficiency. Most of the research performed on CDS technology has focused on the removal of gross pollutants.

TABLE 2-1

STANDARD UNIT CAPACITIES AND PHYSICAL FEATURES OF THE CDS UNIT

MANUFACTURE MATERIAL	MODEL DESIGNATION*	MAXIMUM TREATMENT CAPACITY		DESIGN HEADLOSS (ft)	SUMP CAPACITY (yd^3)	DEPTH BELOW PIPE INVERT (ft)	FOOTPRINT DIAMETER (ft)
		cfs	MGD				
Fiberglass	FSW20_20	1.1	0.7	0.55	0.4	4.5	3.5
	FSW30_28	3.0	1.9	0.77	1.4	5.9	5.0
Precast Concrete**	PSW30_28	3.0	1.9	0.77	1.8	7.0	6.5
	PSW50_42	9.0	5.8	1.37	1.9	9.6	9.5
	PSW50_50	11	7.1	1.37	1.9	10.3	9.5
	PSW70_70	26	16.8	1.91	3.9	14.0	12.5
	PSW100_60	38	24.5	1.64	6.9 or 14.1	12.0	17.5
	PSW100-80	50	32.3	2.18	6.9 or 14.1	14.0	17.5
Cast-in-Place Concrete	PSW100_100	62	40.0	2.74	6.9 or 14.1	16.0	17.5
	CSW150_134	148	95.5	3.67	14.1***	19.6***	25.5
	CSW200_164	270	174	4.47	14.1***	22.6***	34.5
	CSW240_150	300	194	4.33	14.1***	21.2***	41.0

* CDS Fiberglass (F), Precast (P), and Cast-in-Place (C), Stormwater (SW)
** CDS Technologies can customize units to meet specific design flows and sump capacities
*** Sump capacities and depth below pipe invert can vary due to specific site design

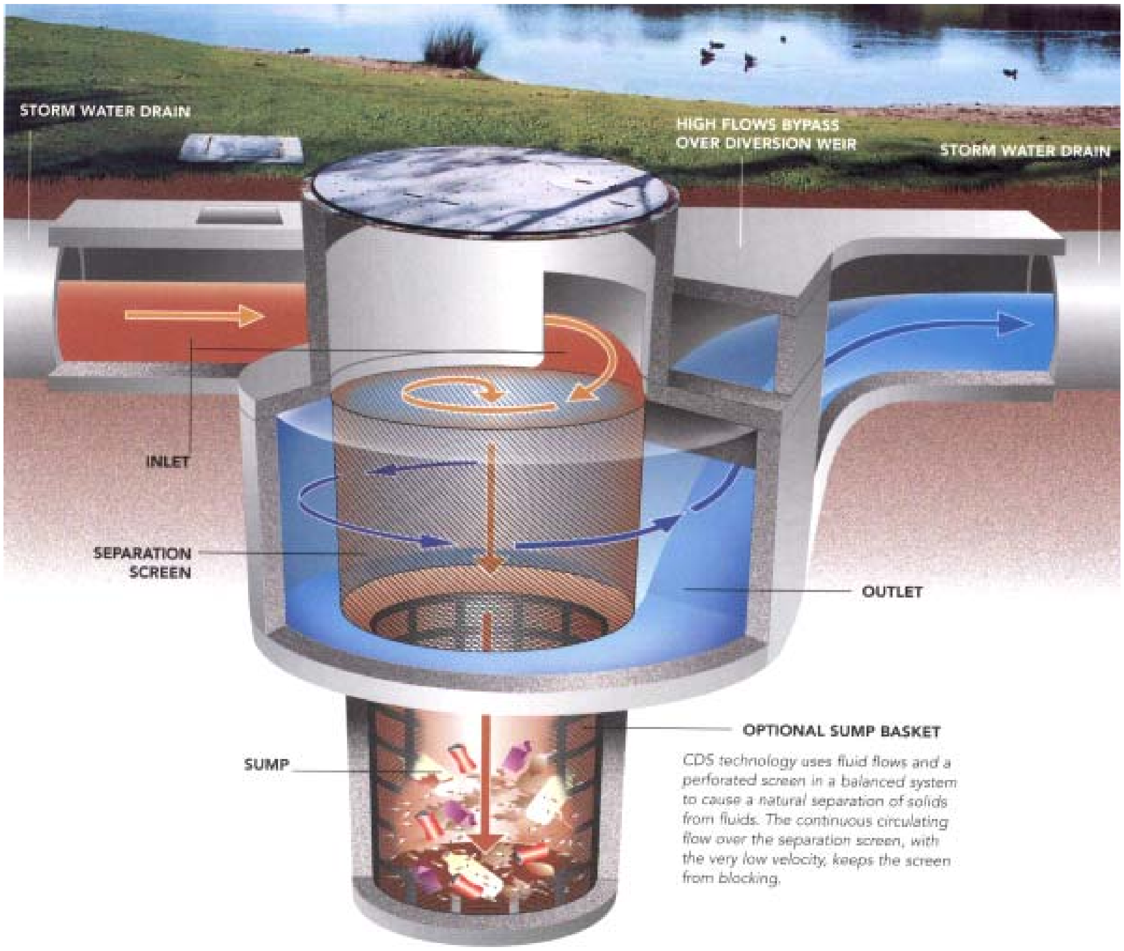


Figure 2-1. Schematic Diagram of CDS Unit.

As seen in Table 2-1, installation of CDS units requires a relatively deep excavation, particularly for units designed for higher treatment capacities. For example, the bottom of the precast structure for a unit to treat 26 cfs would be located approximately 14 ft below the pipe invert of the treated stormsewer line. Assuming a 36- or 48-inch stormsewer line, the required excavation could easily reach 20 ft. The bottom of the concrete structure for units designed to treat in excess of 100 cfs is located approximately 20-23 ft below the invert of the treated pipe. These units are typically designed to treat pipes with 60-inch or greater diameters, which would often mean excavations exceeding 30 ft. With a footprint diameter of 41 ft for the largest unit, the excavated hole would be approximately 50 ft in diameter and 30 ft deep.

CDS units can be purchased in the United States with screen aperture openings of 4700 microns or 1200 microns. Based on research performed by CDS Technologies, Inc., screen aperture opening size has a direct effect on sediment removal efficiency. A summary of coarse sediment removal efficiencies for a CDS unit using a 4700 micron screen, based on information supplied by CDS Technologies, is provided in Table 2-2. Removal efficiencies of 93% for a 1551 micron particle and 50% for a 940 micron particle were observed with a 4700 micron screen. Although not stated by CDS Technologies, removal efficiencies can be expected to decrease rapidly with decreasing particle size.

A summary of fine sediment removal efficiencies for a CDS unit using a 1200 micron screen, based on information supplied by CDS Technologies, is provided in Table 2-3. The 1200 micron screen removed approximately 85% of the particles from 300-425 microns and 22% of the particles from 75-150 microns. Similar to the 4700 micron screen, removal efficiencies can be expected to decrease rapidly with decreasing particle sizes below 75 microns.

TABLE 2-2

COARSE SEDIMENT REMOVAL EFFICIENCIES FOR THE CDS UNIT

PARTICLE SIZE AS PERCENTAGE OF SCREEN OPENING (%)	SCREENING REMOVAL EFFICIENCY	STANDARD SCREEN OPENINGS 4700 micron (0.185 inches)	
		Microns	Inches
100	100%	4700	0.185
50	100%	2350	0.093
33	93%	1551	0.061
20	50%	940	0.037

NOTES: Indirect screening - 4700 micron screen
Particle removal efficiency: Particle SG = 2.65

SOURCE: CDS Stormwater Performance Review

TABLE 2-3

FINE SEDIMENT REMOVAL EFFICIENCIES FOR THE CDS UNIT

PARTICLE SIZE AS PERCENTAGE OF SCREEN OPENING (%)	SCREENING REMOVAL EFFICIENCY	STANDARD SCREEN OPENINGS 1200 micron (0.0475 inches)	
		Microns	Inches
100	100%	1200	0.0475
35-50	93%	425-600	0.017-0.023
25-35	85%	300-425	0.012-0.017
12-25	30%	150-300	0.006-0.012
7-12	22%	75-150	0.003-0.006

NOTES: Indirect screening - 1200 micron screen
Particle removal efficiency: Particle SG = 2.65

SOURCE: CDS Stormwater Performance Review

Recognizing the limitations of CDS units to remove smaller particles at the specified treatment capacity, CDS Technologies, Inc. evaluated the effect of reducing unit flow rates on the removal of smaller particles. A comparison of particle capture at two different flow rates for a variety of particle sizes is given in Figure 2-2. For particle sizes greater than 425 microns, flow rate had no effect on particle capture. For particles less than 425 microns, particle capture improved significantly at a reduced flow rate. For particles in the 75-150 micron range, particle capture increased from 20% to 45% by reducing the flow rate by approximately 50%. Overall mass removal efficiencies were slightly higher for the lower flow rate.

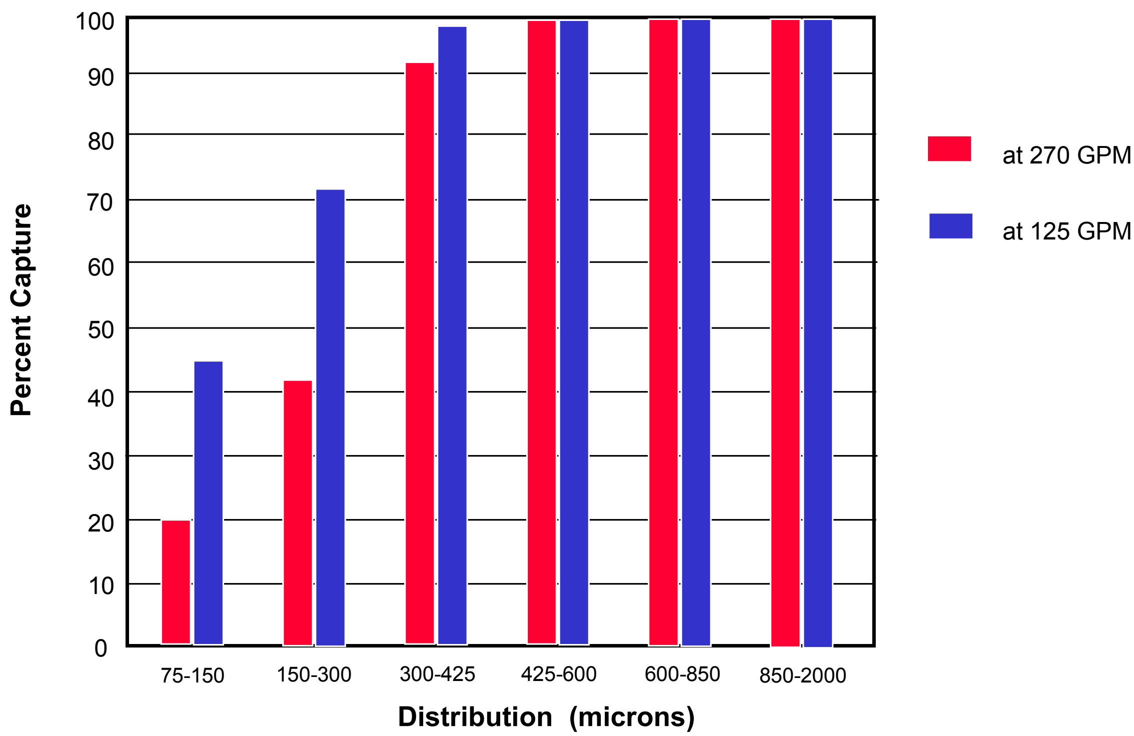


Figure 2-2. CDS Unit Particle Capture vs. Flow Rate (1200 micron screen).

2.1.2 TST Units

Tributary Sediment Traps (TST) are a non-proprietary treatment system used for many years to remove sediments from stormwater runoff. TSTs come in a variety of configurations, some with inlet and outlet controls, and others with internal baffles and screens. TSTs rely primarily on sedimentation for particle removal. As water enters a TST through a pipe, the larger cross-sectional area of the TST significantly reduces water velocity and allows particles to settle to the bottom of the TST. Removal efficiencies can be enhanced using internal baffles which create downward circular patterns behind each baffle. A schematic diagram of a typical sediment trap is provided in Figure 2-3.

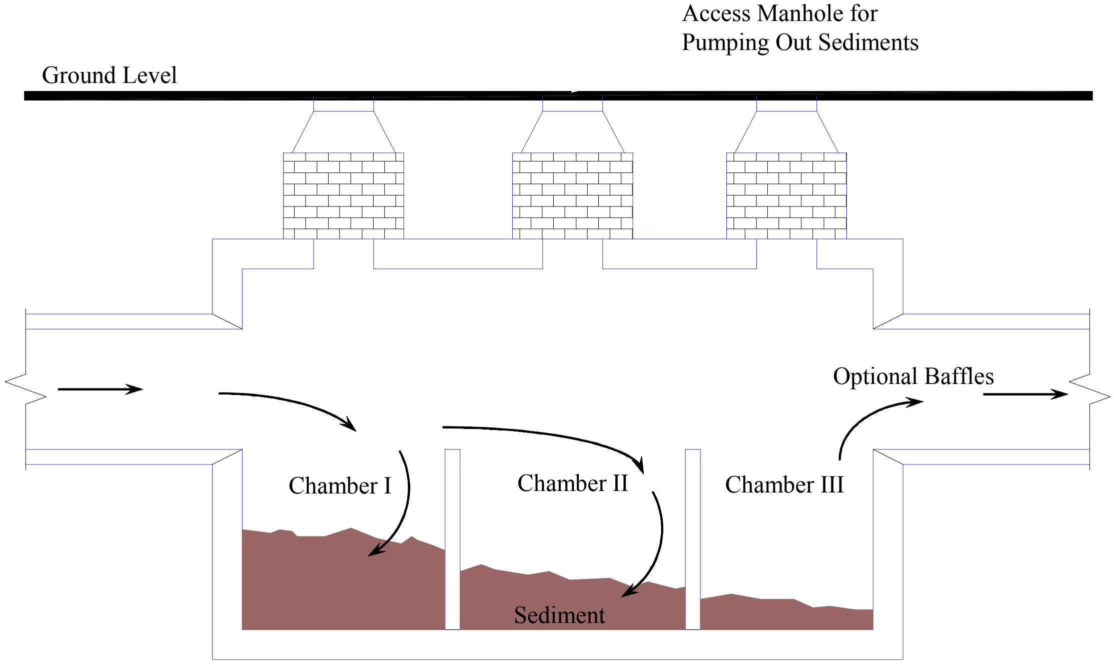


Figure 2-3. Schematic Diagram of Sediment Trap.

Brevard County, Florida has installed approximately 15 sediment traps in submerged stormwater pipes to remove sediment prior to discharging into receiving waters. The standard Brevard County sediment trap is 6-ft wide x 10-ft long x 8-ft deep. The inflow pipe is typically 24-36 inches in diameter, sized to produce a pipe velocity less than 2.5 ft/sec for the design storm event. This velocity equates to a design flow rate of 7.9-17.7 cfs for a 24-36 inch diameter pipe. The trap is typically divided into three equal chambers with two fixed baffles. The trap extends 3 ft below the inflow pipe invert, with the baffles constructed from the floor to the pipe invert elevation. The outflow pipe is typically the same diameter as the inflow pipe and is located at the same elevation. Access is through three manhole covers, one centered over each chamber.

Although no detailed performance efficiency monitoring has been performed on the Brevard County sediment traps, approximately 6500 pounds of sediment was removed from a trap installed in Indialantic, Florida 40 days after installation. Three sediment samples were collected from each of the three chambers and analyzed using a set of seven sieves with openings from 0.075 mm (75 microns) to 2 mm (2000 microns). The sieve analysis results indicate coarser particles settle in the chamber closest to the inflow pipe and finer particles settle in the chamber farthest from the inflow pipe. Trapped particle sizes ranged from greater than 2000 microns to less than 75 microns. Only about 20% of the particles collected in the third chamber were less than 100 microns in size. These results suggest that either the trap was not effective in removing smaller particles or the treated water contained primarily larger particles. Sediment density was also determined for the samples collected from the Indialantic sediment trap. Reported sediment densities were 2680 kg/m^3 for sediments collected from Chamber I, 2570 kg/m^3 for Chamber II, and 2380 kg/m^3 for Chamber III.

In 1996, the Florida Institute of Technology (FIT) completed an evaluation for Brevard County and the National Estuary Program titled "Physical Modeling of a Stormwater Sediment Removal Box". The evaluation was conducted to determine sediment removal efficiencies for the standard Brevard County sediment trap under varying flow conditions and baffle configurations. FIT constructed a scale model which simulated the hydraulic characteristics of a standard Brevard County sediment trap. Separate experiments were performed using sandy clay and fly ash. Grain size distribution curves for sediment materials used in the FIT study are provided in Figure 2-4. For sandy clay, particle size ranged from 75 microns to 4500 microns. Particle size ranged from 1 micron to 75 microns for fly ash. Experiments were conducted with pipe inflow entrance velocities from 0.8 ft/sec to 2.5 ft/sec. At a given pipe inflow entrance velocity, water sediment concentrations were varied from 15 mg/l to 1000 mg/l. Experiments were also performed with up to five chambers and with baffles elevated off the bottom of the trap.

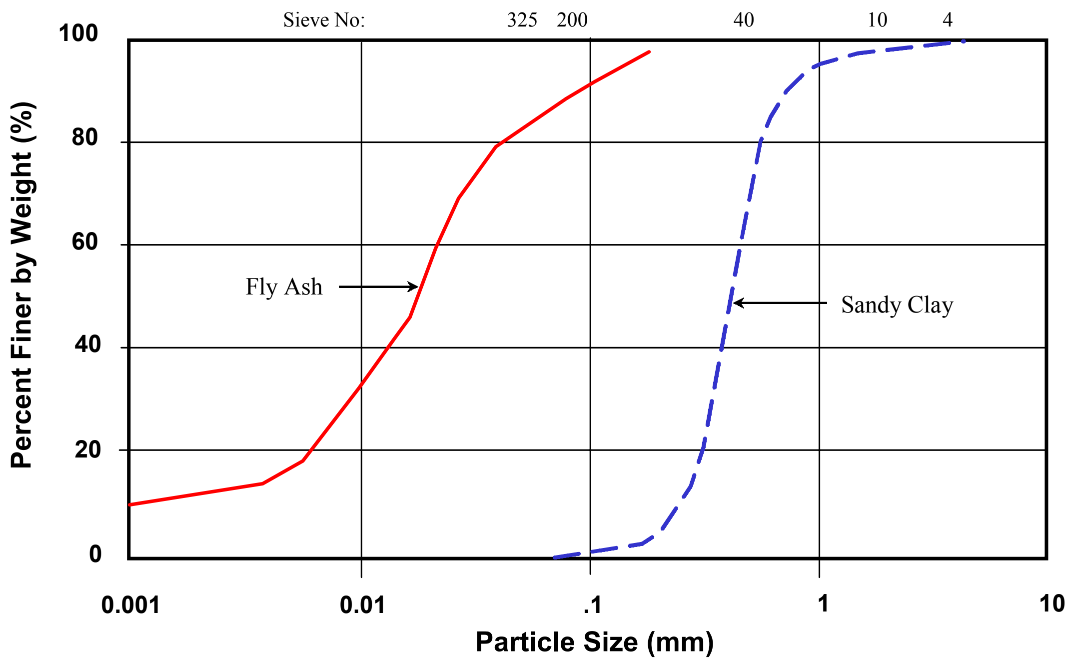


Figure 2-4. Grain Size Distribution Curves for FIT Study.

Overall particle removal efficiencies as a function of pipe entrance velocity for a 3-chamber sediment trap using sandy clay and fly ash are provided in Figure 2-5. For sandy clay, pipe entrance velocity had almost no effect on particle removal efficiency for pipe entrance velocities in the range of 0.8-2.5 ft/sec. For fly ash, however, particle removal efficiency decreased from 30% at 0.8 ft/sec to 18% at 2.5 ft/sec. Pipe entrance velocity had almost no effect on total mass of solids removed for experiments using sandy clay. For experiments using fly ash, the total mass of solids removed decreased by approximately 25% as pipe entrance velocity increased from 0.8 ft/sec to 2.5 ft/sec. Apparently, pipe entrance velocity has a significant effect on particle removal efficiency for smaller sediment particles. For fly ash (fine particles), removal efficiencies increased with increasing inflow sediment concentration. For experiments using sandy clay and fly ash, the mass of solids removed also increased with increasing inflow sediment concentration. Increasing the number of chambers and raising baffles had little effect on performance efficiency.

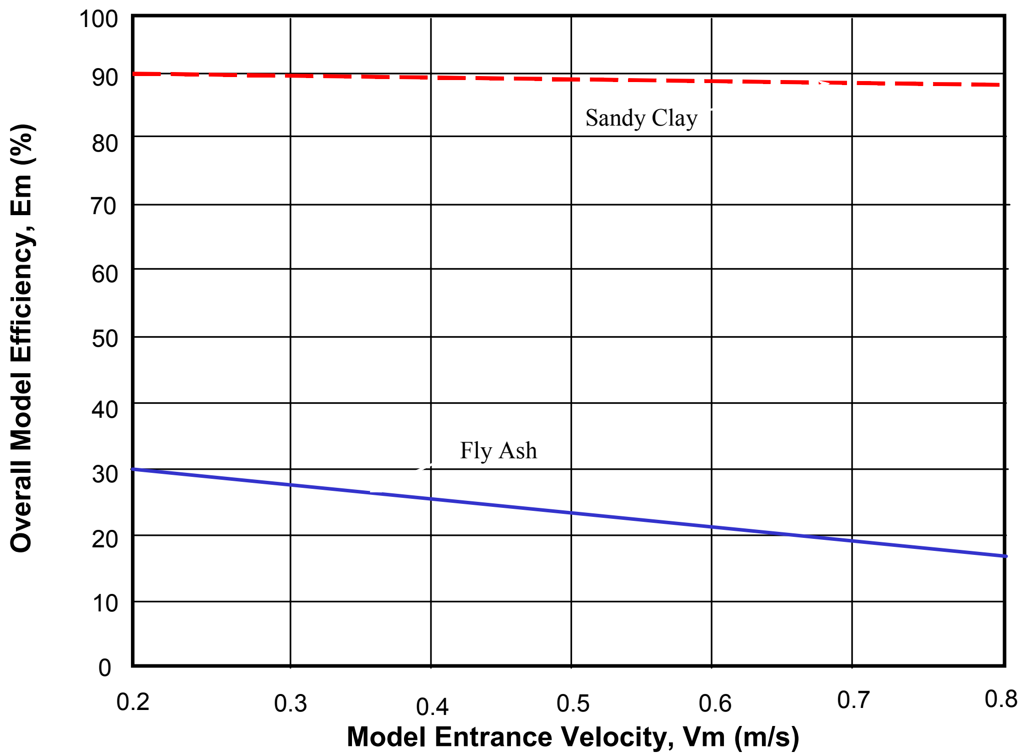


Figure 2-5. FIT Study Overall Removal Efficiency vs. Flow Rate.

2.2 Design Elements

The primary objective of the Lake Okeechobee Tributary Sediment Removal Demonstration Project is to conduct a side-by-side comparison of CDS and TST units for the removal of total suspended solids and particulate phosphorus from water discharging through Lettuce Creek. The design must allow a flow rate from 0-11 cfs, with an equal flow through each system. The basic design elements include the CDS unit, the TST unit, piping from Lettuce Creek to the inflow side of the units, piping from the outflow side of the units back to Lettuce Creek, and independent outlet controls for each unit.

The South Florida Water Management District (District) owns a narrow strip of right-of-way along the L-63S Canal. This right-of-way extends only about 20 ft into Lettuce Creek from the upstream side of the nine 72-inch culverts which discharge water from Lettuce Creek into the L-63S

Canal which is insufficient space to construct the proposed CDS and TST units. CSX Transportation owns the property adjacent to the District's right-of-way, including Lettuce Creek and property adjacent to Lettuce Creek. ERD coordinated with CSX Transportation to obtain approval to construct the proposed facility within the CSX Transportation right-of-way, and on May 10, 2001, ERD obtained verbal approval from CSX Transportation along with a Draft Agreement between the District and CSX Transportation, for the proposed improvements. No work activities were allowed within 30 ft of the centerline of the CSX Transportation railroad tracks.

A plan view of the CDS and TST system design is given in Figure 2-6. Water flowing through Lettuce Creek is diverted into the CDS and TST units through 45 linear ft of 36-inch corrugated metal pipe (CMP). A 6-ft diameter CMP manhole is located at the downstream end of the 36-inch CMP and is used to divert flow into the CDS unit and the TST. A 4-ft x 5-ft sluice gate with handwheel was installed in the 6-ft diameter CMP manhole to isolate the systems from Lettuce Creek for cleaning and maintenance. Ten linear ft of 30-inch CMP are used to connect the 6-ft diameter CMP manhole to the CDS and TST units. The diameter of the inflow pipes to the CDS and TST units was selected so that the maximum pipe entrance velocity, at the maximum design inflow of 11 cfs, will be 2.1 ft/sec which is less than the maximum entrance velocity of 2.5 ft/sec used in the FIT study.

The TST unit is 8-ft wide, 15-ft long, and 10-ft deep, and constructed of welded steel. The steel TST unit has two removable internal baffles so that the TST can be divided into three equal chambers. The bottom of the sediment trap is 3-ft below the inflow pipe invert which is equal to the 3 feet used in the Brevard County design. The baffles extend 6 ft from the bottom of the trap. At a flow rate of 11 cfs, the water depth in the sediment trap is approximately 8 ft. At an 8-ft water depth, the sediment trap has a cross-sectional area of 64 ft^2. At a flow rate of 11 cfs, the average velocity through the TST is approximately 0.17 ft/sec. At a flow rate of 1 cfs, the water depth in the TST is approximately 6 ft, with a cross-sectional area of 48 ft^2. The average velocity at 1 cfs is 0.02 ft/sec. The TST was evaluated at flow rates from 0-11 cfs to determine the effect of flow rate and entrance velocity on performance efficiency.

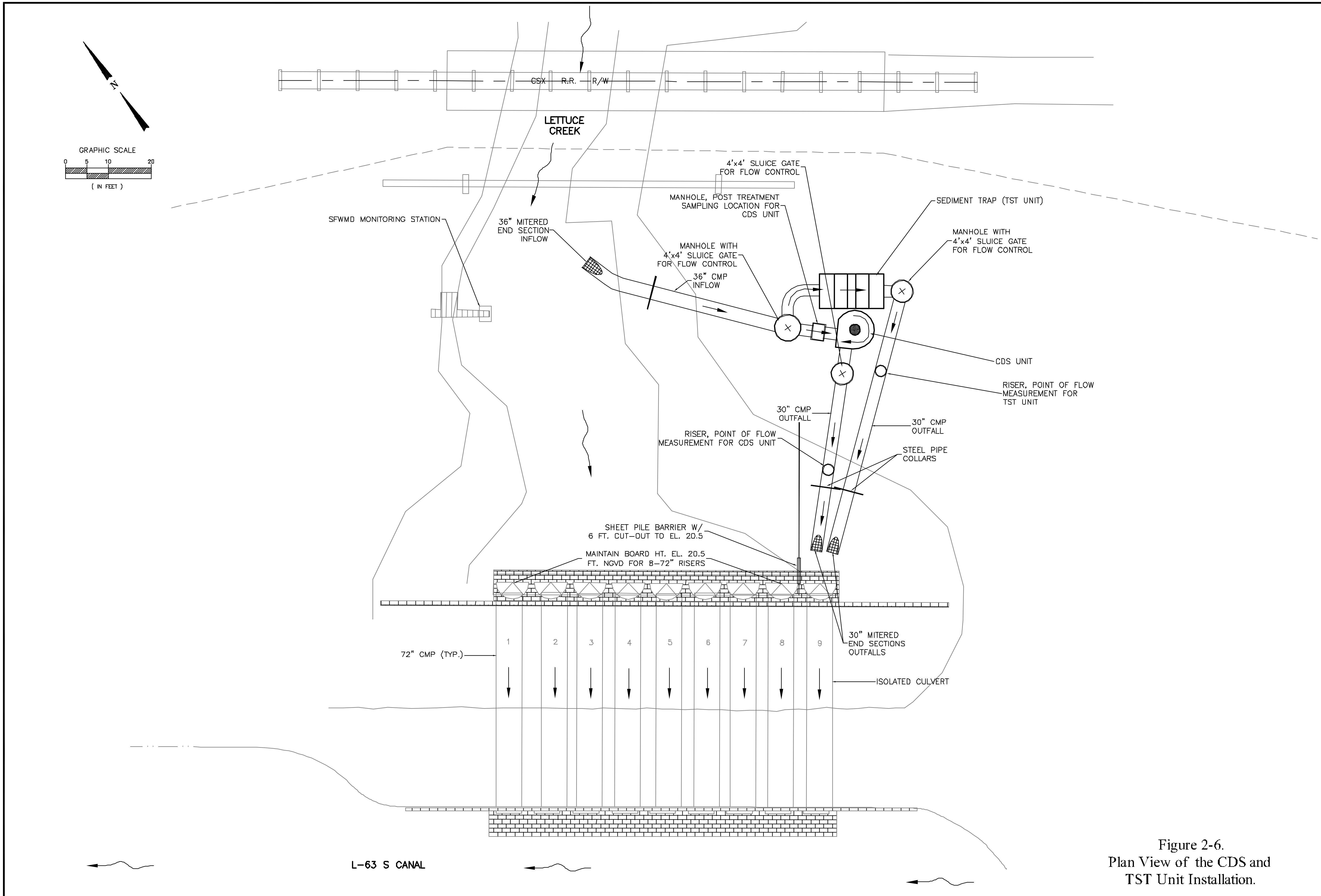


Figure 2-6.
Plan View of the CDS and
TST Unit Installation.

The CDS unit is a pre-cast concrete unit, Model PSW56_53, which contains a 2400-micron stainless steel screen for separation of gross pollutants and large solids. This unit has an inside diameter of approximately 8 ft, an outside diameter of 9 ft-6 in, and an overall depth, from the finished grade to the bottom of the sump, of approximately 18 ft-6 in. The bottom sump area has a diameter of 8 ft and a depth of 3 ft-6 in, with a total volume of 176 ft^3.

Separate 60-inch diameter CMP manholes are located at the outlet end of the TST and CDS units. A 4-ft x 4-ft sluice gate with handwheel was installed in each of the 5-ft diameter CMP manholes for outlet flow rate control and to isolate the systems from Lettuce Creek for cleaning and maintenance. The sluice gate is used to control the flow through each unit from 0-11 cfs. Approximately 60 ft of 30-inch CMP is used to connect the TST outlet manhole to Lettuce Creek. Approximately 45 ft of 30-inch CMP is used to connect the CDS unit outlet manhole to Lettuce Creek. CMP risers (30-inch diameter) are constructed over the 30-inch CMP outlet pipes to allow access for installation of the flow meter sensors.

A detailed hydraulic analysis for the project design was performed by ERD and is discussed in the Final Project Design Report. The CDS system will experience approximately 2 ft of headloss at the maximum design flow of 11 cfs. Therefore, the water surface elevation in Lettuce Creek must be approximately 2 ft higher than the water level in the L-63S Canal to achieve the desired maximum flow. To increase the difference in water surface elevations, approximately 40 linear ft of sheetpile was installed to isolate the southernmost 72-inch CMP culvert from the remaining eight culverts which discharge water from Lettuce Creek to the L-63S Canal. All boards were removed from the isolated riser to ensure the water elevation at the discharge point of the system is the same as the water elevation in the L-63S Canal. Based on historic readings, the water level in the L-63S Canal is typically 2-3 ft below the water elevation in Lettuce Creek. To prohibit water from channeling along the proposed pipes, steel pipe collars were constructed around the 36-inch inflow pipe and the two 30-inch outfall pipes. Photographs of activities at the Lettuce Creek site during pre-construction, construction, and post-construction periods are given in Figure 2-7.

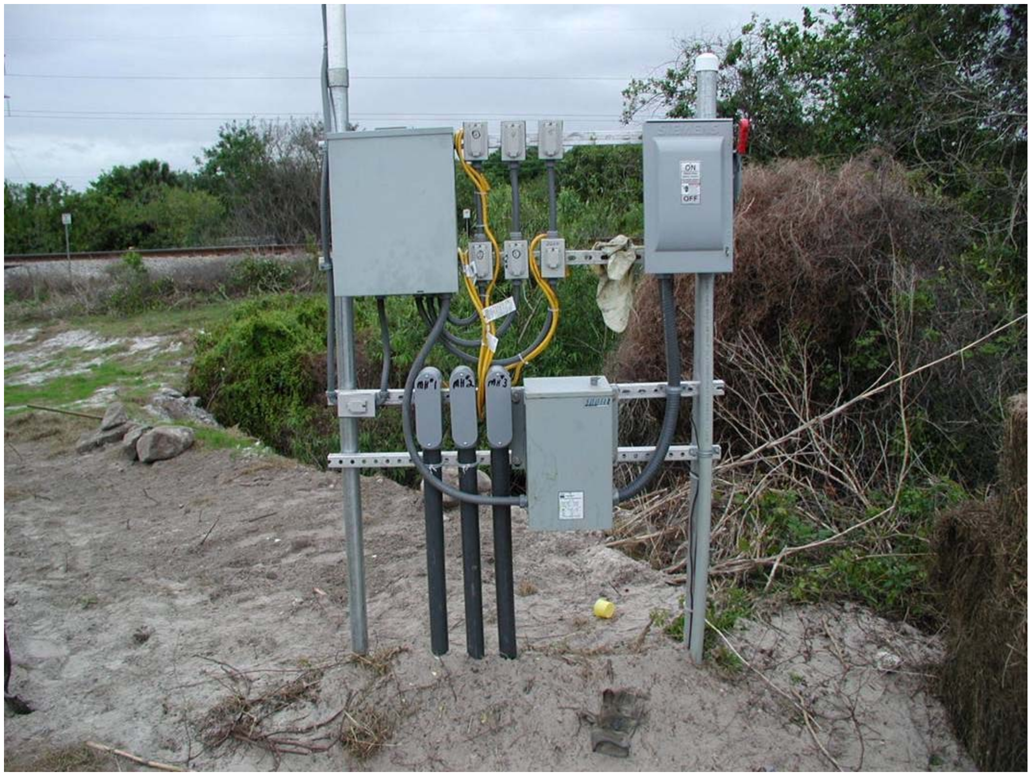
a. Riser Structures in Lettuce Creek

b. Project Site Prior to Construction

Figure 2-7. Photographs of Pre-Construction, Construction, and Post Construction Activities.

c. Downstream Side of the Lettuce Creek Outfall Structure in the L-63S Canal

d. Project Site During Filling Activities



e. Electrical Service for Sampling Network

f. Final Filled Site with Turbidity Curtains

g. Mobilization of Equipment and Structures

h. Initial Installation of the CDS Unit

i. Addition of Upper Riser to the CDS Unit

j. Baffle Box (TST) Unit

k. Installation of Major Hydraulic Elements

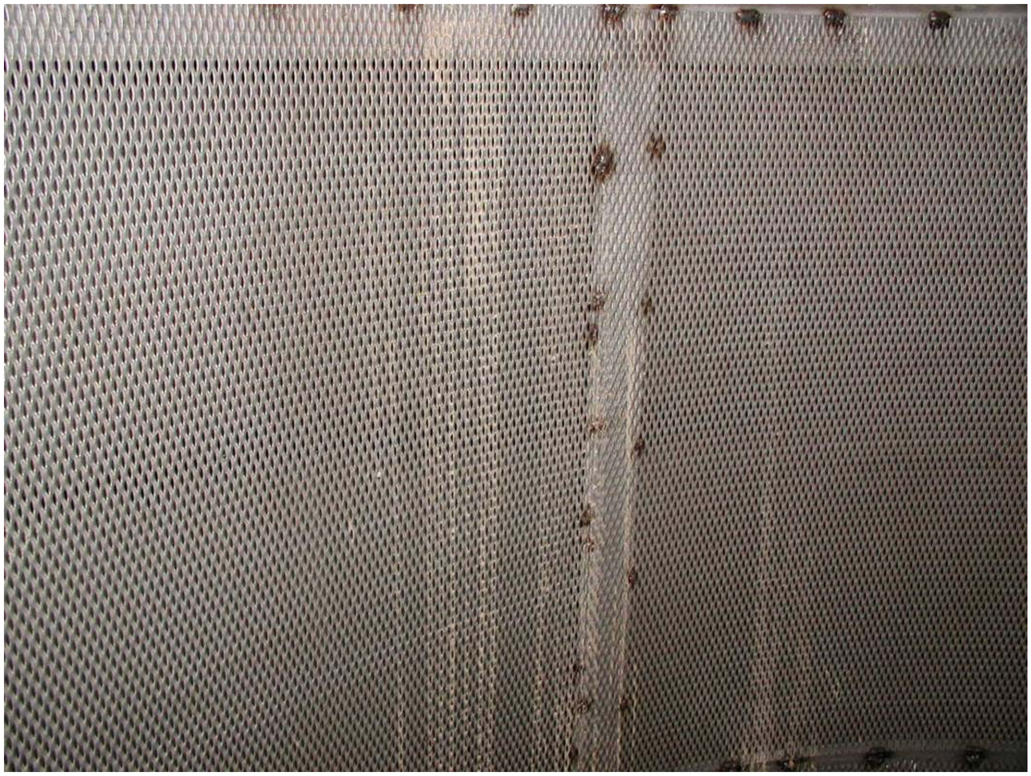
l. Connection Structure for CDS Unit

m. Interior of CDS Unit

n. Installation of Sheet Pile for Isolating CDS and TST Outfall Pipes

o. Completed Site Installation

p. Inflow Pipe for CDS Unit



q. CDS Screen (2400 microns)

r. Outfall for CDS Unit

s. Interior View of CDS Unit

t. Inflow for TST Unit

u. Final Graded and Sodded Site

v. Pad for TST Monitoring Shed

w. Pad for CDS and Inflow Monitoring Shed

SECTION 3

FIELD AND LABORATORY ACTIVITIES

A network of monitoring equipment was installed at the Lettuce Creek site to: (1) provide estimates of the hydraulic characteristics of discharges through Lettuce Creek and (2) perform inflow and outflow monitoring for the CDS and TST units to assist in characterizing the performance efficiency of each unit. In addition, field and laboratory activities were performed to identify the characteristics of sediment particles transported through Lettuce Creek along with the characteristics of existing sediments accumulated on the bottom of Lettuce Creek. Details of field and laboratory activities used to perform these activities are given in the following sections.

3.1 Hydrologic Monitoring

Hydrologic monitoring equipment was installed at the Lettuce Creek site to provide a continuous record of discharge rates through Lettuce Creek throughout the field monitoring program. This information is used primarily to evaluate relationships between water flow rate and chemical characteristics of water samples discharging through the creek. In addition, this information is used by ERD to operate the monitoring network in response to changes in creek flow rate.

During March and April 2001, ERD, with the assistance of AMJ Equipment Corporation, installed water level and data logging equipment in Lettuce Creek and the L-63S Canal. Approximate locations of the hydrologic monitoring equipment installed at the Lettuce Creek site are indicated on Figure 3-1. Flow through Lettuce Creek discharges into nine separate riser structures with board elevations set at approximately El. 20.5 ft (NGVD). The riser structures are connected to nine separate 72-inch CMPs which discharge into the L-63S Canal.

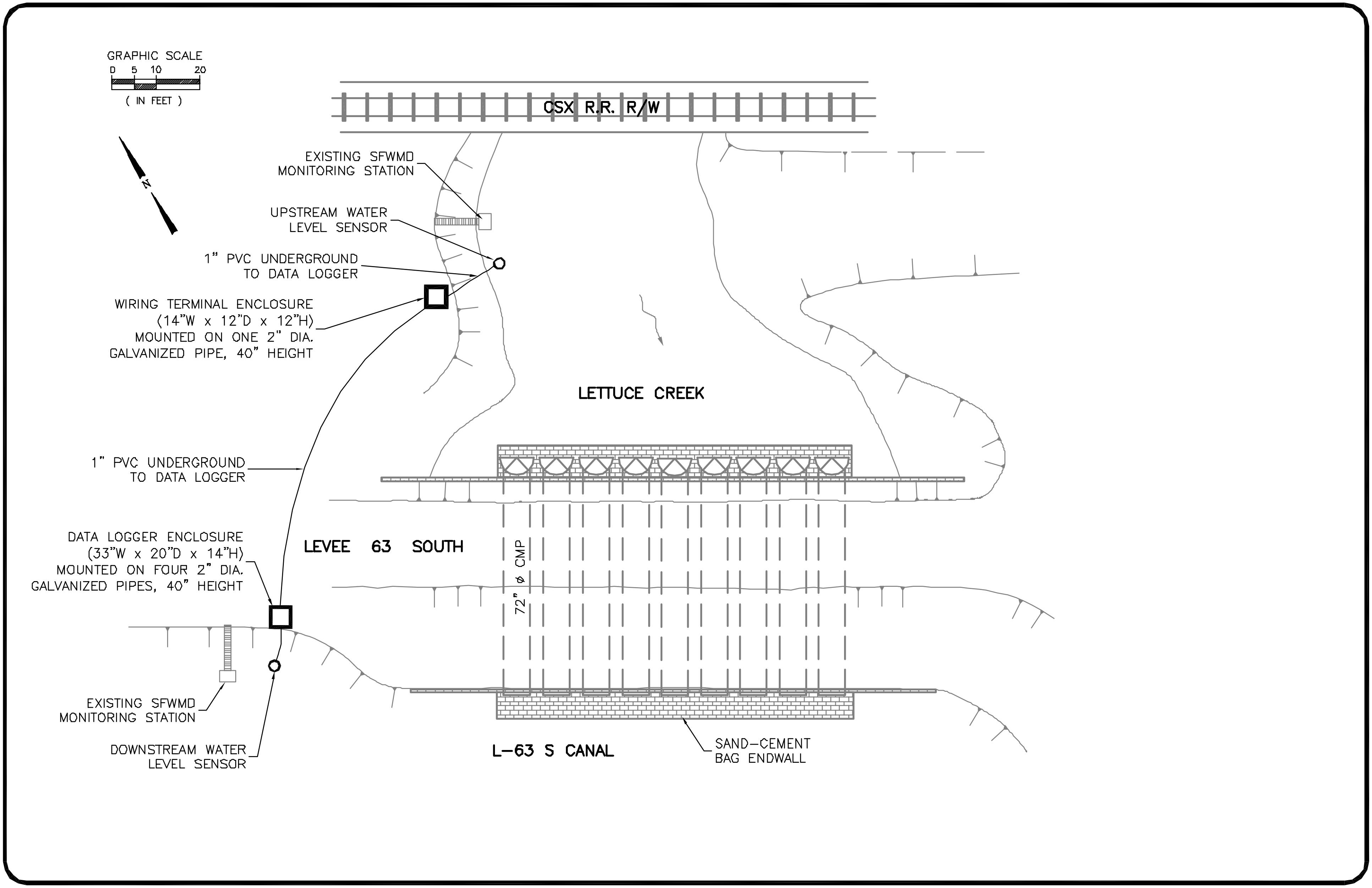


Figure 3-1. Locations of Initial Hydrologic Monitoring Equipment Installed at the Lettuce Creek Site.

At the time of initial installation for the monitoring equipment, relatively little was known about the relationships between water level in Lettuce Creek and the L-63S Canal. It was not known whether water level elevations in the L-63S Canal may periodically increase to the point where the flashboard risers discharging from Lettuce Creek would become submerged, potentially impacting the hydraulic regime through the discharge structure. As a result, the initial hydrologic installation included water level sensors both upstream and downstream of the flashboard riser structure to provide necessary hydraulic information in the event that the water surface elevation in the L-63S Canal should increase to the point that the riser structures would exhibit submerged flow conditions.

KPSI SDI-12 Model 760 shaft encoders were installed in Lettuce Creek upstream of the rock energy dissipator, and in the L-63S Canal downstream of the nine 72-inch CMP culverts connecting Lettuce Creek to the L-63S Canal. A wiring terminal enclosure was installed on the northern shore of Lettuce Creek, adjacent to the upstream water level sensor. A data logger enclosure with a Campbell Scientific (CSI) Model CR10X data logger, CSI cellular telephone package, and CSI Model COM200 telephone, modem, and directional antennae were installed on the east bank of the L-63S Canal, adjacent to the downstream water level sensor. The water level sensors, wiring enclosure, and data logger enclosure were connected with underground electrical cables installed in 1-inch PVC conduit. Data stored within the CR10X data logger could be retrieved, as desired, using the CSI cellular telephone package.

Once installation, start-up, and calibration was completed, water level data was recorded in Lettuce Creek and in the L-63S Canal on a continuous basis. A plot of water surface elevations in Lettuce Creek and the L-63S Canal from August 1, 2001 through September 18, 2001 is given in Figure 3-2. During this period, the water surface elevation in Lettuce Creek ranged from 20.16-22.19 ft (NGVD), and the water surface elevation in the L-63S Canal ranged from 18.08-19.28 ft (NGVD). In general, water surface elevations in the L-63S Canal were found to be approximately 2 ft lower in elevation than the water surface elevations recorded in Lettuce Creek. Rapid increases in water surface elevations in Lettuce Creek, such as those observed during mid-September 2001, did not result in significant increases in water surface elevations in the L-63S Canal. Therefore, it was concluded that tailwater effects in the L-63S Canal have little or no impact on flow discharging through the Lettuce Creek outfall structure.

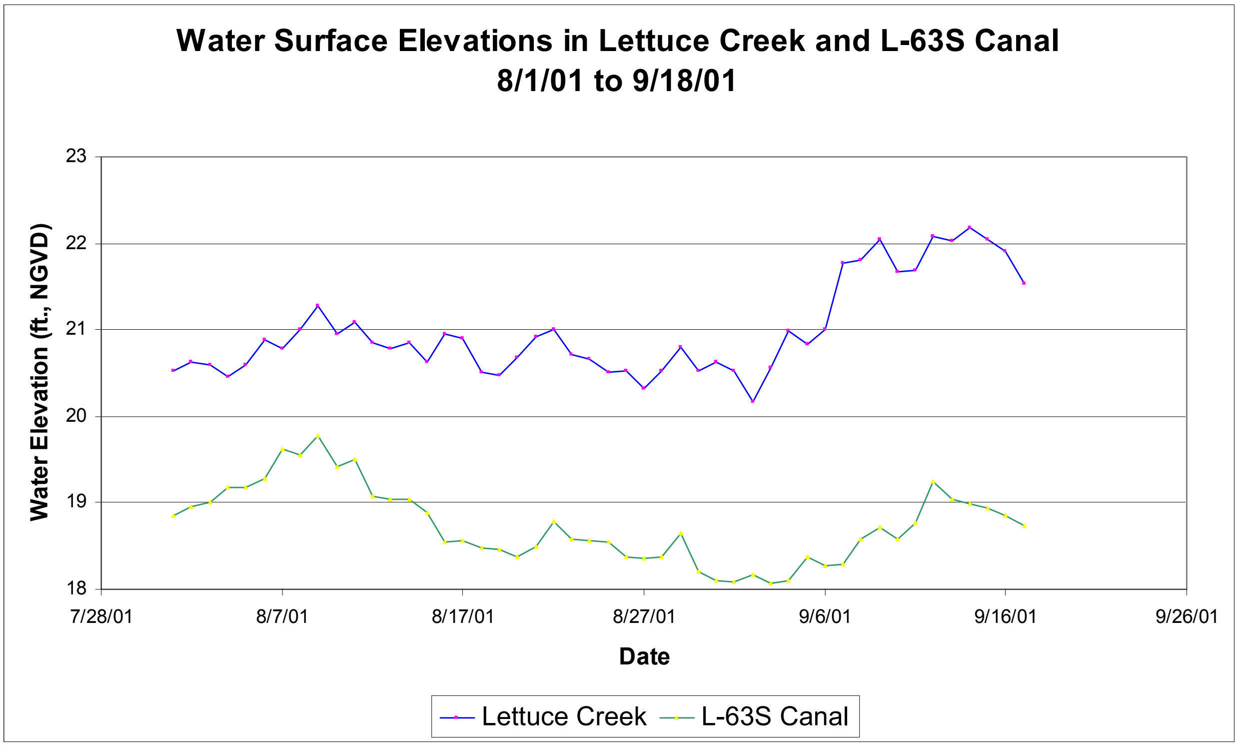


Figure 3-2. Plot of Recorded Water Surface Elevations in Lettuce Creek and L-63S Canal.

Continuous monitoring of water surface elevations in Lettuce Creek and the L-63S Canal was performed from August 2001-March 2002. However, continuing problems with the KPSI pressure transducers raised concerns over the reliability of the data collected over this period. During March 2002, the data logger enclosure was vandalized, and the solar panel, along with several internal components of the data logging equipment, were either vandalized or stolen, rendering the hydrologic monitoring equipment inoperable.

Due to the remote nature of the project site and lack of adequate security, the Project Team decided not to repair or replace the damaged and stolen equipment at the Lettuce Creek and L-63S Canal water level recording sites. Instead, it was decided that, since tailwater conditions in the L-63S Canal do not appear to impact the performance of the discharge structures in Lettuce Creek, water surface elevations recorded by the existing District monitoring station on the west bank of Lettuce Creek would be sufficient for estimation of discharge rates through Lettuce Creek during this project. Therefore, all water surface level elevation data after March 2002 is based upon information obtained from the existing District monitoring station. Quasi-real-time data for this monitoring station can be obtained from the District's website. A photograph of the District monitoring station is given in Figure 3-3.

Figure 3-3. District Water Level Monitoring Station.

3.2 CDS and TST Monitoring

After completion of construction for the CDS and TST units, monitoring equipment was installed at the Lettuce Creek site during April 2002 to document the performance efficiency of the CDS and TST units. An overview of the monitoring system network for evaluation of CDS and TST performance is given in Figure 3-4. Photographs of the installed monitoring equipment are included in Figure 3-5. Construction activities related to replacement of the adjacent CSX Railroad bridge structure can be seen in the background of many of the photographs.

Two separate 5-ft x 8-ft aluminum utility shed structures were installed at the site with one structure located adjacent to the CDS outfall pipe and the second located adjacent to the TST outfall pipe. Three Sigma Model 900MAX all-weather refrigerated samplers were installed at the site, with one unit located in the shed adjacent to the TST outfall and two samplers installed in the shed adjacent to the CDS outfall. Area-velocity (AV) flow meters were extended from the sampler adjacent to the TST unit and one of the samplers adjacent to the CDS unit to a downstream portion of the 30-inch CMP outfall pipe for each structure for flow measurement. The sensor cables were extended underground through a 4-inch PVC conduit which was run from the utility shed to the point of flow measurement. Access to the point of flow measurement in each of the two outfall lines was obtained from a riser structure attached to each pipe. Reinforced sample tubing (3/8-inch ID) was extended from each refrigerated sampler to a manhole structure located downstream of the CDS and TST units. A Teflon sample strainer was attached to the end of each sample tube for collection of discharge samples from each of the two units.

The remaining Sigma refrigerated outfall sampler was used to collect inflow samples for the CDS and TST units. The intake tubing was extended into the initial manhole structure which diverts water into the two units. Sample collection for this sampler was initiated by the sampler used to collect samples from the outfall of the CDS unit. Whenever sample collection activities were initiated for the CDS outfall sampler, an electronic signal would also initiate sampling at the inflow monitoring location. This methodology allowed simultaneous collection of inflow and outflow samples during any given testing program.

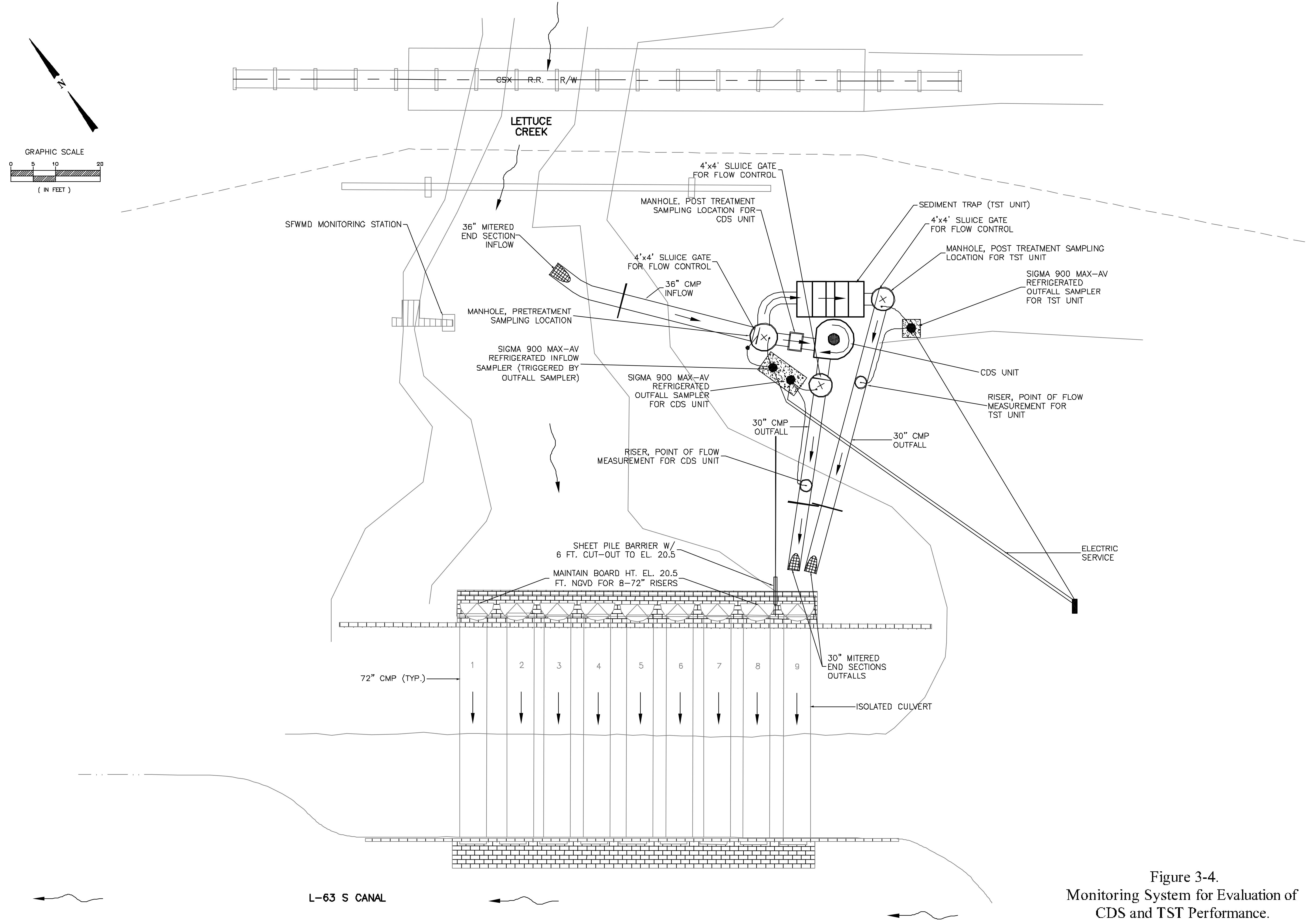
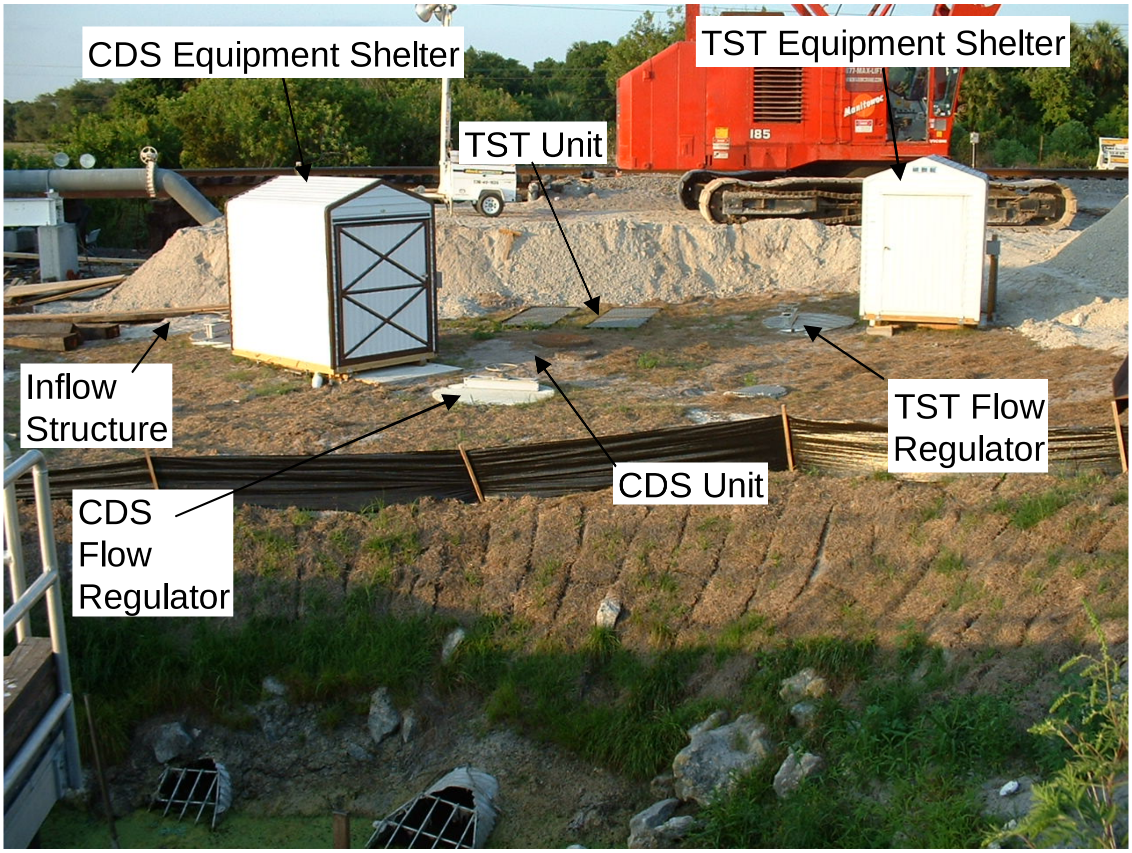
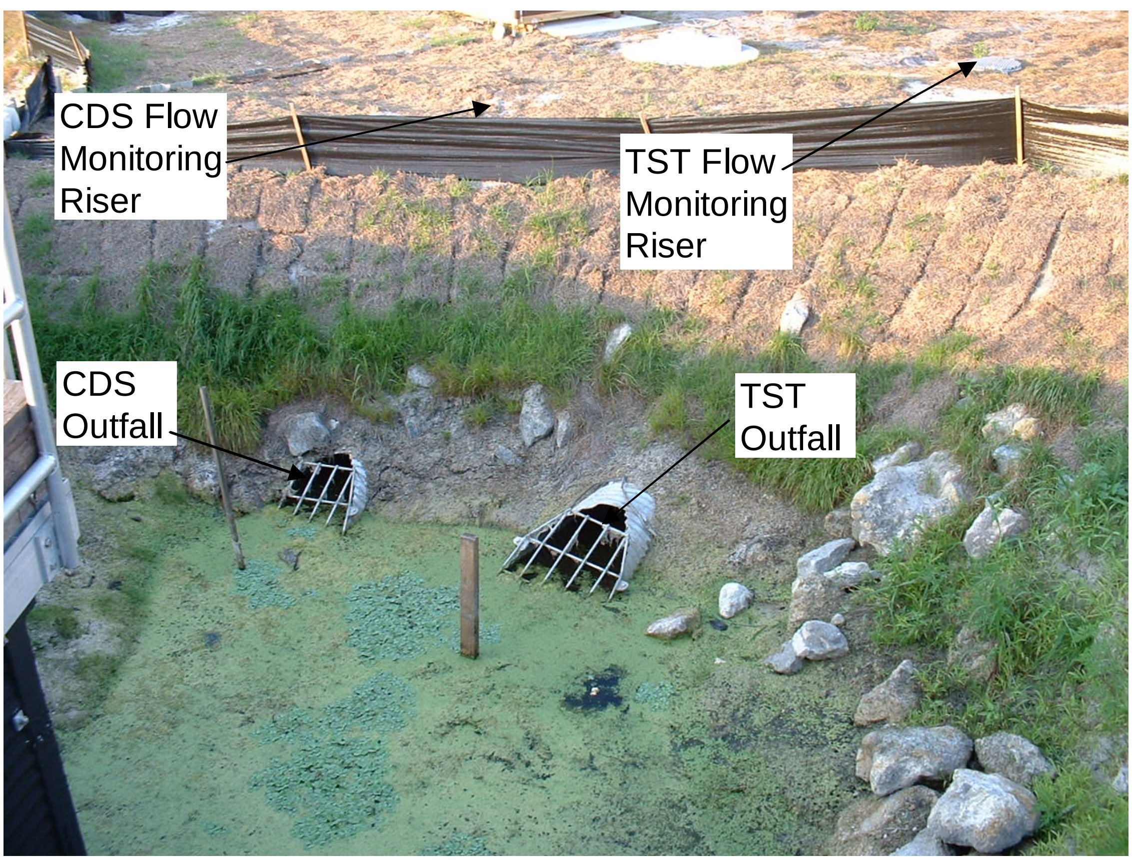


Figure 3-4.
Monitoring System for Evaluation of CDS and TST Performance.



a. Site Details



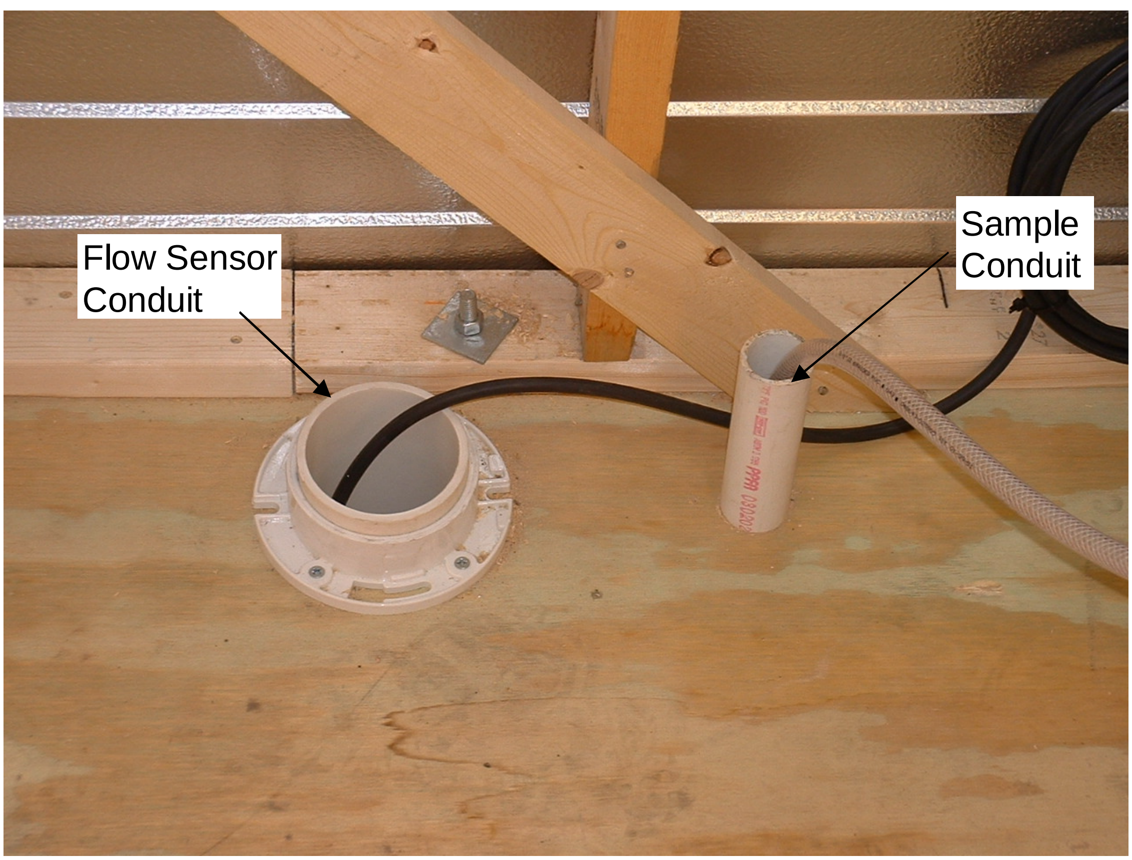
b. CDS and TST Outfall Structures

Figure 3-5. Photographs of the CDS and TST Monitoring Network.

c. Interior of CDS Equipment Shelter

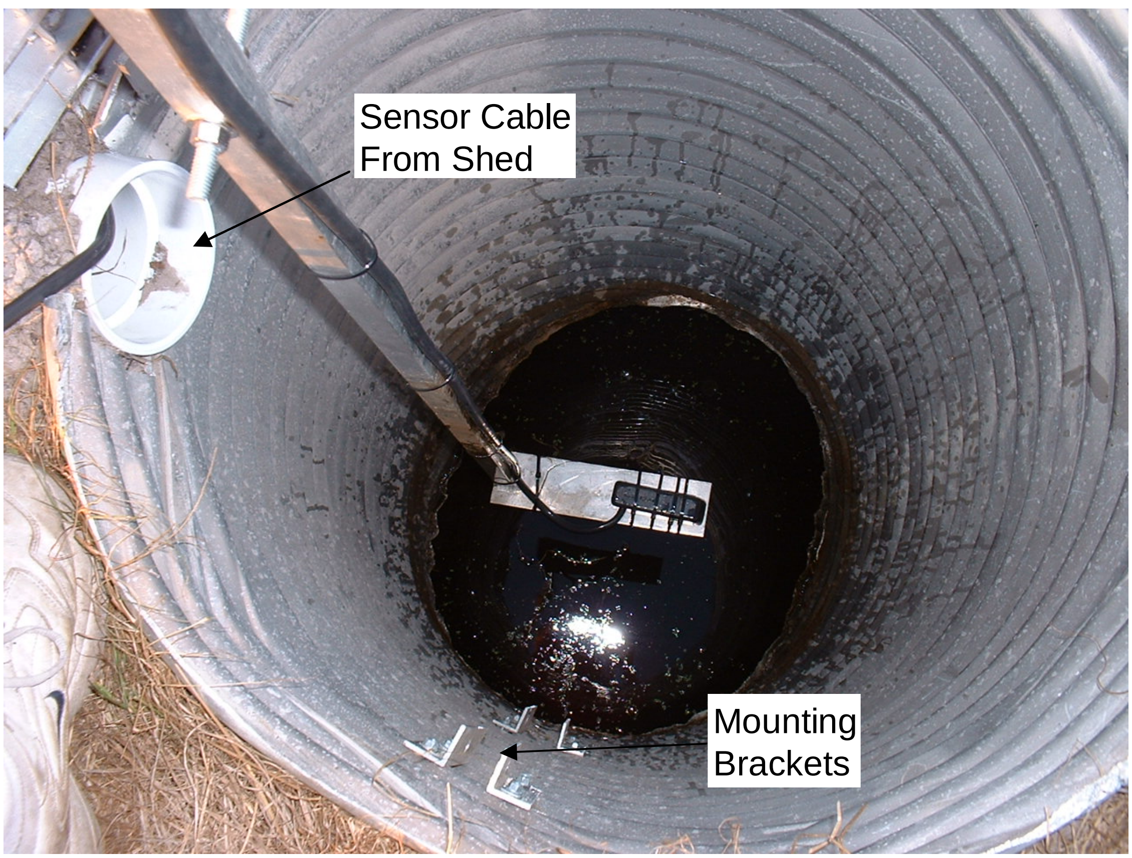
d. Sigma Refrigerated Autosampler

e. Interior of TST Equipment Shelter



f. Sample and Sensor Cable Conduits

g. Area-velocity Probe Attached to Mounting Pole



h. Riser Structure Used for Installation of Flow Probes

Following installation, the flow sensors and automatic samplers were calibrated in accordance with specifications provided by American Sigma. During actual monitoring activities, proper operation of the flow sensors was verified in the field by performing field measurements of discharges in each of the two 30-inch CMP outfall lines for the CDS and TST units. Field flow monitoring was performed through the riser structures provided in each outfall line. Field flow measurements were performed using a Marsh-McBirney Model 2000 electromagnetic flow meter, with measurements performed at 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% of the water depth in each outfall pipe.

A complete listing of field measurements performed for flow rate verification in the CDS and TST units is given in Appendix D. A summary of autosampler flow meter verification measurements is given in Table 3-1. For each monitoring verification date, the nominal flow rate diverted into the CDS and TST units is provided, along with field measured flow rates for both the CDS and TST units. A calculated percent error is also included which compares the measured flow rate with the nominal flow rate indicated by the autosampler. At nominal flow rates less than 1 cfs, the CDS flow meter appears to underestimate actual flow by approximately 2-8%, while the TST unit flow meter appears to over-estimate flow by approximately 7-12%. However, at flow rates in excess of 1 cfs or more, the mean percentage error in measurement between the two units is relatively low in value, with typical mean error percentages of approximately 4% or less.

During routine performance evaluation testing for the CDS and TST units, composite samples of inflow, along with outflow from the CDS and TST units, were collected over a period of approximately 4-7 days. Sub-samples were collected by each of the autosamplers on a flow-weighted basis and composited into a 4-gallon polyethylene container within each autosampler unit. The collected samples were retrieved by ERD field personnel and returned on ice to the ERD Laboratory for subsequent laboratory analyses. New pre-cleaned containers were placed into the autosamplers to begin the next monitoring period.

TABLE 3-1

AUTOSAMPLER FLOW METER VERIFICATION MEASUREMENTS FOR THE CDS AND TST UNITS

DATE	NOMINAL FLOW RATE (cfs)	MEASURED FLOWS (cfs)		PERCENT ERROR (%)	
		CDS	TST	CDS	TST
11/12/03	0.5	0.46	0.56	-8.0	12.0
11/11/03	0.75	0.69	0.82	-8.0	9.3
11/14/03	0.75	0.78	0.79	4.0	5.3
	average	0.74	0.81	-2.0	7.3
4/4/03	1	0.93	0.92	-7.0	-8.0
4/9/03	1	0.95	0.96	-5.0	-4.0
4/29/03	1	0.96	1.12	-4.0	12.0
5/9/02	1	0.94	0.97	-6.0	-3.0
5/29/03	1	0.92	1.04	-8.0	4.0
6/13/03	1	0.94	0.92	-6.0	-8.0
6/19/03	1	0.94	0.90	-6.0	-10.0
6/26/03	1	1.00	0.96	0.0	-4.0
9/12/03	1	1.05	1.17	5.0	17.0
9/23/03	1	1.03	1.15	3.0	15.0
10/31/03	1	0.95	1.01	-5.0	1.0
	average	0.96	1.01	-3.5	1.1
7/10/03	2	1.98	1.88	-1.0	-6.0
10/24/03	2	2.18	1.99	9.0	-0.5
10/30/03	2	1.74	2.15	-13.0	7.5
	average	1.97	2.01	-1.7	0.3
7/16/03	5	5.23	3.95	4.6	-21.0
7/31/03	5	4.94	4.95	-1.2	-1.0
8/2/03	5	4.94	5.08	-1.2	1.6
8/19/03	5	5.16	4.63	3.2	-7.4
8/27/03	5	5.14	5.33	2.8	6.6
	average	5.08	4.79	1.6	-4.2
9/4/03	11	10.93	11.37	-0.6	3.4
10/9/03	11	11.59	11.61	5.4	5.5
10/17/03	11	11.48	10.88	4.4	-1.1
	average	11.33	11.29	3.0	2.6

The refrigerated autosampler used for monitoring at the inflow site was also equipped with a probe capable of performing periodic measurements of pH and temperature of the water entering the TST and CDS unit. This field information was collected in order to better understand relationships between physical characteristics of the inflow and observed removal efficiencies within the two units. The probe was inserted into the inflow structure and used to collect continuous measurements of pH and temperature at approximately 15-minute intervals throughout the monitoring program. This information was stored in the Sigma 900MAX unit and was retrieved, along with the hydrologic data, on approximately a weekly basis. The pH probe was serviced and calibrated at the frequency recommended by the manufacturer's specifications.

3.3 Sediment Monitoring

Collection and analysis of sediment samples from Lettuce Creek was performed on multiple occasions to: (1) identify the characteristics of sediment particles which may become mobilized during periods of high flow conditions within Lettuce Creek and (2) quantify changes in sediment characteristics within Lettuce Creek before and after periods of high flow conditions. Sediment samples were collected at three separate locations in Lettuce Creek, approximately 150 ft (Site 1), 450 ft (Site 2), and 700 ft (Site 3) upstream of the project area. Approximate locations of the sediment collection sites in Lettuce Creek are indicated on Figure 3-6.

Composite sediment samples were generated at each monitoring site by collecting multiple samples along transects perpendicular to the flow in Lettuce Creek. Sediment sub-samples were collected along each transect at distances of 25%, 50%, and 75% of the creek width at each site. Sub-samples collected from each of the three transect sites were combined together to form a single composite sediment sample at each site. Separate composite samples were formed from the 0-1 inch depth and 1-6 inch depth at each site. Sediment samples were collected using a stainless steel split-spoon type core device which was penetrated into the sediments to a depth of approximately 1-2 ft. The core sampler was retrieved and opened to obtain access to the collected core sample. Following collection, the composite sediment samples were returned on ice to the ERD Laboratory for physical and chemical analysis.

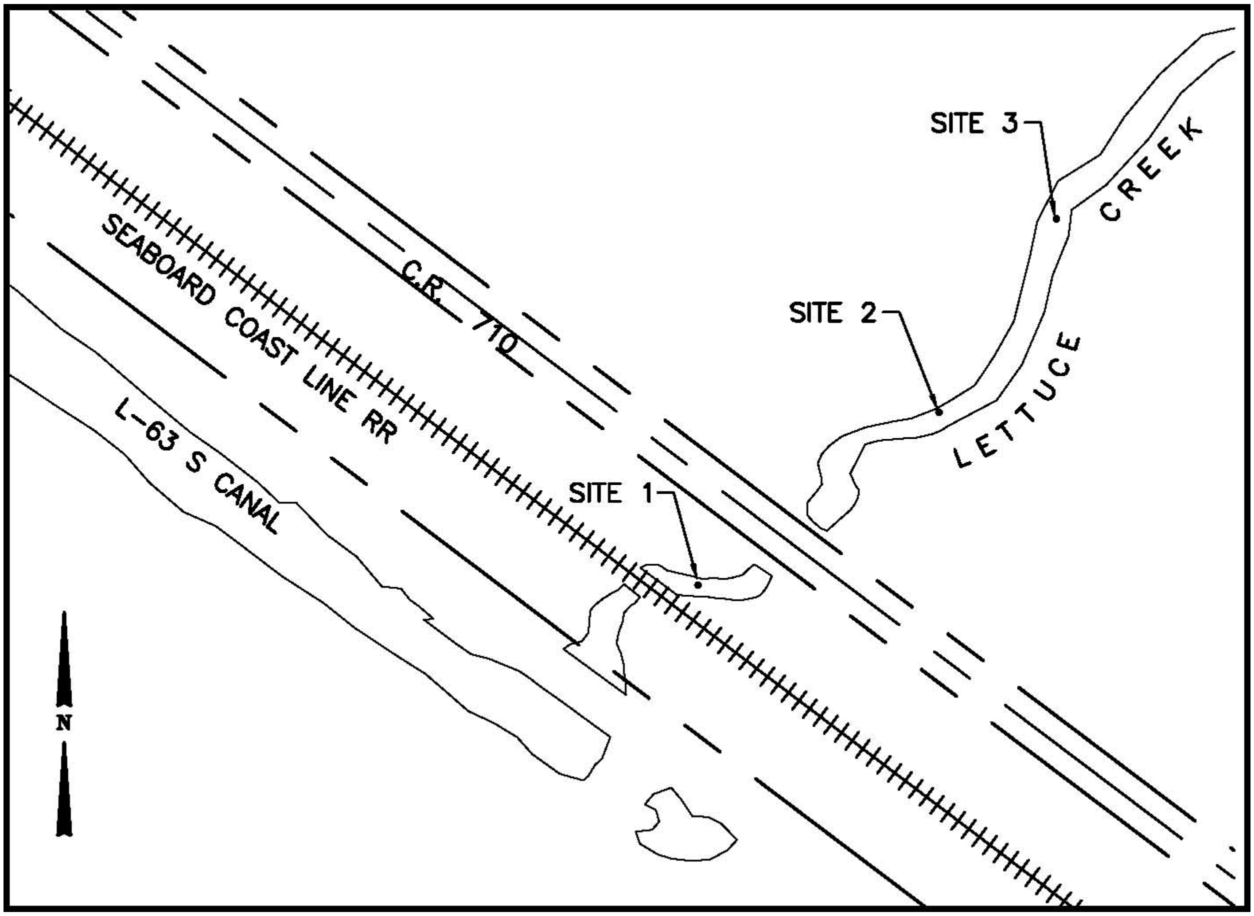


Figure 3-6. Sediment Core Collection Sites in Lettuce Creek.

3.4 Laboratory Analyses

Laboratory analyses were performed by ERD on each of the collected inflow and outflow samples used to evaluate the performance efficiency of the CDS and TST units. A summary of laboratory methods, detection limits, and practical quantification limits for water sample analyses performed by ERD is given in Table 3-2.

Laboratory analyses on sediment samples were also performed by ERD for samples collected from Lettuce Creek as well as accumulated sediments within the CDS and TST units. A summary of laboratory methods and detection limits for sediment analyses performed by ERD is given in Table 3-3.

TABLE 3-2

SUMMARY OF LABORATORY METHODS, DETECTION LIMITS, AND PRACTICAL QUANTIFICATION LIMITS FOR WATER SAMPLE ANALYSES

PARAMETER	METHOD OF ANALYSIS	METHOD DETECTION LIMIT (MDL)	PRACTICAL QUANTIFICATION LIMIT (PQL)
pH (lab/field)	EPA-83[1], Sec. 150-1	NA	NA
Temperature (field)	EPA-83, Sec. 170-1	NA	NA
NH_3-N	EPA-83, Sec. 350.1	0.005 mg/l	0.015 mg/l
NO_x-N	EPA-83, Sec. 353.3	0.005 mg/l	0.015 mg/l
Dissolved Organic N	Alk. Persulfate[2]	0.025 mg/l	0.079 mg/l
Particulate N	Alk. Persulfate[2]	0.025 mg/l	0.079 mg/l
Total N	Alk. Persulfate[2]	0.025 mg/l	0.079 mt/l
Orthophosphorus	EPA-83, Sec. 365.1	0.001 mg/l1	0.003 mg/l
Particulate P	Alk. Persulfate[3]	0.001 mg/l	0.003 mg/l
Total P	Alk. Persulfate[3]	0.001 mg/l	0.003 mg/l
Turbidity	EPA-83, Sec. 180.1	0.1 NTU	0.4 NTU
TSS	EPA-83, Sec. 160.2	0.7 mg/l	2.15 mg/l
Color	EPA-83, Sec. 110.3	1 Pt-Co unit	3 Pt-Co units
TOC	EPA-83, Sec. 415.1	0.382 mg/l	1 mg/l
DOC	EPA-83, Sec. 415.1	0.352 mg/l	1 mg/l

1. Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, Revised March 1983.
2. Alkaline Persulfate Digestion: FDEP-approved alternate method for determination of TKN
3. Alkaline Persulfate Digestion: FDEP-approved alternate method for determination of Total P

TABLE 3-3

SUMMARY OF LABORATORY METHODS AND DETECTION LIMITS FOR SEDIMENT ANALYSES

PARAMETER	METHOD OF ANALYSIS	METHOD DETECTION LIMITS
Moisture Content	EPA/CE-81-1[1]; p. 3-54, p. 3-58	0.1%
Organic Content	EPA/CE-81-1; pp. 3-59 and 3-60	0.1%
Total P	EPA-83[2], Sec. 365.4	0.005 mg/kg
Total N	EPA/CE-81-1; p. 3-205	0.010 mg/kg
Particle Size	EPA/CE-81-1; pp. 3-33 to 3-47	1%

1. Procedures for Handling and Chemical Analysis of Sediments and Water Samples, EPA/Corps of Engineers, EPA/CE-81-1, 1981.

2. Methods for Chemical Analysis of Water and Wastes, EPA/4-79-020, Revised March 1983.

3.5 QA/QC Protocols

Prior to implementation of the field and laboratory activities outlined in this Section, a Quality Assurance Project Plan (QAPP) was developed by ERD and submitted to FDEP for approval. This QAPP included information on site history and historical data, purpose and scope of the proposed monitoring efforts, project organization, project QA objectives, analytical methods for laboratory analyses (including QA targets), field procedures and quality control, and quality assurance management. This document was approved by FDEP and utilized as a guide for the field and laboratory activities performed during this project. A copy of the QAPP is included in Appendix E.

In addition to the protocols outlined in the QAPP, field and laboratory audits were also performed by District staff during this project. A field audit was performed on June 6, 2003, with a Summary of Findings and Corrective Actions/Recommendations provided on July 31, 2003. Each of the recommendations was formally adopted by ERD and incorporated into field protocol at the monitoring site. A laboratory audit was conducted on August 26, 2003, with minor comments and recommendations provided by the District on April 14, 2004. Responses to the recommendations were developed by ERD and forwarded to the District.

SECTION 4

INITIAL CHARACTERIZATION STUDIES

Initial characterization studies were performed during the design process for the CDS and TST units to obtain information on the physical and chemical characteristics of particles entrained in the water column of Lettuce Creek. In addition, sediment samples were also collected and analyzed to identify the characteristics of sediment particles which may potentially become entrained within the water column during high flow conditions. This information was obtained to assist in optimizing the design for each of the two units. Monitoring details and results of the water and sediment characterization studies are given in the following sections.

4.1 Characterization of Water Column Sediment Particles

4.1.1 Collection and Analysis Methodologies

Bulk water samples were collected from Lettuce Creek on two separate occasions to evaluate the physical and chemical characteristics of particles entrained in the water column. The first collection event was performed on August 17, 2001. During this event, approximately 225 gallons of Lettuce Creek water was collected upstream of the discharge riser structures, approximately 2 ft below the water surface. The discharge through Lettuce Creek at the time of this collection event was measured to be approximately 26 cfs, reflecting relatively low flow conditions within the creek. The second monitoring event was conducted on September 18, 2001 after flow conditions in Lettuce Creek had increased significantly to approximately 163 cfs. Following each of the two collection events, the 225-gallon bulk water sample was returned to the ERD Laboratory for fractionation studies and analysis of particulate matter contained within the bulk water sample.

A plot of calculated Lettuce Creek discharge rates from August 1-September 18, 2001 is given in Figure 4-1. It is apparent that the samples collected on August 17 and September 18 represent two widely differing flow regimes within Lettuce Creek. The August 17 sample reflects a period of low water velocities and relatively shallow water, while the September 18 sample reflects rapid flow velocities and a substantially deeper water column.

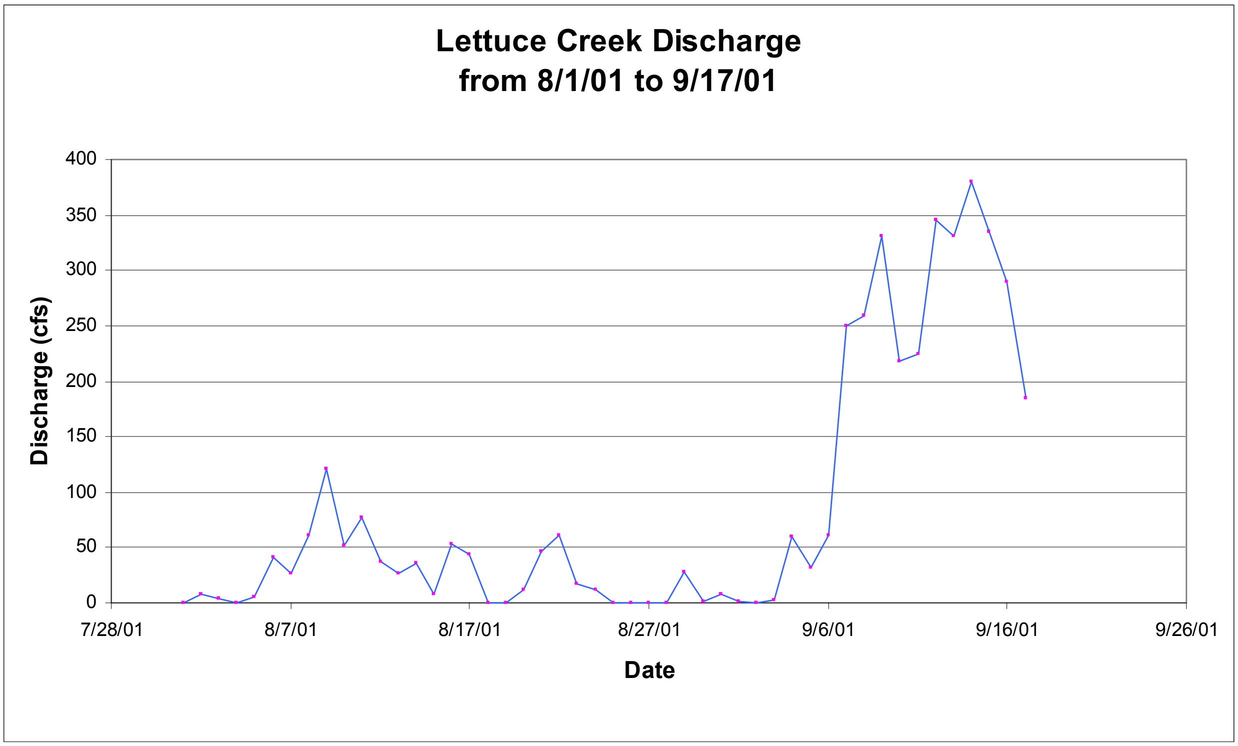


Figure 4-1. Plot of Lettuce Creek Discharge from 8/1/01 to 9/18/01.

Suspended sediment particles were separated from the Lettuce Creek water samples using a series of nylon net filters manufactured by Millipore. A sequential series of filtrations was performed using the net filters with pore sizes of 180 µm, 140 µm, 100 µm, 80 µm, 60 µm, 41 µm, 30 µm, 20 µm, and 11 µm. A 32-liter water sample, sub-sampled from the initial 225-gallon sample, was used for the separation.

Filtration of the sample was performed using a standard 47 mm glass filter holder mounted on top of a 12-liter polycarbonate carboy. Four carboys were used for the test. When one became filled with the filtrate, it was replaced with a rinsed empty carboy. The filtration was performed with very low or no applied vacuum to avoid embedding the particles into the filters. When the flow rate through the filters became too slow, the filter was removed and placed in a 250-ml polycarbonate bottle and labeled with the filter pore size. For larger pore sizes, only one or two filters were necessary to filter the entire sample. However, for the smaller pore sizes, more filters were needed. A 10-liter sample, sub-sampled from the 32-liter water sample, was filtered through the 11 μm filter to reduce the number of total filters needed. The filtrate from the 11 μm filter was filtered through a 1 μm glass fiber TCLP filter and then through a 1 μm glass fiber suspended solids filter.

The filters were segregated by pore size and placed in 250-ml polycarbonate bottles labeled with the appropriate pore size. Deionized water (50 ml) was added to each bottle and shaken for fifteen minutes on a shaker table to resuspend the sediment particles from the filters. The resuspended particulate solution was then analyzed for total suspended solids, volatile suspended solids, and total phosphorus. The TCLP filters with sediment were digested to determine total phosphorus. Due to filter unavailability, the first sample collected on August 17, 2001 was only filtered through 100 μm, 80 μm, 41 μm, 20 μm, and 11 μm pore sizes.

Settling rates for the particle fractions were calculated using Stokes Law:

$$v_s = \frac{9.8\ (\rho_{part} - \rho_{H_2O})\ D_p^2}{(18\ \ \mu)\ 1000}$$

where:

ρ_{part}	=	particle density
ρ_{H2O}	=	density of water (at 20 °C, 0.9982 g/cm^3)
D_p	=	particle diameter
μ	=	dynamic viscosity of water (at 20 °C, 1003 N-S/m^2)

4.1.2 Laboratory Results

The particles collected from the August 17, 2001 bulk water sample were divided into six particle size ranges from >100 µm to <11 µm. A summary of the physical and chemical characteristics of the various particle fractions for the August 17, 2001 sample is provided in Table 4-1. For this sample, particles <11 µm accounted for approximately 46% of the total suspended solids (TSS) concentration in the sample. Particles >100 µm accounted for approximately 11% of the TSS concentration. Similarly, particles <11 µm accounted for 52% of the volatile suspended solids (VSS) concentration, while particles >100 µm accounted for only 9% of the VSS concentration. In general, organic content increased with decreasing particle size. Particle density also decreased with decreasing particle size. Over one-third of the total particulate phosphorus concentration was comprised of particles <11 µm. Similar to total suspended solids, particles >100 µm accounted for just over 10% of the total phosphorus concentration. Calculated particle settling velocities ranged from 1.2×10^{-2} m/s to 2.3×10^{-6} m/s.

Particles collected from the September 18, 2001 bulk water sample were divided into 10 particle fractions ranging from <11 µm to >180 µm. A summary of the physical and chemical characteristics of the sediment particles contained in water from Lettuce Creek collected on September 18, 2001 is provided in Table 4-2. Several differences were observed in the particle data from this sample as compared to the August 17, 2001 sample. Particles in the 100-140 µm particle size range accounted for approximately 35% of the TSS concentration. This same fraction accounted for 56% of the non-volatile suspended solids concentration. Particles <11 µm also contained just over one-third of the total suspended solids concentration and over 50% of the volatile suspended solids concentration. With the exception of particles >140 µm in size, organic content appears to increase with decreasing particle size, while density decreases with decreasing particle size. Based on visual observations, particles >140 µm were primarily small pieces of leaves and detritus rather than particulate solids. Most importantly, 73% of the total particulate phosphorus concentration was comprised of particles <11 µm. Settling velocity varied from 1.4×10^{-2} m/s to 6.1×10^{-6} m/s, decreasing with decreasing particle size.

TABLE 4-1

PHYSICAL-CHEMICAL CHARACTERISTICS OF SEDIMENT PARTICLES CONTAINED IN WATER FROM LETTUCE CREEK COLLECTED ON AUGUST 17, 2001

(Q = 26 cfs)

PARTICLE SIZE (µm)	TSS (mg/l)	VSS (mg/l)	NVSS (mg/l)	ORGANIC CONTENT (%)	DENSITY (g/cm^3)	TOTAL PARTICULATE PHOSPHORUS[(1)]		SETTLING VELOCITY (m/s)
						(µg/l)	(µg/g)	
> 100	0.61	0.39	0.22	63.6	1.55	4.9	8050	1.2×10^{-2} [(2)]
80-100	0.34	0.24	0.09	72.3	1.42	2.4	7016	1.8×10^{-3} [(3)]
41-80	0.91	0.65	0.26	71.7	1.42	5.5	6057	8.3×10^{-4} [(3)]
20-41	0.72	0.52	0.20	72.1	1.42	6.9	9605	2.1×10^{-4} [(3)]
11-20	0.41	0.32	0.10	76.9	1.35	3.6	8629	4.2×10^{-5} [(3)]
< 11	2.55	2.27	0.28	88.9	1.17	13.2	5180	2.3×10^{-6} [(4)]
TOTALS:	5.54	4.39	1.15	--	--	36.5	--	--

(1) Total phosphorus was determined by EPA Method 365.1. The detection limit is lower because the sediment particles were extracted into a 50 ml sample but expressed as a concentration in terms of the original 32-liter or 10-liter samples.

(2) Calculated using a particle size of 200 µm

(3) Calculated using a particle size of the midpoint of the range

(4) Calculated using a particle size of 5 µm

TABLE 4-2

PHYSICAL-CHEMICAL CHARACTERISTICS OF SEDIMENT PARTICLES CONTAINED IN WATER FROM LETTUCE CREEK COLLECTED ON SEPTEMBER 18, 2001

(Q = 163 cfs)

PARTICLE SIZE (µm)	TSS (mg/l)	VSS (mg/l)	NVSS (mg/l)	ORGANIC CONTENT (%)	DENSITY (g/cm^3)	TOTAL PARTICULATE PHOSPHORUS[(1)]		SETTLING VELOCITY (m/s)
						(µg/l)	(µg/g)	
> 180	0.2	0.2	0.0	85.0	1.03	0.1	370	7.8×10^{-4} [(2)]
140-180	0.6	0.2	0.4	34.7	1.98	0.5	743	1.4×10^{-2} [(3)]
100-140	5.2	0.3	5.0	4.8	2.43	1.0	195	1.1×10^{-2} [(3)]
80-100	0.8	0.1	0.6	14.7	2.28	1.2	1516	5.6×10^{-3} [(3)]
60-80	0.4	0.2	0.2	43.5	1.85	0.8	2229	2.3×10^{-3} [(3)]
41-60	0.6	0.2	0.4	41.4	1.88	1.8	2937	1.2×10^{-3} [(3)]
30-41	0.4	0.2	0.2	44.9	1.83	1.8	3992	5.5×10^{-4} [(3)]
20-30	0.5	0.2	0.2	48.2	1.78	2.2	4824	2.6×10^{-4} [(3)]
11-20	0.8	0.4	0.4	51.7	1.73	5.6	7078	8.9×10^{-5} [(3)]
< 11	5.3	3.7	1.6	70.0	1.45	41	7696	6.1×10^{-6} [(4)]
TOTALS:	14.8	5.7	9.0	--	--	56.0	--	--

(1) Total phosphorus was determined by EPA Method 365.1. The detection limit is lower because the sediment particles were extracted into a 50 ml sample but expressed as a concentration in terms of the original 32-liter or 10-liter samples.

(2) Calculated using a particle size of 200 µm

(3) Calculated using a particle size of the midpoint of the range

(4) Calculated using a particle size of 5 µm

The water flow rate through Lettuce Creek on September 18, 2001 was 163 cfs or approximately six times the flow rate through the Creek on August 17, 2001. The TSS concentration of the bulk water sample collected on September 18, 2001 is approximately three times the TSS concentration of the sample collected on August 17, 2001. The VSS concentration on September 18 is slightly higher than the VSS concentration on August 17, 2001. Most of the measured increase in TSS concentration occurred in the non-volatile suspended solids fraction. Although the TSS increased three-fold, the total particulate phosphorus concentration only increased by a factor of approximately 1.5. The significantly higher flow rate on September 18, 2001 appears to have increased the mobilization of particles in the 100-140 µm size range, although total particulate phosphorus concentrations for these particles is relatively low and insignificant to the overall total particulate phosphorus concentration. Particles on the 100-140 µm size range are commonly associated with fine sand.

Estimates of the instantaneous total particulate phosphorus load, in terms of mg phosphorus per second, were calculated for each measured particle size fraction by multiplying the total particulate phosphorus concentration measured for particles in each size range times the measured discharge rate in Lettuce Creek on each of the two monitoring dates. A bar graph of the instantaneous total particulate phosphorus load by particle size is provided in Figure 4-2.

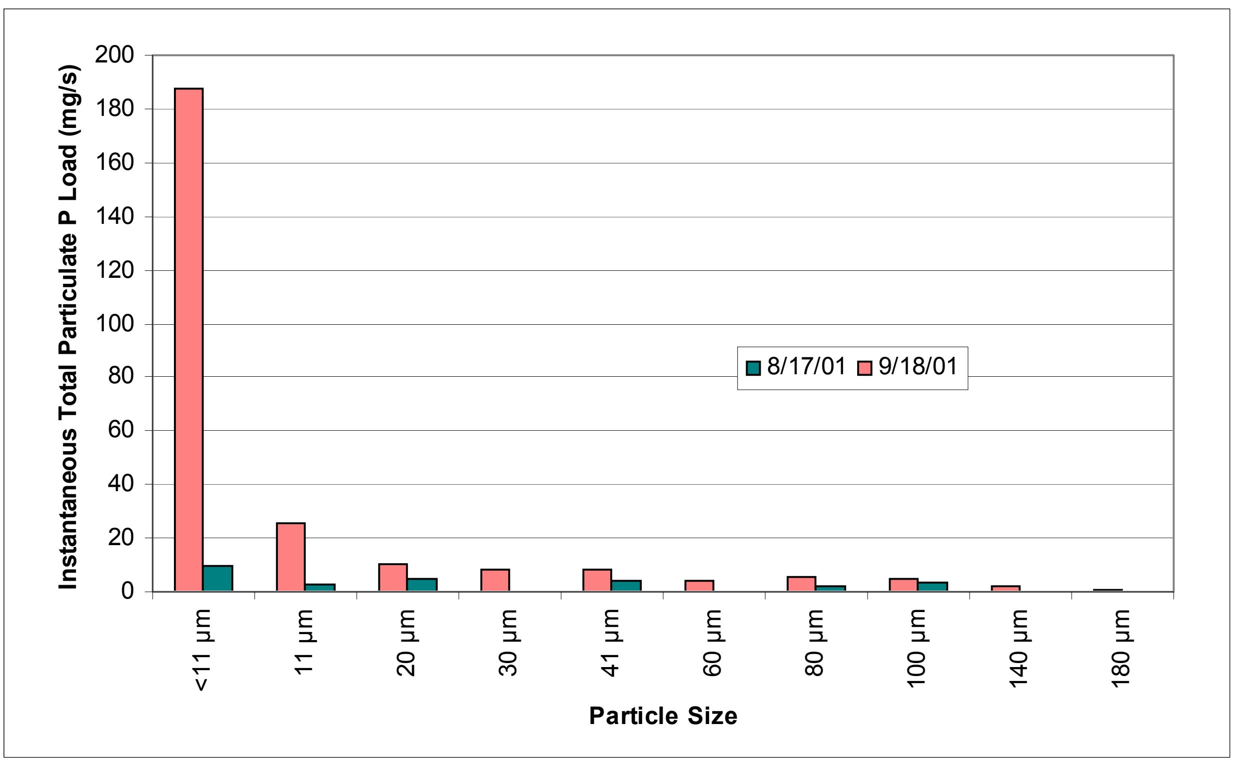


Figure 4-2. Lettuce Creek Instantaneous Total Particulate Phosphorus Load by Particle Size.

During low flow conditions, observed on August 17, 2001, the total particulate phosphorus load appears to be relatively evenly distributed throughout each of the measured particle sizes, with a slight skew to higher particulate phosphorus loadings at lower particle sizes. However, under high flow conditions, observed on September 18, 2001, the vast majority of the instantaneous total particulate phosphorus load is comprised of particles < 11 μm in size. It appears that these particles have become mobilized from the sediments or other source and entrained within the creek flow.

Based on the information contained in Table 4-1, Table 4-2, and Figure 4-2, it appears that the vast majority of particulate phosphorus transported through Lettuce Creek under high flow conditions and to a lesser extent, low flow conditions as well, is comprised of particles < 30-40 μm in size. Particles in this size range have estimated settling velocities ranging from approximately 10^{-4} to 10^{-6} m/s, suggesting extremely slow settling for these particles. Particles in this size range can only be effectively settled by extended periods of sedimentation under quiescent conditions.

4.2 Characterization of Lettuce Creek Sediments

4.2.1 Collection and Analysis Procedures

Lettuce Creek sediment samples were collected on October 12, 2001 at the three locations indicated on Figure 3-5. Samples were collected approximately 150 ft (Site 1), 450 ft (Site 2), and 700 ft (Site 3) upstream of the project area. Composite sediment samples were generated at each location by collecting multiple samples along a transect perpendicular to the flow in Lettuce Creek. At each location, composite samples were collected from the 0-1 inch layer and the 1-6 inch layer, for a total of six composite sediment samples. The six composite samples were returned to the ERD Laboratory for physical and chemical analysis.

The sediment particle size separation technique used is similar to the method described for the bulk water samples. Particle fractionation was conducted by suspending approximately 5 g of wet sediment into 100 ml of deionized water. The resulting suspension was then sequentially filtered through a series of nylon net filters. Deionized water was used to rinse the finer sediment particles through the filter pores.

After filtering, the nylon net filters were placed in 250 ml polycarbonate bottles with 50 ml of deionized water and shaken for fifteen minutes to resuspend the sediment particles. The resuspended sediment particles were then analyzed for TSS, VSS, and total phosphorus. The total phosphorus value reported in units of μg/g is the mass of total phosphorus divided by the dry weight of the particle sample for that size range.

4.2.2 Laboratory Results

A summary of the physical and chemical characteristics of the sediment samples collected at Sites 1, 2, and 3 in Lettuce Creek is provided in Tables 4-3, 4-4, and 4-5, respectively. The physical and chemical characteristics of the sediment samples collected are similar for both depths at all three sites. Approximately 70-85% of the sediments collected at each of the three sites are within the particle size of 100-180 μm. Particles in this range correspond primarily to fine sand. The particles in this range are characterized by extremely low levels of organic content and total phosphorus, while exhibiting the highest sediment densities, all of which are consistent with fine sand particles. Particles > 180 μm in size are primarily associated with detritus which exhibits an elevated value for both organic content and total phosphorus.

Particles < 100 μm in size represent less than 5-7% of the particle weight observed in any of the collected sediment samples. However, these particles, particularly those < 60 μm in size, are characterized by extremely elevated organic content and total phosphorus concentrations, while exhibiting low sediment densities. These characteristics suggest that particles in this range are primarily organic in nature and exhibit extremely high total phosphorus content per unit weight. Unfortunately, these particles are characterized by settling velocities ranging from 10^{-3} to 10^{-5} m/s, indicating extremely slow settling velocities which makes these particles difficult to remove except with extended sedimentation periods. In general, for particles < 100 μm in size, organic content and total phosphorus concentration exhibit a general pattern of increasing value with decreasing particle size. The opposite trend is apparent for particle density which appears to decrease with decreasing particle size.

TABLE 4-3

PHYSICAL-CHEMICAL CHARACTERISTICS OF LETTUCE CREEK SEDIMENT SAMPLES COLLECTED AT SITE 1 ON OCTOBER 12, 2001

0-1" Depth

PARTICLE SIZE (μm)	SEDIMENT WEIGHT		ORGANIC SEDIMENT WEIGHT (g)	ORGANIC CONTENT (%)	PARTICLE SIZE FRACTION (%)	DENSITY (g/cm^3)	TOTAL PHOSPHORUS (μg/g)	SETTLING VELOCITY (m/s)
	@ 103ºC (g)	@ 550ºC (g)						
> 180	0.5248	0.4072	0.1176	22.4	9.7	2.16	60	2.5×10^{-2}
140-180	2.3158	2.2950	0.0208	0.9	43.0	2.49	2	2.1×10^{-2}
100-140	2.1987	2.1900	0.0087	0.4	40.8	2.49	2	1.2×10^{-2}
60-100	0.2137	0.2054	0.0082	3.8	4.0	2.44	47	5.0×10^{-3}
30-60	0.0267	0.0196	0.0071	26.6	0.5	2.10	553	1.2×10^{-3}
11-30	0.0277	0.0169	0.0108	39.1	0.5	1.91	935	2.0×10^{-4}
< 11	0.0801	0.0572	0.0229	28.6	1.5	2.07	3680	1.5×10^{-5}
TOTALS:	5.3873	5.1913	0.1961	3.6	100.0	2.45	--	--

1-6" Depth

PARTICLE SIZE (μm)	SEDIMENT WEIGHT		ORGANIC SEDIMENT WEIGHT (g)	ORGANIC CONTENT (%)	PARTICLE SIZE FRACTION (%)	DENSITY (g/cm^3)	TOTAL PHOSPHORUS (μg/g)	SETTLING VELOCITY (m/s)
	@ 103ºC (g)	@ 550ºC (g)						
> 180	0.5456	0.5218	0.0239	4.4	16.4	2.43	18	3.1×10^{-2}
140-180	1.5931	1.5906	0.0026	0.2	48.0	2.50	1	2.1×10^{-2}
100-140	0.9321	0.9281	0.0040	0.4	28.1	2.49	1	1.2×10^{-2}
60-100	0.1328	0.1308	0.0020	1.5	4.0	2.48	24	5.1×10^{-3}
30-60	0.0361	0.0295	0.0066	18.4	1.1	2.22	285	1.3×10^{-3}
11-30	0.0183	0.0122	0.0061	33.3	0.6	2.00	915	2.2×10^{-4}
< 11	0.0620	0.0416	0.0204	32.9	1.9	2.01	2493	1.4×10^{-5}
TOTALS:	3.3200	3.2544	0.0655	2.0	100.0	2.47	--	--

TABLE 4-4

PHYSICAL-CHEMICAL CHARACTERISTICS OF LETTUCE CREEK SEDIMENT SAMPLES COLLECTED AT SITE 2 ON OCTOBER 12, 2001

0-1" Depth

PARTICLE SIZE (µm)	SEDIMENT WEIGHT		ORGANIC SEDIMENT WEIGHT (g)	ORGANIC CONTENT (%)	PARTICLE SIZE FRACTION (%)	DENSITY (g/cm³)	TOTAL PHOSPHORUS (µg/g)	SETTLING VELOCITY (m/s)
	@ 103ºC (g)	@ 550ºC (g)						
> 180	1.1740	1.0221	0.1519	12.9	17.4	2.31	42	2.8×10^{-2}
140-180	2.6308	2.6213	0.0094	0.4	38.9	2.49	4	2.1×10^{-2}
100-140	2.4353	2.4226	0.0128	0.5	36.0	2.49	7	1.2×10^{-2}
60-100	0.2167	0.2076	0.0091	4.2	3.2	2.44	103	5.0×10^{-3}
30-60	0.0727	0.0603	0.0124	17.0	1.1	2.24	527	1.4×10^{-3}
11-30	0.0263	0.0154	0.0108	41.3	0.4	1.88	3088	1.9×10^{-4}
< 11	0.2027	0.1393	0.0633	31.3	3.0	2.03	2610	1.4×10^{-5}
TOTALS:	6.7584	6.4886	0.2698	4.0	100.0	2.44	--	--

1-6" Depth

PARTICLE SIZE (µm)	SEDIMENT WEIGHT		ORGANIC SEDIMENT WEIGHT (g)	ORGANIC CONTENT (%)	PARTICLE SIZE FRACTION (%)	DENSITY (g/cm³)	TOTAL PHOSPHORUS (µg/g)	SETTLING VELOCITY (m/s)
	@ 103ºC (g)	@ 550ºC (g)						
> 180	0.5492	0.5660	0.0281	4.7	17.5	2.43	16	3.1×10^{-2}
140-180	1.9737	1.9699	0.0038	0.2	58.1	2.50	2	2.1×10^{-2}
100-140	0.6448	0.6402	0.0046	0.7	19.0	2.49	3	1.2×10^{-2}
60-100	0.0520	0.0482	0.0038	7.3	1.5	2.39	64	4.8×10^{-3}
30-60	0.0100	0.0050	0.0050	50.0	0.3	1.75	543	8.3×10^{-4}
11-30	0.0302	0.0208	0.0093	31.0	0.9	2.04	761	2.3×10^{-4}
< 11	0.0929	0.0620	0.0310	33.3	2.7	2.00	2697	1.4×10^{-5}
TOTALS:	3.3977	3.3122	0.0856	2.5	100.0	2.46	--	--

TABLE 4-5

PHYSICAL-CHEMICAL CHARACTERISTICS OF LETTUCE CREEK SEDIMENT SAMPLES COLLECTED AT SITE 3 ON OCTOBER 12, 2001

0-1" Depth

PARTICLE SIZE (µm)	SEDIMENT WEIGHT @ 103°C (g)	SEDIMENT WEIGHT @ 550°C (g)	ORGANIC SEDIMENT WEIGHT (g)	ORGANIC CONTENT (%)	PARTICLE SIZE FRACTION (%)	DENSITY (g/cm^3)	TOTAL PHOSPHORUS (µg/g)	SETTLING VELOCITY (m/s)
> 180	0.4791	0.4531	0.0259	5.4	16.4	2.42	42	3.1×10^{-2}
140-180	1.8362	1.8319	0.0043	0.2	62.8	2.50	2	2.1×10^{-2}
100-140	0.4751	0.4720	0.0031	0.7	16.2	2.49	10	1.2×10^{-2}
60-100	0.0360	0.0339	0.0021	5.9	1.2	2.41	132	4.9×10^{-3}
30-60	0.0217	0.0184	0.0034	15.5	0.7	2.27	301	1.4×10^{-3}
11-30	0.0290	0.0223	0.0067	23.1	1.0	2.15	415	2.5×10^{-4}
< 11	0.0478	0.0288	0.0190	39.7	1.6	1.90	3074	1.2×10^{-5}
TOTALS:	2.9249	2.8604	0.0645	2.2	100.0	2.47	--	--

1-6" Depth

PARTICLE SIZE (µm)	SEDIMENT WEIGHT @ 103°C (g)	SEDIMENT WEIGHT @ 550°C (g)	ORGANIC SEDIMENT WEIGHT (g)	ORGANIC CONTENT (%)	PARTICLE SIZE FRACTION (%)	DENSITY (g/cm^3)	TOTAL PHOSPHORUS (µg/g)	SETTLING VELOCITY (m/s)
> 180	0.7492	0.7345	0.0147	2.0	21.1	2.47	12	3.2×10^{-2}
140-180	1.7878	1.7849	0.0029	0.2	50.3	2.50	1	2.1×10^{-2}
100-140	0.7594	0.7558	0.0037	0.5	21.4	2.49	1	1.2×10^{-2}
60-100	0.0502	0.0482	0.0020	4.0	1.4	2.44	14	5.0×10^{-3}
30-60	0.0461	0.0410	0.0051	11.0	1.3	2.33	34	1.5×10^{-3}
11-30	0.1436	0.1360	0.0076	5.3	4.0	2.42	22	3.1×10^{-4}
< 11	0.0204	0.0146	0.0058	28.6	0.6	2.07	714	1.5×10^{-5}
TOTALS:	3.5567	3.5150	0.0418	1.2	100.0	2.48	--	--

A general absence of small sediment particles <100 μm was observed in all sediment samples. The density and total mass of these particles are significantly lower than those of larger particles. The flow velocities in Lettuce Creek are often sufficient to mobilize the smaller particles and transport the particles downstream. This observation is confirmed by the particulate analyses provided in Tables 4-1 and 4-2 for bulk water samples. At a Lettuce Creek flow rate of 26 cfs, almost half of the TSS concentration was associated with particles <11 μm in size. At a flow rate of 163 cfs, approximately one-third of the TSS concentration was associated with particles <11 μm while an additional one-third of the TSS concentration was associated with particles in the 100-140 μm size range. At higher flow rates, larger particles are mobilized. It appears that the higher the flow rate in Lettuce Creek, the larger the particles mobilized and transmitted downstream.

Plots of sediment phosphorus concentration as a function of distance from the project site for particles >100 μm, 11-100 μm, and particles <11 μm are provided in Figures 4-3, 4-4, and 4-5, respectively. Particles > 100 μm in size are characterized by relatively low total phosphorus concentrations which appear to decrease slightly with increasing distance upstream from the project site. In general, total phosphorus concentrations in the 1-6 inch sample depth are approximately one-third of the concentrations measured in the 0-1 inch layer.

As seen in Figure 4-4, total sediment phosphorus concentrations for particles in the 11-100 μm range are substantially higher than particles > 100 μm in size. Sediment phosphorus concentrations at the most upstream monitoring site appear to be lower in both the 0-1 inch and 1-6 inch layer than observed closer to the project site, although maximum sediment total phosphorus concentrations were observed in both the 0-1 and 1-6 inch layers at the 450 ft monitoring site. Sediment phosphorus concentrations in the 1-6 inch layer appear to be somewhat lower than concentrations measured in the 0-1 inch layer.

A plot of total phosphorus concentrations in the < 11 μm particle size are indicated on Figure 4-5. In general, sediment phosphorus concentrations appear to be greater in the < 11 μm particle size than observed for other particle sizes. The highest sediment total phosphorus concentrations were observed in the 0-1 inch layer at the most downstream monitoring site, while the highest sediment phosphorus concentrations were observed in the 1-6 inch layer at the most upstream monitoring site.

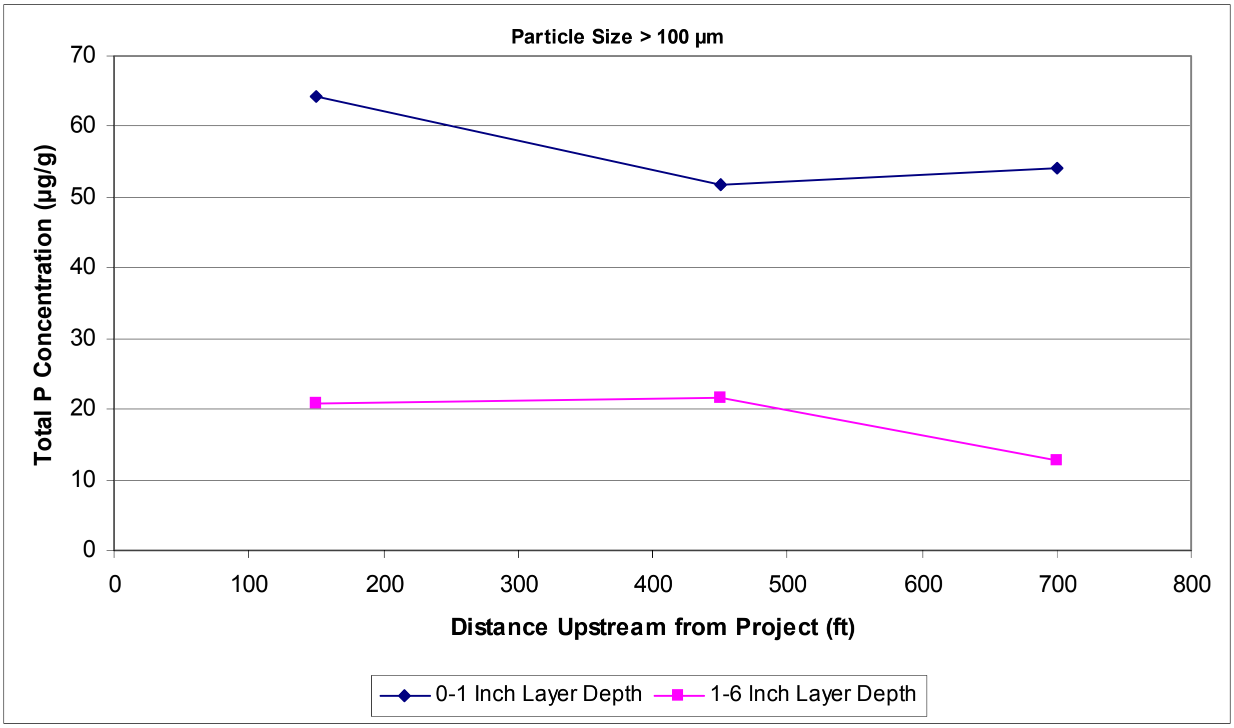


Figure 4-3. Lettuce Creek Sediment Total Phosphorus Concentration in the > 100 µm Particle Size Range at Three Upstream Sample Sites.

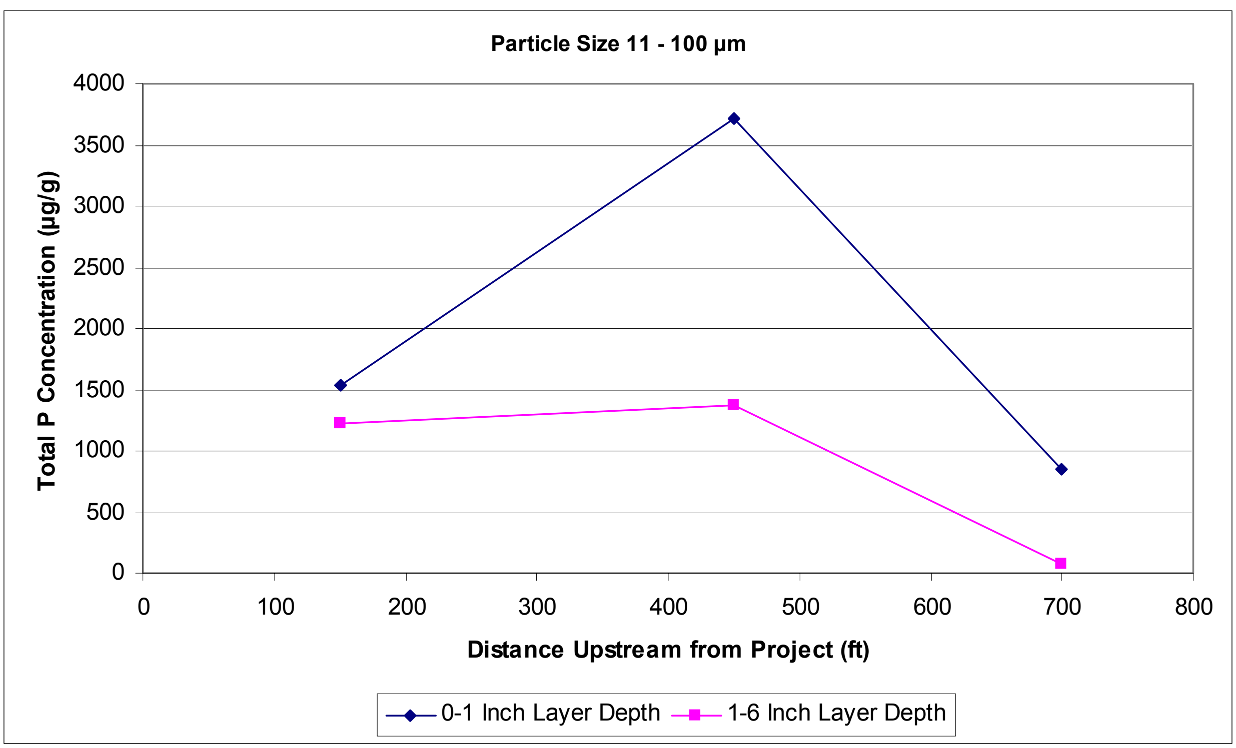


Figure 4-4. Lettuce Creek Sediment Total Phosphorus Concentration in the 11-100 µm Particle Size Range at Three Upstream Sample Sites.

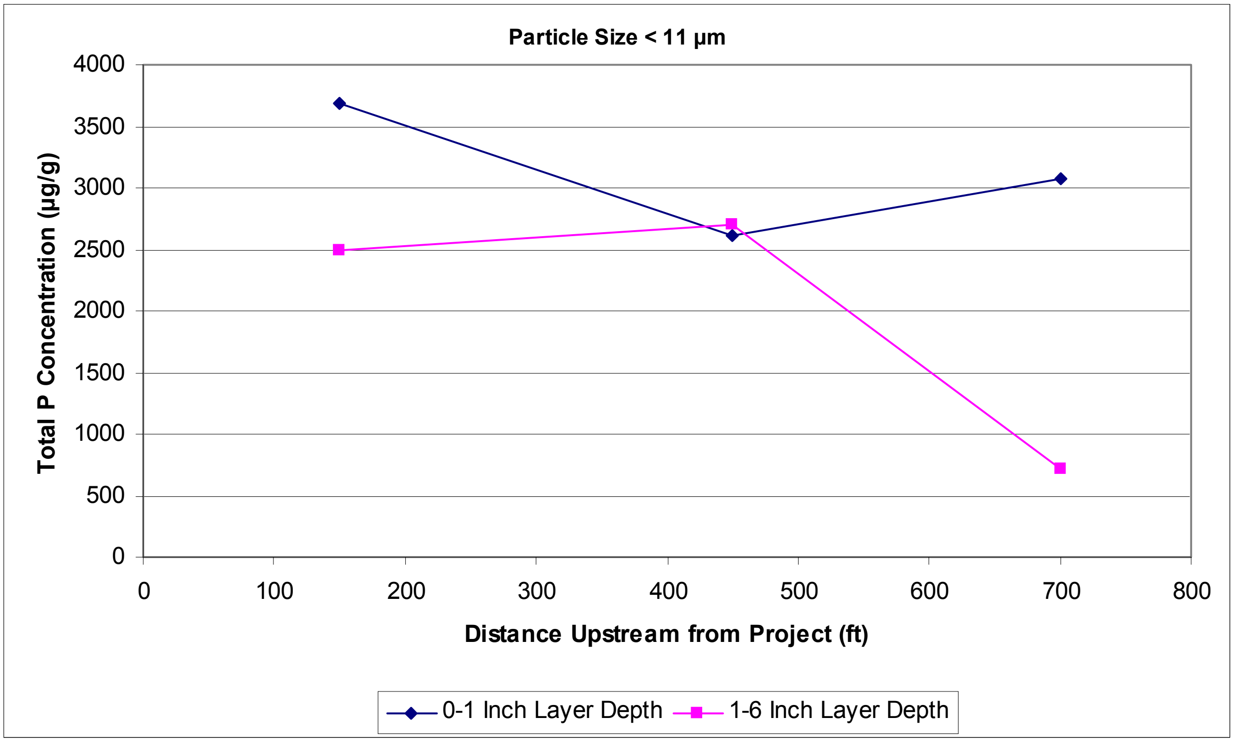


Figure 4-5. Lettuce Creek Sediment Total Phosphorus Concentration in the < 11 µm Particle Size Range at Three Upstream Sample Sites.

SECTION 5

RESULTS OF FIELD MONITORING ACTIVITIES

Field monitoring activities were performed by ERD from July 2002 through November 2003 to: (1) evaluate the hydraulic characteristics of discharges through Lettuce Creek; (2) evaluate the chemical characteristics and variability in characteristics of discharges in Lettuce Creek; (3) determine the removal efficiency of the CDS and TST units operated under a variety of flow rates; (4) quantify the characteristics of suspended solids collected by the CDS and TST units; and (5) document changes in sediment characteristics in Lettuce Creek during low and high flow conditions. An evaluation of the results of these activities is given in the following sections, along with a detailed history of field monitoring activities.

5.1 History of Monitoring Activities

A detailed history of monitoring activities at the Lettuce Creek site is given in each of the four Quarterly Monitoring Reports provided in Appendix B. A summary of field monitoring activities performed at the Lettuce Creek site is given in Table 5-1.

Installation of monitoring equipment at the Lettuce Creek site was completed on April 20, 2002. However, at this time, the water level in Lettuce Creek was below the weir discharge elevation of 20.5 ft (NGVD), and the monitoring equipment was not placed into operation at that time. During the period from early-May through mid-July, the project site was heavily impacted by adjacent construction activities by CSX, Inc. related to replacement of the railroad bridge crossing Lettuce Creek. These activities not only caused damage to the sediment removal equipment and piping, but also allowed a large amount of adjacent soil to enter both the TST and CDS units. Damage to the sediment removal units was subsequently repaired, and CSX hired a consultant to remove the accumulated sediment from the CDS and TST units. These activities were completed on July 22, 2002, and the scheduled 12-month monitoring period was initiated on this date.

TABLE 5-1

HISTORY OF FIELD MONITORING ACTIVITIES

DATE	ACTIVITY
4/20/02	Installation of monitoring equipment completed
4/21-7/21/02	Monitoring delayed due to low flow conditions and CSX bridge replacement
7/22/02	Monitoring initiated following completion of CSX construction
7/22-8/30/02	Monitoring performed; data compromised due to vandalism and theft
9/12/02	Team meeting in West Palm; vandalism and theft issues discussed; decided to discard data collected from 7/22-8/30/02
9/25/02	Security fence installed at project site
9/30/02, 10/4/02	CDS and baffle box units drained and sediment removed prior to initiation of monitoring
10/4/02	Phase III monitoring restarted
10/6/02	Monitoring equipment damaged by lightning strike; equipment returned for repair
10/31/02	Repaired equipment reinstalled at site with surge protection added; monitoring re-initiated at 1 cfs in each unit
11/1/02	Flow through units create drawdown of Creek below weir invert elevation (20.5 ft); monitoring discontinued
11/15/02-2/12/03	Creek levels rise; monitoring resumed at 1 cfs in each unit
12/17/02	Creek water collected for lab jar tests using alum; jar tests conducted at alum doses of 5.0, 7.5, 10.0, 12.5, and 15 mg Al/liter
1/16/03	Team review meeting in West Palm
2/12/03	Flow through units create drawdown of Creek below weir invert elevation (20.5 ft); monitoring discontinued
2/19/03	Creek levels rise; monitoring resumed at 1 cfs in each unit
3/12/03	Flow through units create drawdown of Creek below weir invert elevation (20.5 ft); monitoring discontinued
3/20/03	Creek levels rise; monitoring resumed at 1 cfs in each unit
4/15/03	Flow through units create drawdown of Creek below weir invert elevation (20.5 ft); monitoring discontinued
4/29/03	Creek levels rise; monitoring resumed at 1 cfs in each unit
5/14/03	Flow through units create drawdown of Creek below weir invert elevation (20.5 ft); monitoring discontinued
5/29/03	Creek levels rise; monitoring resumed at 1 cfs in each unit
6/6/03	Flow through units create drawdown of Creek below weir invert elevation (20.5 ft); monitoring discontinued
6/12-13/03	CDS and baffle box units drained and sediment removed
6/13/03	Creek levels rise; monitoring resumed at 1 cfs in each unit

TABLE 5-1 – CONTINUED

DATE	ACTIVITY
6/27/03	Flow rate adjusted to 5 cfs in each unit
7/3/03	While operating at 5 cfs per unit, flow through units creates drawdown of Creek below weir invert elevation (20.5 ft); monitoring discontinued; fish observed in units
7/10-16/03	Screen installed on intake pipe to keep fish out of units; Creek levels rise; monitoring resumed at 5 cfs
7/24/03	Intake pipe (30-inch CMP) becomes dislodged due to clogged intake; collected sediment samples along 3 transects in Lettuce Creek
7/28-30/03	Pipe repaired; original screen removed and larger mesh screen installed
7/31/03	Monitoring resumed at 5 cfs; collected sediment samples along 3 transects in Lettuce Creek
8/6/03	Intake pipe (30-inch CMP) becomes dislodged due to clogged intake
8/6/03	Installed equipment (tanks, pumps, valves) for alum testing; filled tank with 1000 gallons of alum
8/8/03	Pipe repaired; opened gates to test system but kept monitoring system off
8/12-19/03	Monitoring resumed at 5 cfs
8/19-21/03	Noticed sand accumulation in units from recent pipe breaks; cleaned out baffle box and CDS units; removed 150 gallons of sand and hundreds of fish from baffle box (initial chamber only), no sand in second or third chambers; removed 300 gallons of vegetation, debris, and fish from center of CDS unit and 37 gallons of sand
8/19/03	Performed flow rate experiments using flows of 2.5, 5.0, 7.5, and 10.0 cfs in each unit; samples collected for water and particle size analyses
8/21-27/03	Monitoring resumed at 5 cfs per unit
8/27/03	Flow rate adjusted from 5 cfs to 11 cfs; monitoring resumed
8/27/03	Sediment samples collected along 3 transects in Lettuce Creek
8/27-9/4/03	Conducted testing at 11 cfs per unit
9/9/03	Removed accumulated debris from units; disposed of sediments on-site; removed 560 gallons of vegetation and 40 gallons of sand from CDS unit; no significant accumulation in baffle box
9/11-12/03	Performed testing using alum at 1 cfs per unit
9/19/03	Drained structures and removed accumulated floc; used adjacent land provided by District for disposal
9/22-23/03	Observed unusual floc distribution during initial testing; continued testing with alum in CDS only at 1 cfs
10/6-17/03	Flows in Creek increase; performed testing at 11 cfs per unit without alum
10/6/03	Performed flow rate experiments using flows of 2.5, 5.0, 7.5, and 10.0 cfs in each unit; samples collected for water and particle size analyses
10/9/03	Sediment samples collected along 3 transects in Lettuce Creek
10/23-24/03	Performed testing in CDS unit using alum at 2 cfs
10/29-30/03	Performed testing in baffle box using alum at 2 cfs
10/30-31/03	Performed testing in baffle box using alum at 1 cfs
11/10-11/03	Performed testing in baffle box using alum at 0.75 cfs
11/11-12/03	Performed testing in baffle box using alum at 0.5 cfs
11/12-13/03	Performed testing in CDS unit using alum at 0.5 cfs
11/13-14/03	Performed testing in CDS unit using alum at 0.75 cfs

Immediately after initiation of the monitoring program, vandalism and theft occurred at the project site which resulted in damage to the equipment shed, along with several of the flow sensors and stormwater samplers. Because of this ongoing vandalism, data collected at the site from July 22-August 30, 2002 was discarded. A security fence was installed around the perimeter of the project site on September 25, 2002. The CDS and TST units were drained, and all sediment was removed from the structures prior to restart of the monitoring program.

The Phase 3 monitoring program was restarted on October 4, 2002. On October 6, two of the three autosamplers were severely damaged by a lightning strike in the vicinity of the area. The equipment was returned for repair, and surge protection was added at the project site. Monitoring was reinitiated in each unit on October 31, 2002 at a flow rate of 1 cfs. However, on November 1, the water elevation in Lettuce Creek dropped below the riser elevation of 20.5 ft (NGVD), and monitoring was subsequently discontinued.

On November 15, 2002, the water level in Lettuce Creek rose above the riser structures and monitoring was resumed at a flow rate of 1 cfs in each unit. Field monitoring was performed on a continuous basis until February 12, 2003 when the water level again dropped below the riser structure.

During the period from February 12-June 26, 2003, the CDS and TST units were operated intermittently at a flow rate of 1 cfs. Based upon the operational protocol developed for this project, field experimentation is only to be performed when the elevation in Lettuce Creek is above 20.5 ft (NGVD) and discharge is occurring through the fixed weir structure. Monitoring was discontinued on a periodic basis whenever flow within the creek did not meet these operational guidelines.

On June 27, 2003, the flow rate discharging into the CDS and TST units was increased to 5 cfs in each unit. This operation continued until July 3 when drawdown of the creek resulted in elevations lower than the riser structures.

During the first few weeks of July, both the CDS and baffle box units were operated at flow rates of 5 cfs to evaluate particulate removal under higher loading conditions. However, at these higher flow rates, fish were pulled into the intake structure in Lettuce Creek and began accumulating in the CDS and baffle box units. On July 10, a screen was installed over the intake pipe in an attempt to keep fish from entering the units. However, on July 24, the screen on the intake pipe became clogged, causing air to accumulate inside the 30-inch CMP. The pipe then popped out of the ground and rose above the water elevation in Lettuce Creek. A photograph of the dislodged pipe is given in Figure 5-1. The intake pipe was repaired during late-July, and a screen with larger mesh was installed for fish control. Monitoring was resumed at a flow rate of 5 cfs through each unit on July 31. On August 6, the intake screen became clogged again, causing the pipe to again pop out of the ground and rise above the water level in Lettuce Creek. The pipe was again repaired on August 8, and the screen structure was permanently removed.

Figure 5-1. Dislodged Intake Pipe.

The CDS and TST units were operated at a flow rate of 5 cfs during the period from July 10-August 27, 2003. Several off-line periods occurred due to lack of adequate flow within the creek. Performance evaluations at a flow rate of 11 cfs per unit were conducted from August 27-September 4 and from October 6-17.

On August 19, a series of flow rate experiments were performed on both the CDS and baffle box units by diverting flows of 2.5, 5, 7.5, and 10 cfs into each unit for a period of several hours. The purpose of these activities is to evaluate removal characteristics within the collection units during periods of elevated flow within Lettuce Creek. Samples were collected for both water and particle size analyses. An additional set of flow rate experiments was conducted on October 6 at the same flow rates used during the initial testing.

Sediment sampling was also conducted in Lettuce Creek to monitor sediment transport following significant rain events within the watershed. Collection of sediment samples along three transects in upstream portions of Lettuce Creek was conducted on July 24, July 31, August 27, and October 9.

In addition to the activities outlined above, field testing was performed using alum to enhance the phosphorus removal capabilities of the two units. Removal and analysis of accumulated sediments from the CDS and TST units was also conducted on multiple occasions. Details related to each of these activities are provided in other sections.

5.2 Characteristics of Lettuce Creek

Field monitoring was performed to evaluate the hydraulic and chemical characteristics of discharges through Lettuce Creek during this project. A discussion of these activities is given in the following sections.

5.2.1 Hydraulic Characteristics

As discussed in Section 3, water surface elevations in Lettuce Creek were recorded on a continuous basis (15-minute intervals) at the District monitoring station approximately 100 ft upstream from the outfall discharge structure in Lettuce Creek. This information was downloaded by ERD on a periodic basis and utilized for evaluation of hydraulic characteristics within the creek. A plot of mean daily Lettuce Creek water surface elevations from November 1, 2002-December 1, 2003 is given in Figure 5-2. Water surface elevations in Lettuce Creek were frequently observed at levels below the water control weir elevation, indicating conditions of zero discharge through the creek. However, water levels are capable of rapidly rising in response to rain events, particularly during extended periods of rainfall.

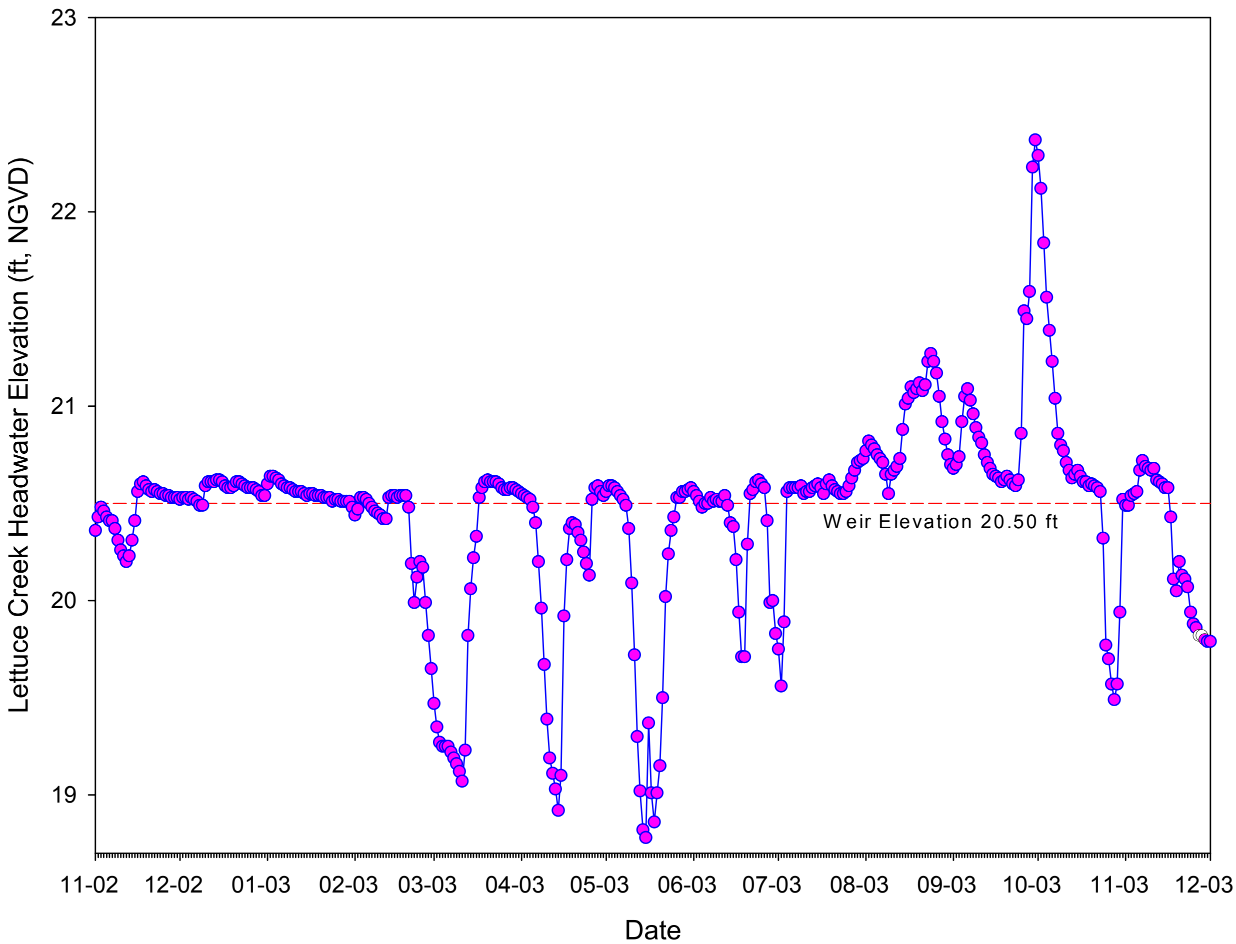


Figure 5-2. Lettuce Creek Water Surface Elevations (11/1/02 – 12/1/03).

During periods when the Lettuce Creek water surface elevation was above 20.50 ft (NGVD), ERD performed periodic stream flow measurements in Lettuce Creek to collect data for calibration of a stage-discharge relationship for Lettuce Creek. Instantaneous measurements of tributary discharge rates were performed on 23 separate occasions using the velocity/cross-sectional area method, as outlined by USGS. A calibrated rope was stretched across Lettuce Creek, immediately downstream from the CSX railroad bridge at a narrow constricted point within the creek. Field measurements of water depth and flow velocities were performed at approximately 25 separate locations across the channel. Typical channel width at the point of measurement is approximately 60 ft, suggesting that flow measurements were conducted at approximately 2-ft intervals.

When the water depth at a particular measurement point was 2.5 ft or less, velocity measurements were performed at 60% of the water depth. When the water depth exceeded 2.5 ft, velocity measurements were performed at 20% and 80% of the water depth, with the two values averaged to obtain an estimate of average flow velocity for a given section. All velocity measurements were performed using a Marsh-McBirney Model 2000 flow meter. Many of the measured velocities were very low, particularly when total measured discharge rates are less than 3-4 cfs. The Model 2000 velocity meter has a zero stability of ±0.05 ft/sec and an accuracy at the zero stability of ±2%. Therefore, there is a possibility of increasing error in the discharge measurements at low velocities.

Discharge rates were calculated for each channel section by multiplying the mean section velocity times the cross-sectional area for each section. A complete listing of stream discharge measurements performed in Lettuce Creek is given in the Quarterly Reports included in Appendix B.

During the first, second, and third monitoring quarters, ERD evaluated relationships between Lettuce Creek water surface elevation and flow rate, based upon surface elevations measured by District equipment and field flow measurements of Lettuce Creek discharge conducted by ERD field personnel. After evaluating several different empirical relationships and rating curves to express flow rate as a function of water surface elevation, it appears that the relationship between stream flow rate and water surface elevation in Lettuce Creek can best be expressed by a standard weir-type equation of the following form:

$$Q = C\,(L - 0.2H)\,H^{1.5}\,n$$

where:

Q	=	Lettuce Creek flow rate (cfs)
C	=	weir coefficient
L	=	weir length = 8.0 ft
H	=	height of water over weir, calculated as water elevation-20.50 ft (ft)
n	=	number of identical weirs = 8

Textbook weir coefficients (C value) for rectangular weirs range from approximately 2.9-3.33, depending upon the size of the weir, configuration, influences from other hydraulic structures, and ratio of weir length to water height above the weir. Site-specific weir coefficients were estimated for the Lettuce Creek outfall structure based upon the field monitoring program performed by ERD. Methodology for estimation of weir discharge coefficients for the Lettuce Creek outfall structure is summarized in Table 5-2. This table provides a summary of the flow characteristics on each of the field discharge monitoring dates performed by ERD. The field measured discharge rate is provided, along with the upstream water surface elevation at the time of the flow monitoring event. The combined flow through the CDS and TST units occurring at the time of the monitoring event is noted. The estimated flow over the weir structure is equal to the field measured Lettuce Creek discharge minus the flow diverted into the CDS and TST units. Each of these values was entered into the standard weir-type equation based upon a weir length of 8.0 ft, eight identical rectangular weirs, and the height of water over the weir calculated as the water surface elevation minus 20.50 ft. An optimization program was used to determine the weir coefficient which minimized the difference between the estimated flow over the discharge weir and the calculated weir discharge summarized in the final two columns of Table 5-2. Based upon this optimization program, the weir coefficient for the Lettuce Creek discharge structure is estimated to be 2.99 which is within the range of values commonly observed for rectangular weir structures.

TABLE 5-2

METHODOLOGY FOR ESTIMATION OF WEIR DISCHARGE COEFFICIENTS FOR THE LETTUCE CREEK OUTFALL STRUCTURE

DATE	UPSTREAM WATER ELEVATION (ft)	FIELD MEASURED LETTUCE CREEK DISCHARGE (cfs)	COMBINED FLOW THROUGH CDS AND TST UNITS (cfs)	ESTIMATED FLOW OVER WEIR[1] (cfs)	CALCULATED WEIR DISCHARGE[2] (cfs)
11/19/02	20.59	8.96	2.00	6.96	6.30
11/21/02	20.56	7.52	2.00	5.52	3.76
12/6/02	20.61	10.01	2.00	8.01	8.22
12/17/02	20.59	7.34	2.00	5.34	6.30
12/26/02	20.58	7.70	2.00	5.70	5.40
1/7/03	20.59	6.22	2.00	4.22	6.30
1/16/03	20.55	4.57	2.00	2.57	3.01
1/22/03	20.53	3.13	2.00	1.13	1.70
1/30/03	20.51	2.66	2.00	0.66	0.66
2/20/03	20.54	3.58	2.00	1.58	2.32
3/20/03	20.61	11.94	2.00	9.94	8.22
3/28/03	20.57	4.20	0.00	4.20	4.56
4/4/03	20.52	3.27	2.00	1.27	1.14
4/29/03	20.58	4.83	0.00	4.83	5.40
5/29/03	20.57	5.02	0.00	5.02	4.56
6/13/03	20.55	3.28	0.00	3.28	3.01
6/26/03	20.58	8.84	2.00	6.84	5.40
7/10/03	20.52	6.29	5.00	1.29	1.14
7/16/03	20.55	12.03	5.00	7.03	3.01
8/1/03	20.71	23.08	0.00	23.08	20.04
8/19/03	21.08	96.51	10.00	86.51	86.14

1. Calculated as field measured Lettuce Creek discharge minus combined flow through CDS and TST units
2. Based on a weir coefficient (C value) of 2.99

Discharge rates through Lettuce Creek were calculated for the period from November 1, 2002-December 1, 2003 using measured water surface elevations, the standard weir equation, and the estimated discharge coefficient of 2.99. Discharge rates were calculated for each day during which the mean water surface elevation exceeded a value of 20.50 ft.

A plot of discharges through Lettuce Creek from November 1, 2002-December 1, 2003 is given in Figure 5-3. The vast majority of flow rates observed in Lettuce Creek during this monitoring program were approximately 10 cfs or less. However, short-term increases in discharge rates of approximately 100 cfs were observed on two separate occasions, and approximately 475 cfs on one occasion.

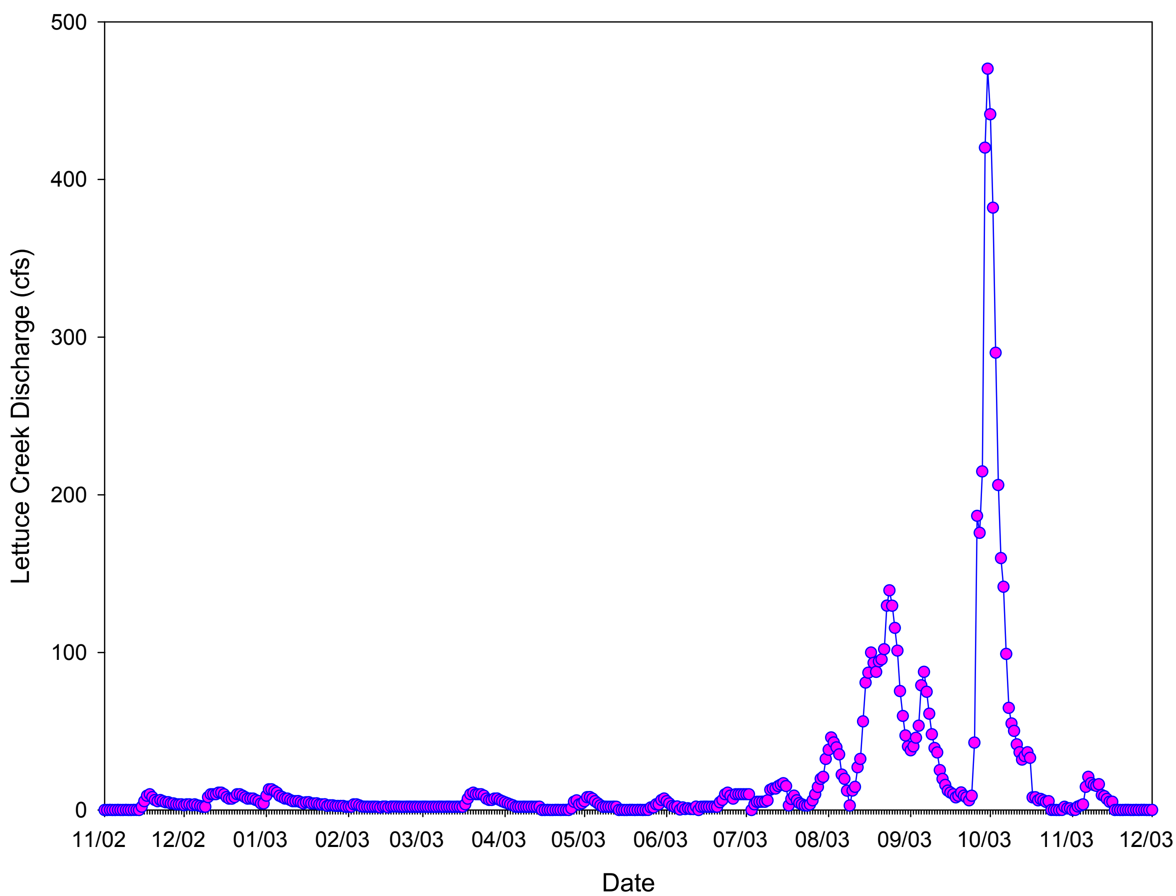


Figure 5-3. Lettuce Creek Discharge (11/1/02 – 12/1/03)

A probability distribution of discharge rates in Lettuce Creek from November 1, 2002-December 1, 2003 is given in Figure 5-4. The vast majority of discharges through Lettuce Creek on an annual basis appear to be less than approximately 10-20 cfs, with larger discharge events representing a relatively small proportion of the events on an annual basis.

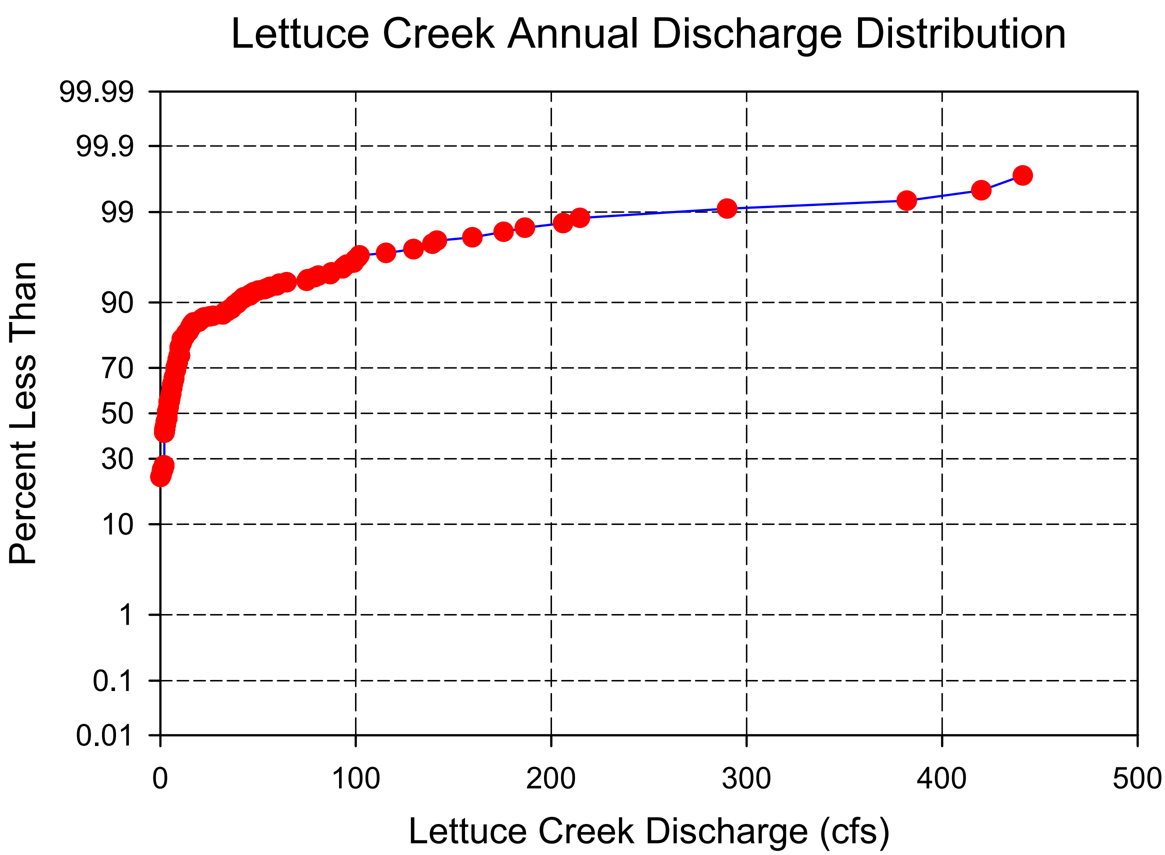


Figure 5-4. Probability Plot of Discharge Rates in Lettuce Creek from 11/1/02-12/1/03.

A probability distribution of Lettuce Creek discharge rates for annual and seasonal conditions is given in Table 5-3. On an annual basis, approximately 90% of the daily discharge events will be approximately 39.9 cfs or less. During dry conditions, approximately 90% of the annual average events will be less than 10.5 cfs, with 90% less than 95.4 cfs under wet season conditions. Based on the information summarized in Table 5-3, flow conditions in Lettuce Creek appear to be substantially different during wet and dry season conditions.

TABLE 5-3

PROBABILITY DISTRIBUTION OF LETTUCE CREEK DISCHARGE RATES FOR ANNUAL AND SEASONAL CONDITIONS

CUMULATIVE PERCENTAGE	ANNUAL (cfs)	SEASON (cfs)	
		WET	DRY
95	89.9	134.4	19.7
90	39.9	95.4	10.5
70	8.0	38.0	5.2
50	3.5	12.3	2.1
30	2.0	6.2	0.2

5.2.2 Chemical Characteristics of Lettuce Creek Flow

Discharge through Lettuce Creek was monitored on a continuous basis from November 2002-November 2003 during periods of discharge through the Lettuce Creek outfall structure into the L-63S Canal. All monitoring in Lettuce Creek was performed at the point of inflow into the CDS and TST units. Chemical characteristics of Lettuce Creek inflow samples collected from November 2002-November 2003 are given in Table 5-4. All inflow samples were collected as flow-weighted composites collected over a specified monitoring interval. Monitoring intervals for inflow samples ranged from 1-21 days, with a mean composite interval of 6.03 days. Mean flow rates through Lettuce Creek during each of the composite monitoring periods is also included in Table 5-4 and is used for evaluation of the effects of flow rate on water quality characteristics within the creek.

Summary statistics are provided for each evaluated inflow parameter which include a calculation of the mean, minimum and maximum values, and coefficient of variation (CV, defined as the standard deviation expressed as a percentage of the mean). In general, CV values in excess of 100 generally indicate highly variable data sets, while CV values less than 100 indicate low to moderate variability in measured data. Based upon the calculated CV values listed in Table 5-4, a considerable degree of variability was observed in measured flow rate, organic phosphorus,

TABLE 5-4

CHEMICAL CHARACTERISTICS OF LETTUCE CREEK INFLOW SAMPLES COLLECTED FROM NOVEMBER 2002 TO NOVEMBER 2003

Start	End	No. of Days	Flow (cfs)	pH (s.u.)	Temp (°C)	Ortho P (µg/l)	Diss. Org. P µg/l)	Part P (µg/l)	TP (µg/l)	Dis. Org. N (µg/l)	Part N (µg/l)	TKN (µg/l)	TN (µg/l)	TSS (mg/l)	Turb (NTU)	TOC (mg/l)	DOC (mg/l)
11/15/02	11/19/02	4	6.9	7.83	23.82	308	54	63	425	1,217	142	1,444	2,054	4.7	5.1	26.61	24.60
11/19/02	11/21/02	2	6.6	7.67	23.79	381	59	44	484	1,529	360	2,010	2,507	4.4	4.4	26.62	25.06
11/21/02	11/26/02	5	5.2	7.72	22.87	255	323	35	613	1,964	129	2,146	3,036	2.5	4.4	27.97	27.83
11/26/02	12/03/02	7	6.7	7.41	21.54	376	69	50	495	1,223	106	1,433	2,461	5.6	5.5	29.79	27.06
12/03/02	12/06/02	3	3.3	7.51	21.47	387	74	58	519	1,151	105	1,496	3,115	3.6	4.7	27.58	25.96
12/06/02	12/11/02	5	4.6	7.20	21.23	356	82	54	492	965	174	1,279	1,665	6.6	5.9	28.34	28.31
12/11/02	12/17/02	6	9.9	7.21	20.46	352	67	56	475	1,029	132	1,327	1,614	8.3	6.6	30.78	29.03
12/17/02	12/26/02	9	8.2	7.65	19.72	262	83	35	380	3,074	248	4,150	4,381	3.9	5.2	34.60	34.01
12/26/02	01/07/03	12	8.4	7.46	18.23	227	219	53	499	1,479	1,048	2,603	3,575	6.8	7.1	28.33	26.51
01/07/03	01/16/03	9	5.9	7.15	20.10	318	49	57	424	969	223	1,387	2,179	3.0	3.0	27.49	26.30
01/16/03	01/23/03	7	4.1	7.34	18.90	394	60	169	623	959	225	2,416	3,557	4.9	4.8	26.23	23.60
01/23/03	01/30/03	7	2.7	7.25	19.80	625	314	499	1,438	1,097	987	11,072	12,582	6.5	11.6	29.13	28.32
01/30/03	02/12/03	13	2.3	6.96	22.80	691	1,039	3,845	5,575	6,396	1,355	9,147	9,733	3.8	3.7	22.70	22.35
02/19/03	03/12/03	21	2.0	6.99	27.40	710	708	247	1,665	2,388	420	4,743	6,885	10.6	7.8	26.38	26.34
03/20/03	03/28/03	8	8.5	6.96	26.30	955	116	169	1,240	1,532	245	2,864	4,155	9.5	7.1	35.10	33.93
03/28/03	04/04/03	7	5.2	7.99	26.00	471	84	92	647	1,158	269	1,586	2,649	5.5	2.7	30.54	29.68
04/04/03	04/15/03	11	1.9	7.37	27.70	529	147	149	825	922	437	1,474	2,261	4.8	5.5	22.35	22.09
04/29/03	05/09/03	10	4.8	7.49	32.40	594	7	49	650	1,480	268	2,443	3,536	3.6	3.5	29.07	28.29
05/09/03	05/14/03	5	1.7	7.54	31.60	756	141	287	1,184	1,008	523	1,945	4,336	14.7	8.5	28.70	27.97
05/29/03	06/06/03	8	3.7	7.28	32.10	854	39	168	1,061	2,090	147	4,439	5,381	12.6	7.2	27.68	27.41
06/13/03	06/19/03	6	1.7	7.39	32.50	417	170	39	626	767	799	1,957	2,250	4.2	2.4	21.65	21.10
06/19/03	06/26/03	7	6.5	7.33	32.30	588	17	22	627	3,086	176	4,166	4,909	4.1	3.1	26.58	23.03
06/27/03	07/03/03	6	8.6	6.93	32.10	406	95	68	569	1,828	122	2,281	2,705	5.3	4.0	25.94	24.97
07/10/03	07/16/03	6	14.7	7.22	31.90	246	46	89	381	1,160	496	1,968	2,117	6.4	3.9	32.74	30.23
07/31/03	08/06/03	6	36.6	7.17	32.40	276	40	56	372	1,636	293	2,334	2,485	13.5	7.2	42.83	42.43
08/12/03	08/19/03	7	70.5	6.90	31.50	977	19	25	1,021	2,245	943	3,461	3,599	17.2	8.7	42.23	36.96
08/21/03	08/27/03	6	116.0	7.20	30.80	1,345	61	175	1,581	2,189	266	2,778	2,802	11.4	4.5	44.10	38.30
08/27/03	09/04/03	8	55.6	7.04	31.40	1,161	84	51	1,296	2,139	272	2,635	2,681	10.4	4.3	44.30	42.00
10/06/03	10/09/03	3	90.0	6.68	31.70	1,208	233	270	1,711	1,673	751	2,972	3,018	47.3	9.9	37.70	32.80
10/09/03	10/14/03	5	41.5	6.81	30.10	923	102	348	1,373	1,415	887	2,817	2,985	51.5	8.9	34.70	33.40
10/14/03	10/17/03	3	27.9	6.99	31.30	733	216	49	998	1,068	259	1,759	2,186	4.5	2.7	33.60	32.00
10/23/03	10/24/03	1	2.8	6.32	29.80	562	240	92	894	4,705	596	5,303	5,710	32.3	5.9	30.00	29.00
10/29/03	10/30/03	1	1.5	6.78	29.40	264	27	63	354	3,297	526	4,036	4,368	18.3	6.2	32.00	30.00
10/30/03	10/31/03	1	1.0	7.19	29.60	245	10	90	345	1,444	167	1,613	1,944	22.8	5.3	44.30	38.70
11/10/03	11/11/03	1	15.8	6.90	28.70	509	16	122	647	4,682	450	5,579	5,809	29.6	6.5	78.90	55.20
11/11/03	11/12/03	1	12.9	6.90	29.50	462	29	85	576	959	773	1,734	1,977	61.0	44.4	53.20	38.00
11/12/03	11/13/03	1	9.1	6.67	28.90	214	139	157	510	1,680	399	2,541	2,764	10.8	5.4	55.40	37.40
11/13/03	11/14/03	1	7.8	7.84	29.30	380	36	128	544	710	340	1,195	1,458	6.5	9.0	47.80	35.60

	Flow (cfs)	pH (s.u.)	Temp (°C)	Ortho P (µg/l)	Diss. Org. P µg/l)	Part P (µg/l)	TP (µg/l)	Dis. Org. N (µg/l)	Part N (µg/l)	TKN (µg/l)	TN (µg/l)	TSS (mg/l)	Turb (NTU)	TOC (mg/l)	DOC (mg/l)
Mean	16.4	7.22	27.14	545	140	213	898	1,850	423	2,961	3,617	12.7	6.8	34.1	30.7
Min	1.0	6.32	18.23	214	7	22	345	710	105	1,195	1,458	2.5	2.4	21.7	21.1
Max	116.0	7.99	32.50	1,345	1,039	3,845	5,575	6,396	1,355	11,072	12,582	61.0	44.4	78.9	55.2
C.V.	158	5.0	17.6	54.4	141	288	97.4	65.8	73.7	70.1	61.7	110	98.2	32.9	22.6
95% Confidence Interval	7.3-25.5	7.09-7.35	25.46-28.82	441-649	71-209	0-429	590-1,206	1,421-2,279	313-533	2,231-3,691	2,832-4,402	7.8-17.6	4.5-9.1	30.2-38.0	28.3-33.1

particulate phosphorus, total phosphorus, TSS, and turbidity. A relatively low degree of variability was observed for pH and temperature, with a moderate level of variability observed for measured concentrations of orthophosphorus, dissolved organic nitrogen, particulate nitrogen, TKN, total nitrogen, total organic carbon (TOC), and dissolved organic carbon (DOC).

Also listed in Table 5-4 is the 95% confidence interval of the mean for each evaluated parameter. This interval reflects the range in values which would contain the mean value for each evaluated parameter at a confidence level of 95%. The 95% confidence interval appears to be relatively small for parameters such as pH, temperature, orthophosphorus, TSS, turbidity, TOC, and DOC. However, the 95% confidence interval of the mean appears to be an extremely wide range for constituents such as particulate phosphorus, total phosphorus, dissolved organic nitrogen, particulate nitrogen, TKN, and total nitrogen.

In general, measured pH values in Lettuce Creek appear to be approximately neutral in pH, with measured values ranging from 6.32-7.99, with an overall mean of 7.22. Temperature measurements within the creek range from 18.23-32.50 ^{o}C, with an overall mean of 27.14 ^{o}C.

Measured orthophosphorus concentrations in Lettuce Creek were found to be highly variable, ranging from 214-1345 μg/l. Measured concentrations of organic phosphorus, particulate phosphorus, and total phosphorus cover several orders of magnitude between minimum and maximum values, with dissolved organic phosphorus ranging from 7-1039 μg/l, particulate phosphorus ranging from 22-3845 μg/l, and total phosphorus ranging from 345-5575 μg/l. On an average basis, approximately 61% of the total phosphorus concentration in Lettuce Creek is comprised of dissolved orthophosphorus, with 16% comprised of dissolved organic phosphorus and 23% contributed by particulate phosphorus.

Similar to the trends exhibited for phosphorus species, measured concentrations of dissolved organic nitrogen, particulate nitrogen, and total nitrogen cover one order of magnitude or more between minimum and maximum values measured during the monitoring program in Lettuce Creek. Measured dissolved organic nitrogen concentrations range from 710-6396 μg/l, with particulate nitrogen ranging from 105-1355 μg/l, and total nitrogen ranging from 1458-12,582 μg/l. On an average basis, particulate nitrogen comprises approximately 12% of the total nitrogen measured in Lettuce Creek.

A wide range of values was also observed for measured concentrations of TSS and turbidity, with measured TSS values ranging from 2.5-61.0 mg/l and turbidity ranging from 2.4-44.4 NTU. In general, increases in TSS also corresponds to increases in turbidity throughout the monitoring program.

In contrast to the trends exhibited by nitrogen and phosphorus, very little variability in dissolved organic carbon (DOC) and total organic carbon (TOC) was observed in Lettuce Creek. DOC concentrations range from 21.1-55.2 mg/l, with TOC ranging from 21.7-78.9 mg/l. On an average basis, approximately 90% of the organic carbon discharging through Lettuce Creek is in a dissolved form.

A statistical comparison of Lettuce Creek characteristics for pH, phosphorus species, nitrogen species, TSS, turbidity, DOC, and TOC is given in Figures 5-5, 5-6, and 5-7. A graphical summary of data at each site is presented in the form of Tukey box plots, also often called "box and whisker plots". The bottom line of the box portion of each plot represents the lower quartile, with 25% of the data points lying below this value. The upper line of the box represents the 75% upper quartile, with 25% of the data lying above this value. The horizontal line within the box represents the median value, with 50% of the data lying both above and below this value. The vertical lines, also known as "whiskers", represent the 5 and 95 percentiles for the data sets. Individual values which lie outside of the 5-95 percentile range, sometimes referred to as “outliers”, are indicated as red dots.

5.2.3 Relationships Between Chemical Characteristics and Flow Rates in Lettuce Creek

Relationships between Lettuce Creek flow rate and chemical characteristics in Lettuce Creek water were evaluated by plotting each of the evaluated parameters as a function of flow rate through the creek. A “best fit” linear regression line was calculated for each relationship, along with the R-square value for the regression line. For purposes of this analysis, obvious extreme anomalies in the data sets (illustrated in Figures 5-5, 5-6, and 5-7) were removed for particulate phosphorus (1 point), dissolved organic nitrogen (3 points), TKN (2 points), particulate nitrogen (1 point), total nitrogen (3 points), and particulate phosphorus (1 point).

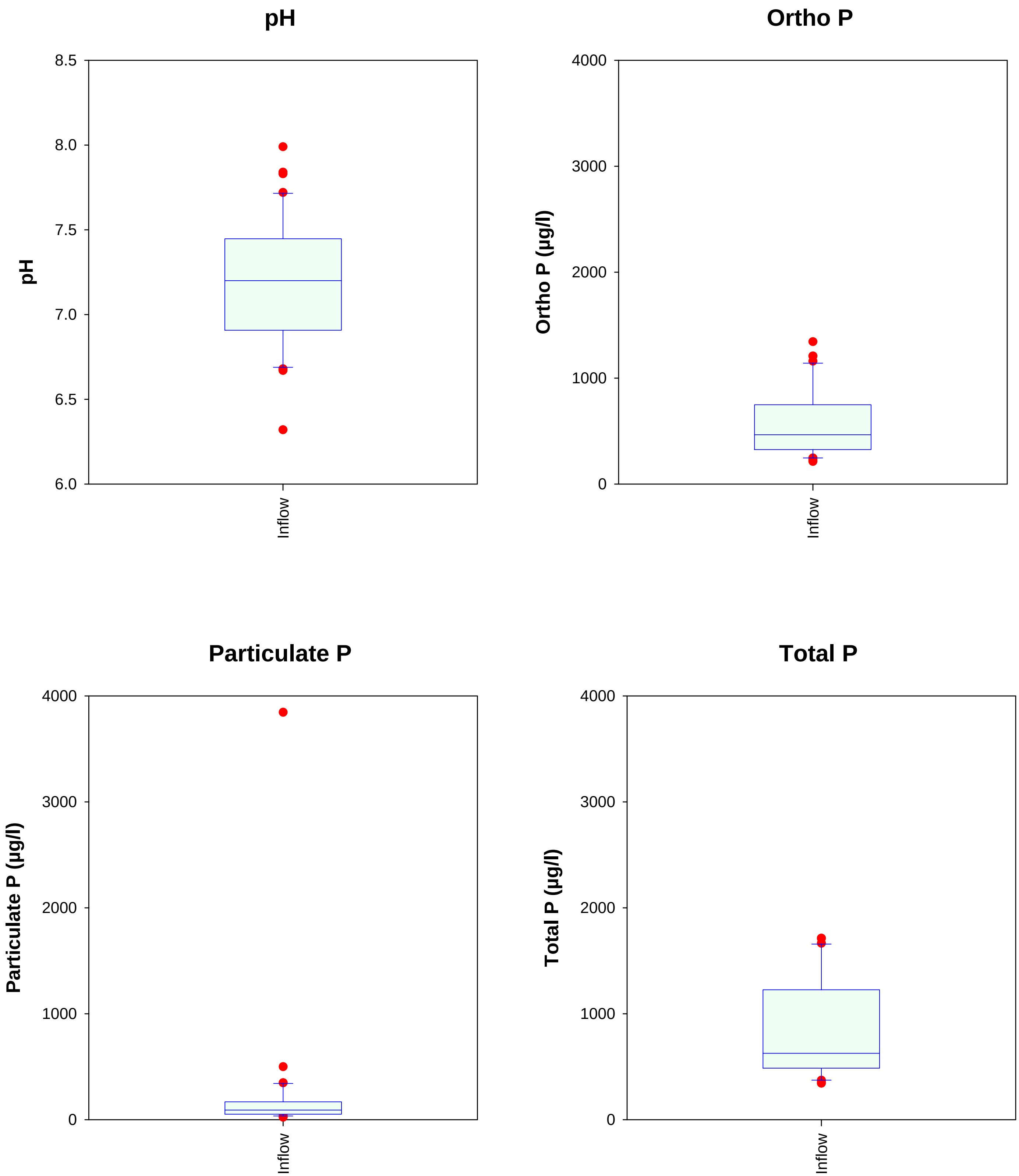


Figure 5-5. Statistical Comparison of Measured Values of pH, Ortho P, Particulate P, and Total P in Lettuce Creek.

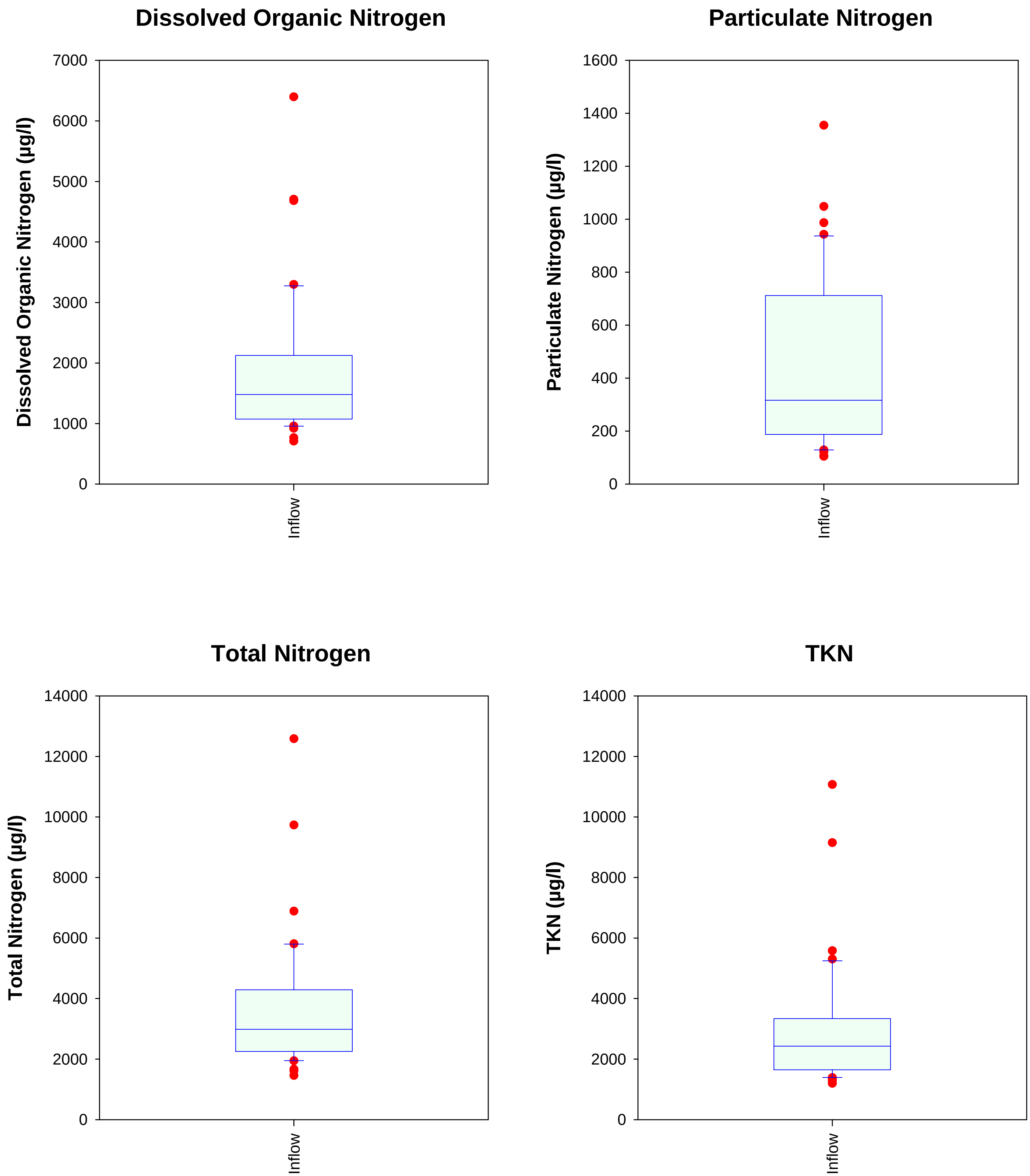


Figure 5-6. Statistical Comparison of Measured Values of Dissolved Organic N, Particulate N, TKN, and Total N in Lettuce Creek.

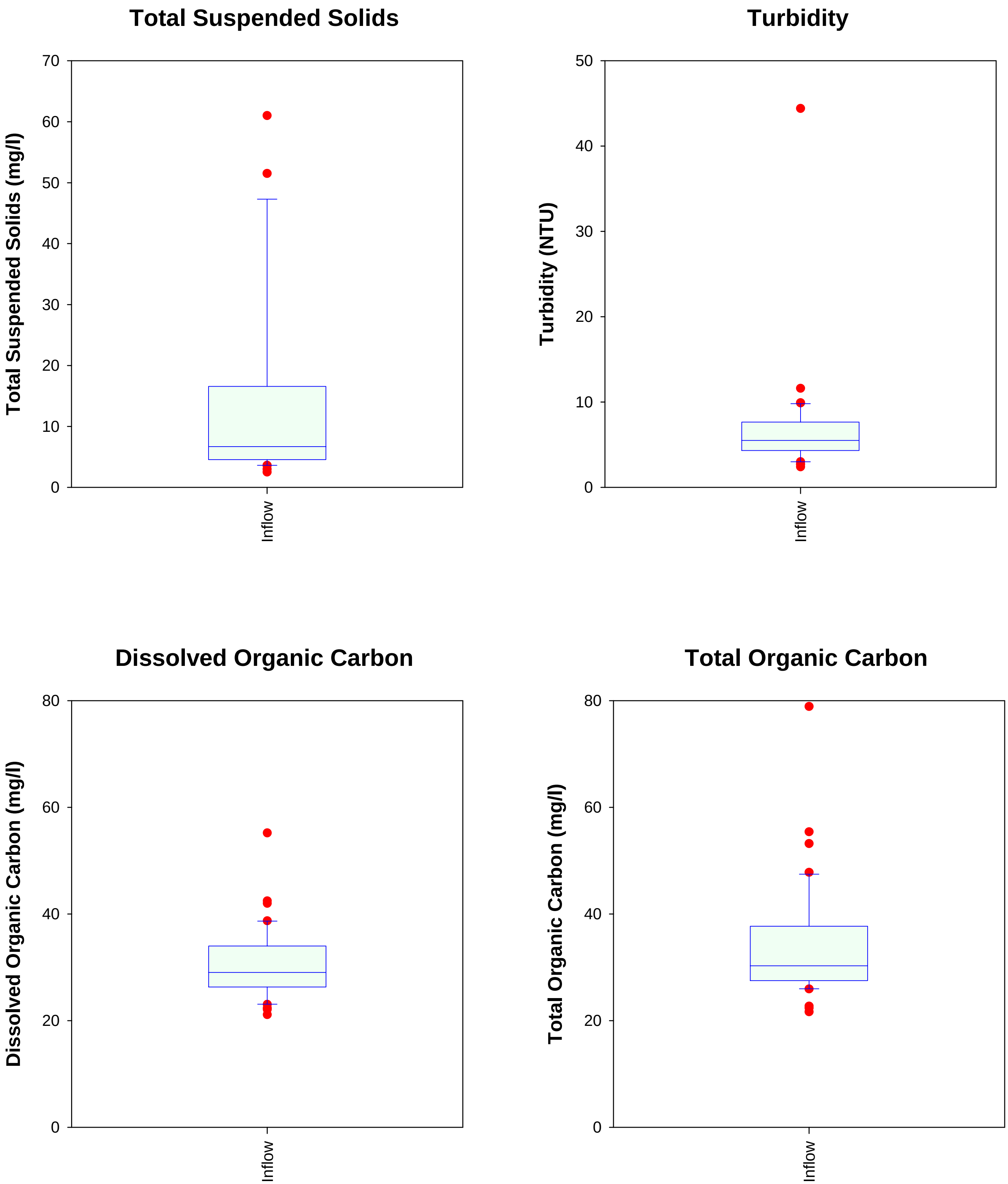


Figure 5-7. Statistical Comparison of Measured Values of TSS, Turbidity, DOC, and TOC in Lettuce Creek.

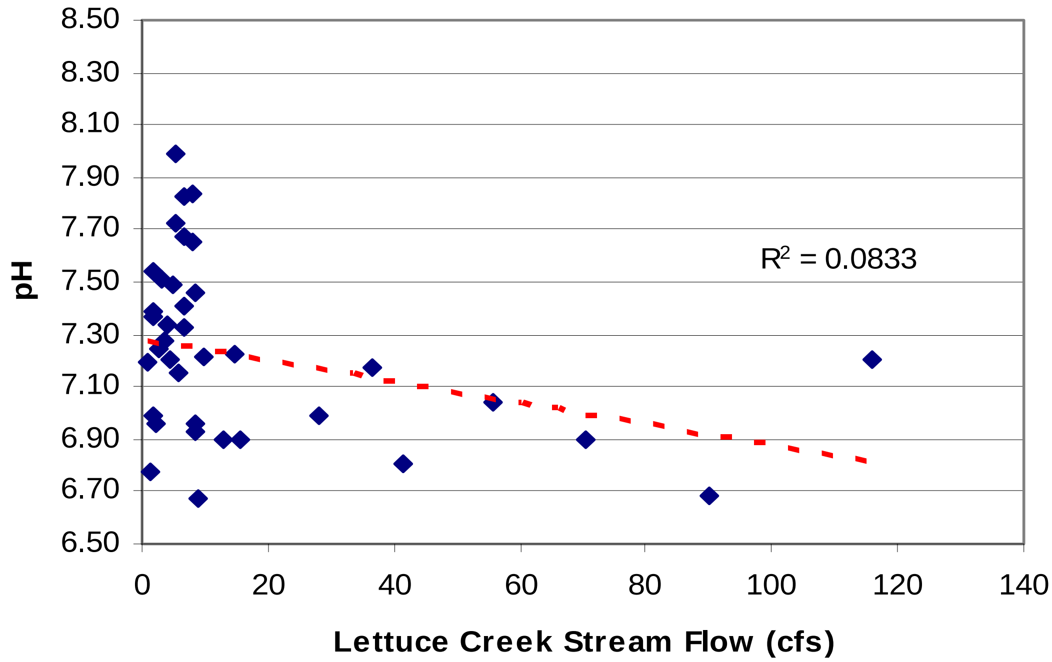
Relationships between Lettuce Creek flow, pH, and temperature are illustrated on Figure 5-8. Water column pH appears to exhibit a slight decrease in value with increasing flow rate within the stream, although the relationship between pH and flow rate is extremely weak. In contrast, a trend of increasing temperature with increasing stream flow was observed during the monitoring program. However, this relationship is likely related to the increased flows observed during the warmer rainy period.

Relationships between Lettuce Creek flow, dissolved organic nitrogen, and TKN are illustrated on Figure 5-9. A general trend of increasing concentration with increasing flow rate is apparent for each of these constituents, although the observed increases in flow rate explain only a small proportion of the variability in measured concentrations of dissolved organic nitrogen and TKN.

Relationships between Lettuce Creek flow, particulate nitrogen, and total nitrogen are illustrated on Figure 5-10. Particulate nitrogen appears to exhibit a slight increase in concentration with increasing flow rate, while total nitrogen appears to exhibit a slight decrease in concentration with increasing stream flow. However, the relationships between concentration and stream flow are extremely weak for both parameters. It appears that flow rates in Lettuce Creek have an insignificant impact on concentrations of either particulate nitrogen or total nitrogen in Lettuce Creek.

Relationships between Lettuce Creek flow, orthophosphorus, and dissolved organic phosphorus are illustrated on Figure 5-11. Orthophosphorus concentrations in Lettuce Creek appear to be clearly impacted by increases in flow within the creek. The calculated R-square value of 0.526 is the strongest relationship with flow observed for any of the measured constituents. In contrast, dissolved organic phosphorus does not appear to exhibit a significant relationship with discharge rates through Lettuce Creek.

Relationships between Lettuce Creek flow rate, particulate phosphorus, and total phosphorus are illustrated in Figure 5-12. A weak positive correlation is apparent between particulate phosphorus and flow rate, although increases in flow rate explain less than 2% of the



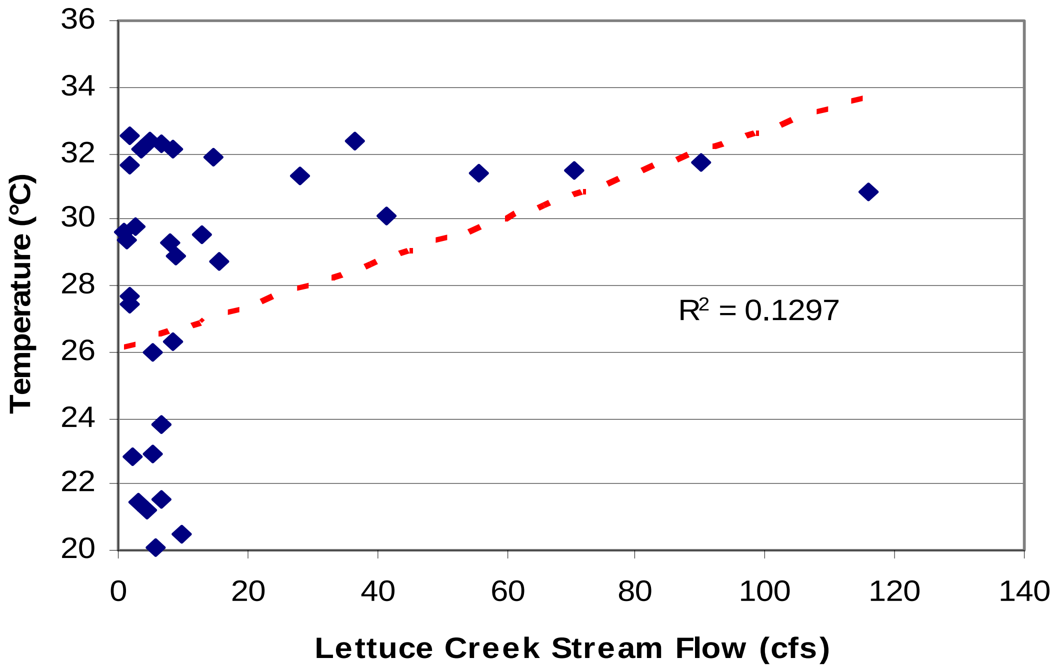


Figure 5-8. Relationship Between Lettuce Creek Flow, pH and Temperature.

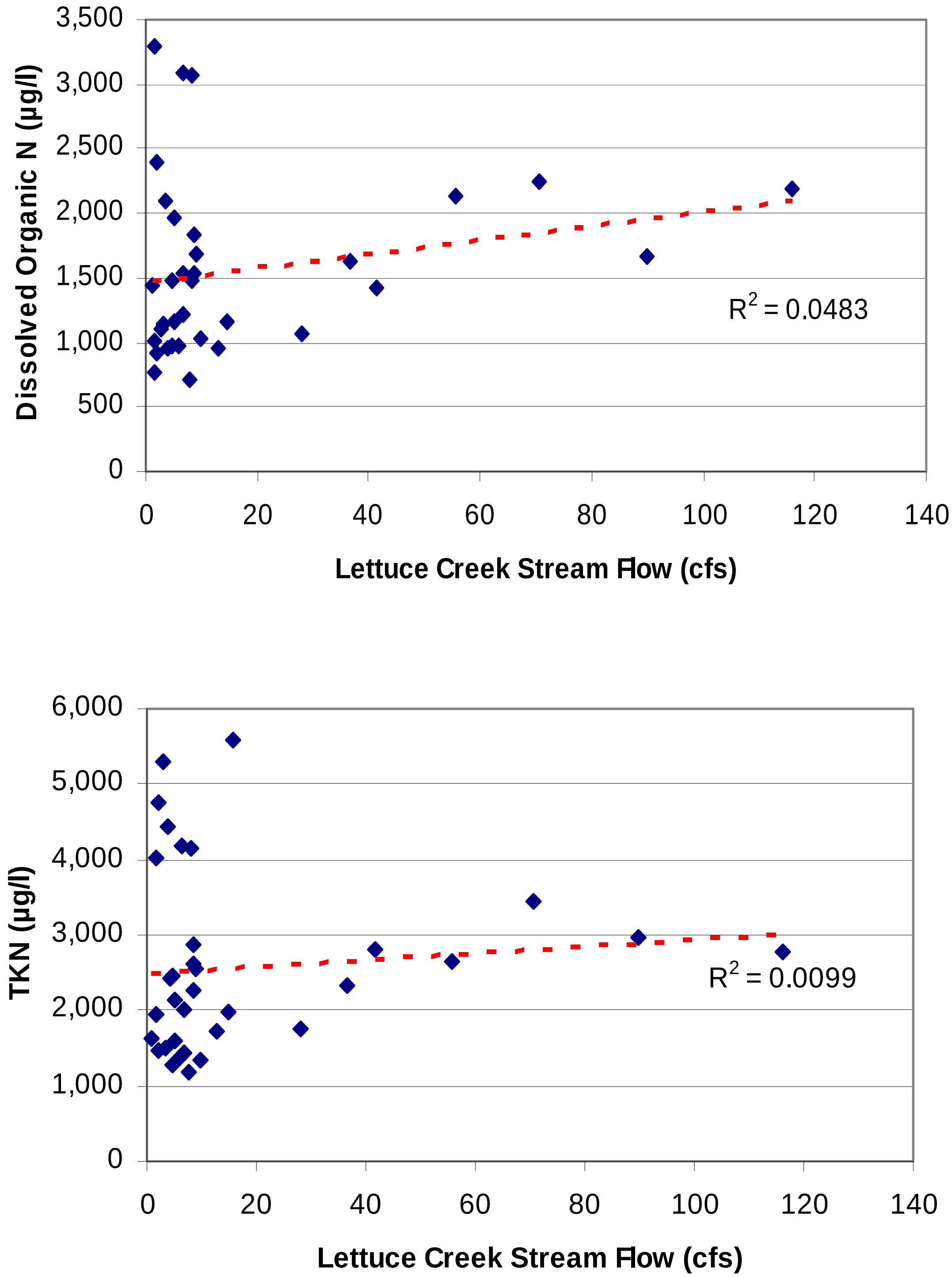
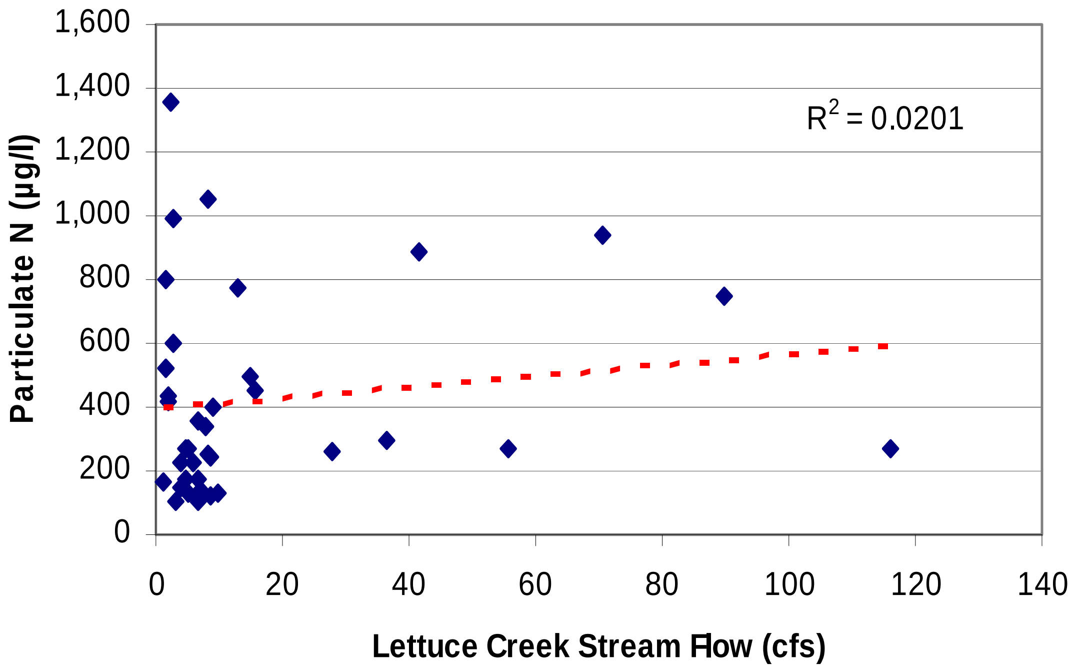


Figure 5-9. Relationship Between Lettuce Creek Flow, Dissolved Organic N and TKN.



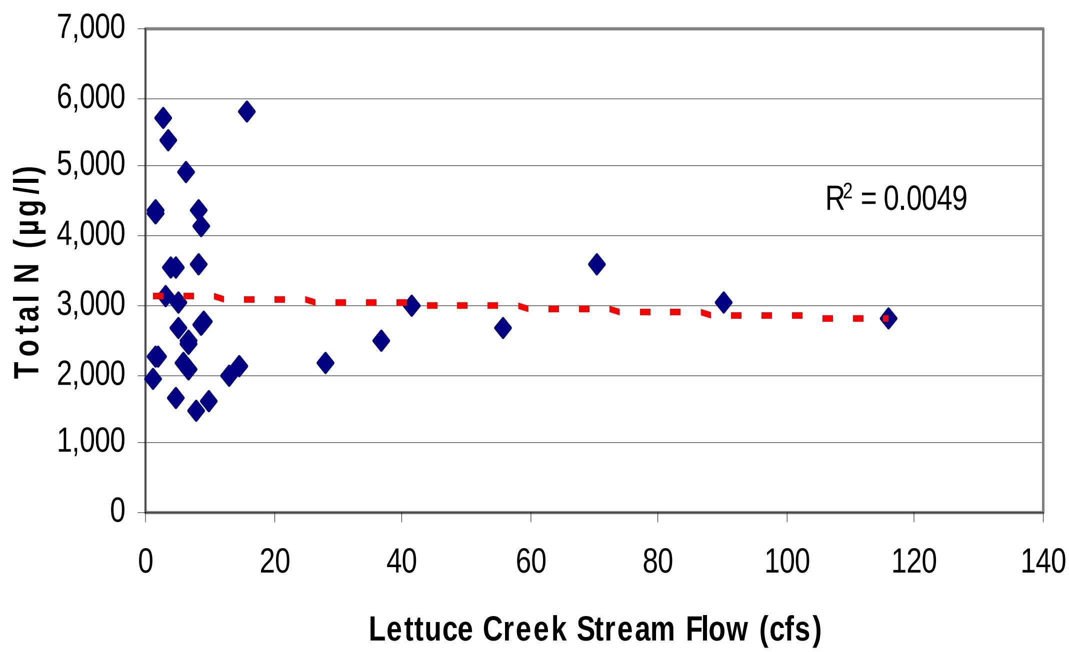
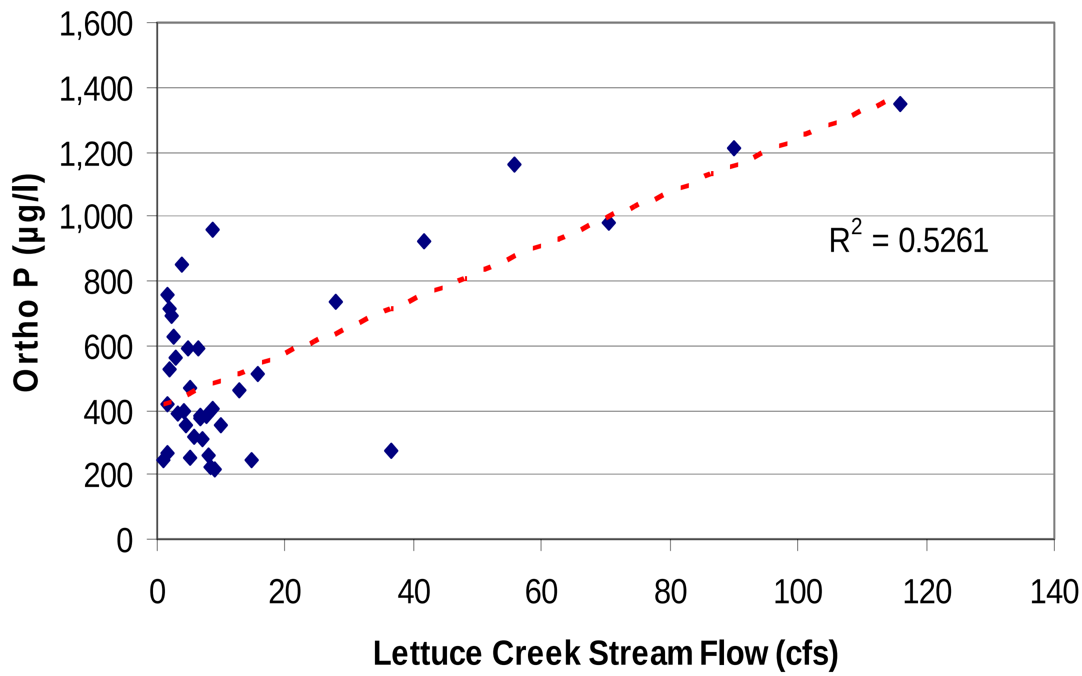


Figure 5-10. Relationship Between Lettuce Creek Flow, Particulate N and Total N.



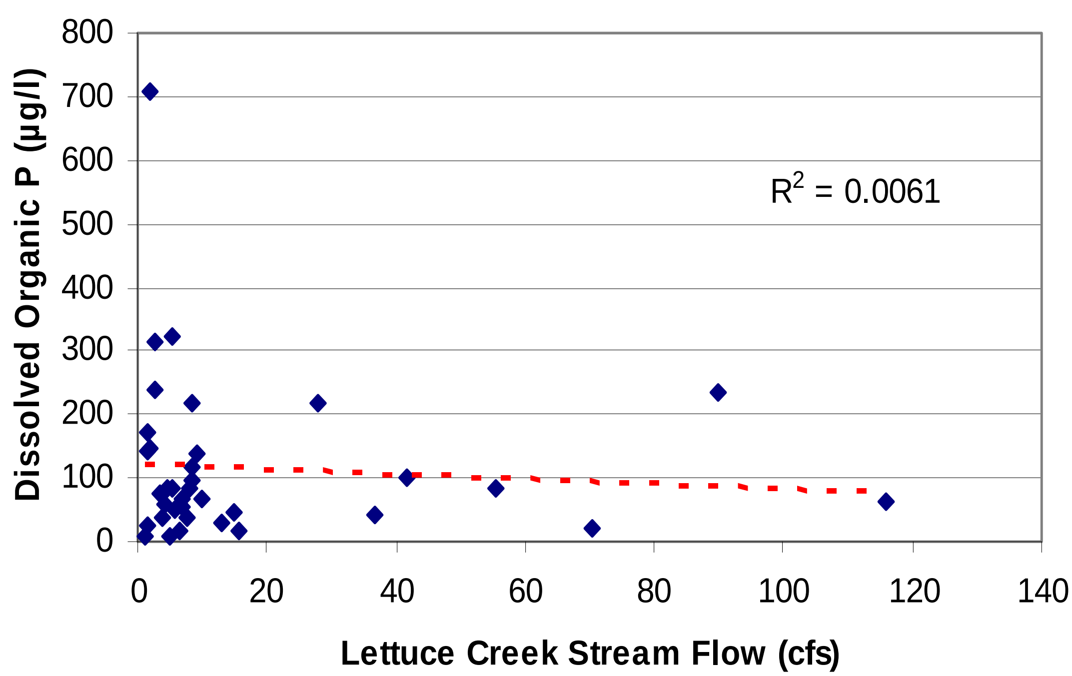
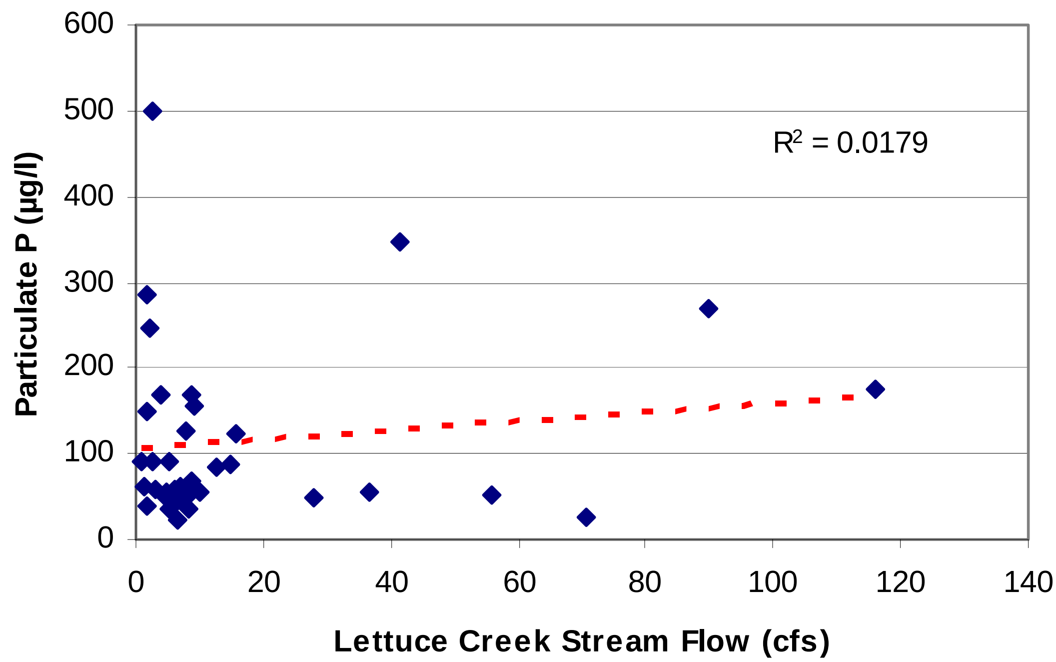


Figure 5-11. Relationship Between Lettuce Creek Flow, Ortho P and Dissolved Organic P.



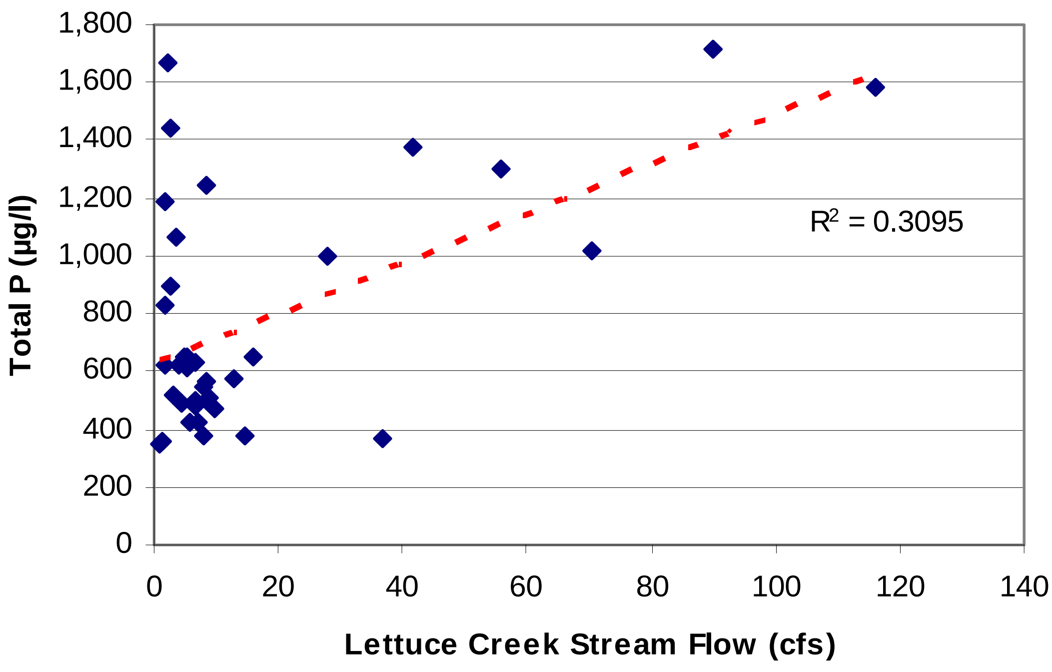


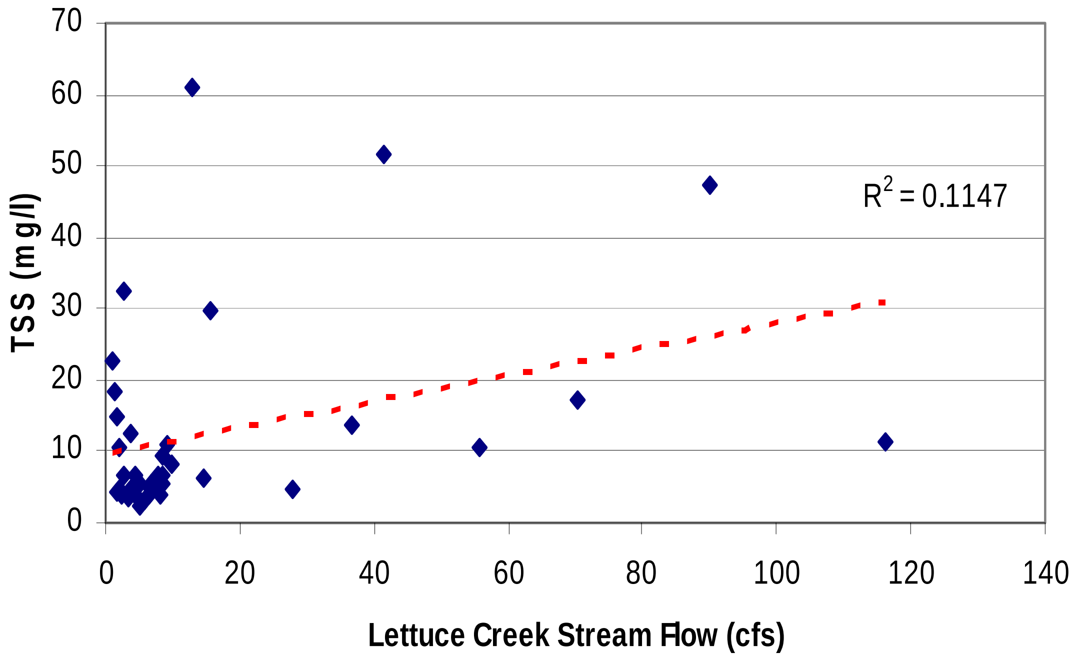
Figure 5-12. Relationship Between Lettuce Creek Flow, Particulate P and Total P.

variability in particulate phosphorus concentrations measured in Lettuce Creek. However, increases in Lettuce Creek flow do appear to be significantly correlated with increases in total phosphorus concentrations, with flow rate explaining approximately 31% of the variability observed in concentrations of total phosphorus. The observed relationship between total phosphorus and creek flow is primarily influenced by the strong relationship observed between orthophosphorus and flow rate.

Relationships between Lettuce Creek flow rate, TSS, and turbidity are illustrated on Figure 5-13. Extremely weak positive relationships were observed between Lettuce Creek flow, TSS, and turbidity. In general, Lettuce Creek flow rate appears to have only a minimal relationship with concentrations of TSS and turbidity. The lack of significant relationship between flow rate and TSS supports the weak relationship observed between flow rate and particulate phosphorus.

Relationships between Lettuce Creek flow rate, DOC, and TOC are illustrated on Figure 5-14. Increases in Lettuce Creek flow rate appear to explain approximately 19% of the observed variability in DOC concentrations and 11% of the variability in TOC concentrations. With the exceptions of orthophosphorus and total phosphorus, the relationships between flow rate, DOC, and TOC are the strongest relationships observed for the measured parameters.

A summary of correlations between Lettuce Creek flow rates and chemical characteristics of Lettuce Creek water is given in Table 5-5. With the exceptions of orthophosphorus, total phosphorus, DOC, and TOC, no significant relationships are apparent between Lettuce Creek flow rate and the chemical characteristics of the water discharging through the creek.



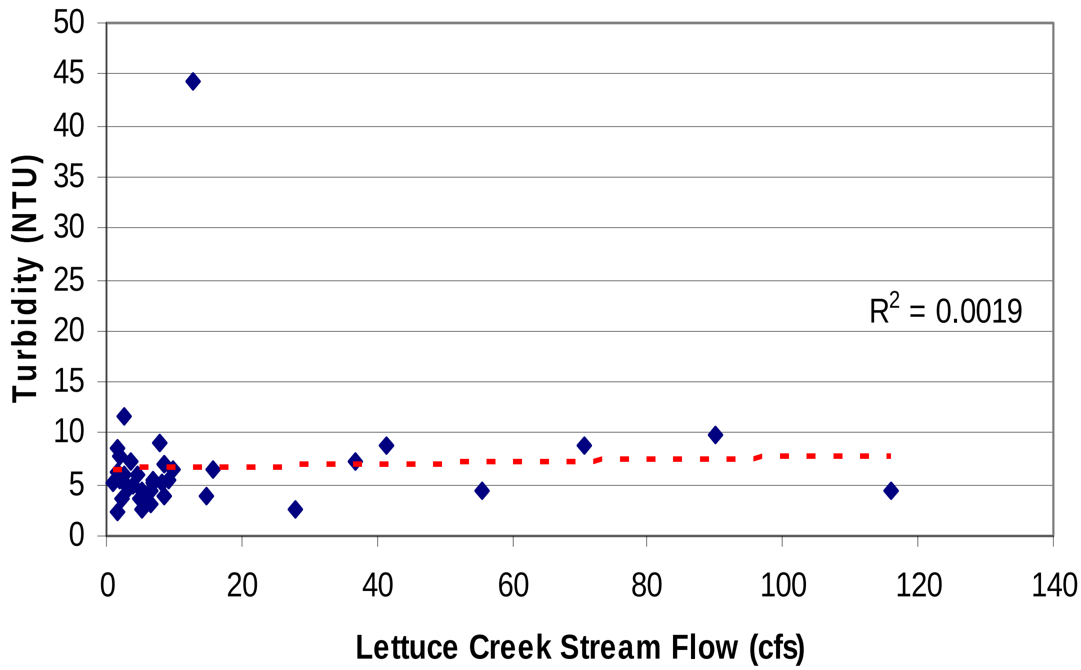
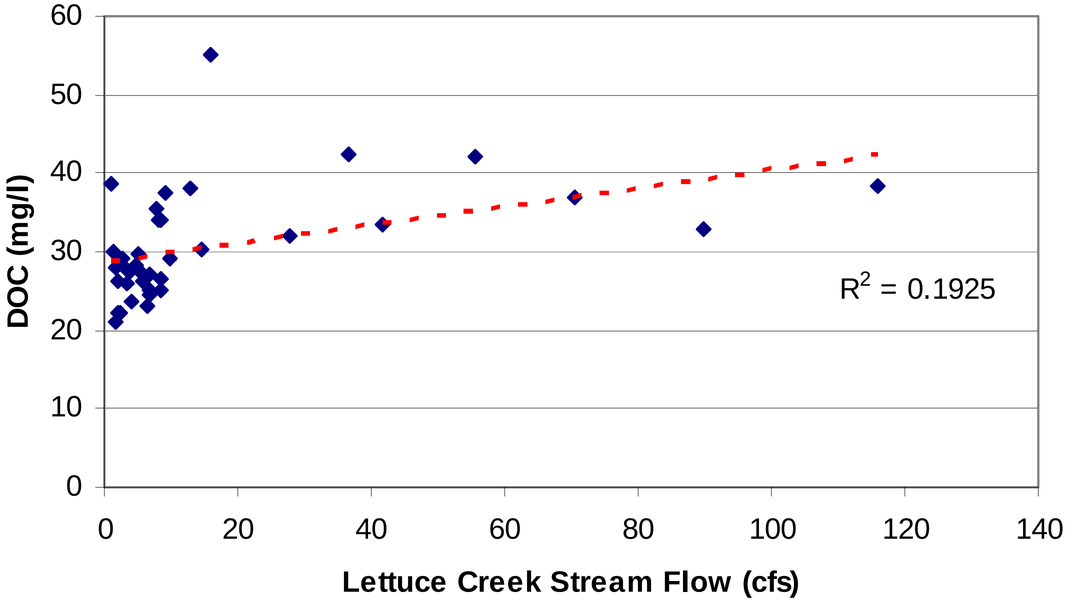


Figure 5-13. Relationship Between Lettuce Creek Flow, TSS and Turbidity.



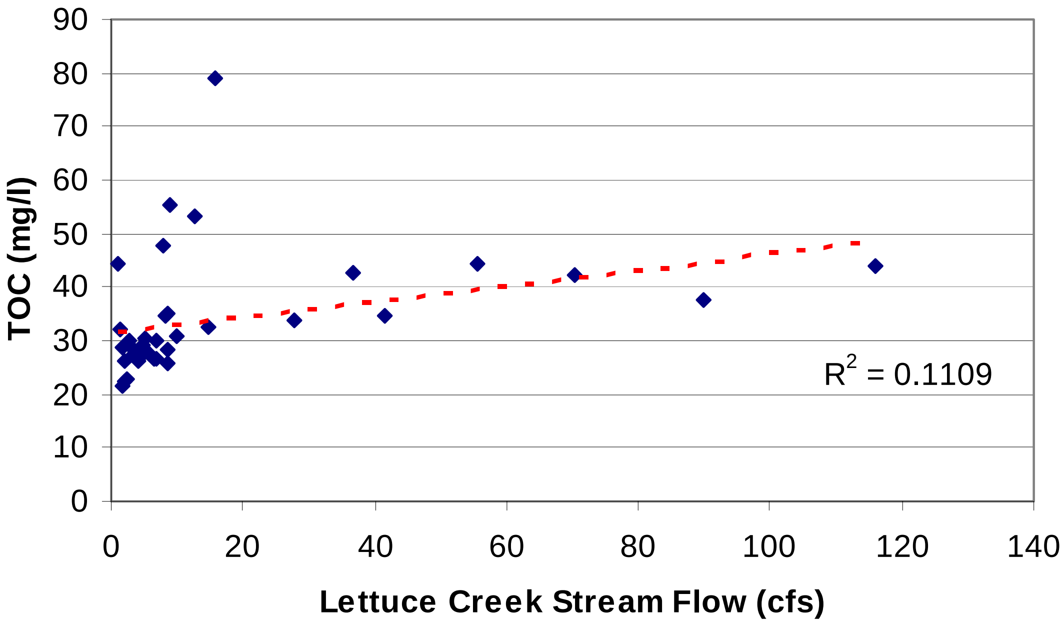


Figure 5-14. Relationship Between Lettuce Creek Flow, DOC and TOC.

TABLE 5-5

CORRELATIONS BETWEEN LETTUCE CREEK FLOW RATE AND CHEMICAL CHARACTERISTICS OF CREEK WATER

PARAMETER	CORRELATION BETWEEN FLOW RATE AND PARAMETER (R^2 value)
pH	0.083
Temperature	0.130
Diss. Organic N	0.048
TKN	0.010
Particulate N	0.020
Total N	0.005
Ortho-P	0.526
Diss. Organic P	0.006
Particulate P	0.018
Total P	0.310
TSS	0.115
Turbidity	0.002
DOC	0.193
TOC	0.111

5.3 Performance Efficiencies of the CDS and TST Units

Field monitoring was performed from October 2002-October 2003 to evaluate the performance efficiency of the CDS and TST units during operation at flow rates of 1, 5, and 11 cfs. Performance efficiencies of the CDS and TST units were calculated on both a concentration and mass balance basis. Concentration-based efficiencies are calculated using the event mean concentrations for the inflow and outflow from each unit during a given monitoring period. Concentration-based efficiencies were calculated using the following equation:

$$Eff = \frac{C_{in} - C_{out}}{C_{in}} * 100$$

where: Eff = efficiency for a given monitoring period

C_{in} = event mean concentration for inflow

C_{out} = event mean concentration for outflow

Mass removal efficiencies were also calculated for the TST and CDS units for each monitoring period. The mass removal approach is useful since it incorporates not only concentration but the volume of water discharging through the unit. Mass inputs and outputs to the units were calculated using the following relationships:

$$Mass \ \ Input = Q_{o(\Delta t)} \ \ C_{o(\Delta t)}$$

where: $Q_{o(\Delta t)}$ = total volumetric inflow over time interval, Δt

$C_{o(\Delta t)}$ = mean inflow concentration over time interval, Δt

$$Mass \ \ Output = Q_{e(\Delta t)} \ \ C_{e(\Delta t)}$$

where: $Q_{e(\Delta t)}$ = total volumetric outflow over time interval, Δt

$C_{e(\Delta t)}$ = mean outflow concentration over time interval, Δt

$$Solids \ \ Trapped \ \ (Storage) = S_{(\Delta t)}$$

Overall:

$$Mass\ Input = Mass\ Output + Storage$$

$$Removal\ Efficiency = \left[\frac{Mass\ Input - Mass\ Output}{Mass\ Input} \right] x\ 100$$

A persistent problem which potentially compromised the results of the monitoring program on numerous occasions is the presence of large accumulations of fish in both the CDS and TST units. Hundreds of fish, primarily catfish, were observed in both the CDS and TST units on many occasions. Photographs of accumulated fish in the CDS and TST units are given in Figure 5-15. When these problems were noted, the units would be drained and the fish removed. Accumulation of fish was a particular problem in the CDS unit since the fish had no avenue of escaping the unit once they had entered the center sump area. Fish which accumulated in the TST unit had the potential to swim over the internal baffles, as water discharged from one baffle area to the other. Impacts from fish waste, from both living and dead organisms, are apparent throughout the monitoring data, particularly for TKN, particulate nitrogen, and particulate phosphorus. The problem of contamination with fish wastes seemed to be more prevalent during testing performed at 1 cfs than at higher flow rates. It appears that the higher flow rates were useful in diluting the waste products, while the waste products seemed to accumulate within the units at lower flow rates.

As discussed in Section 5.1, numerous activities were conducted to prevent fish from entering the test structures. However, as seen in Figure 5-1, these efforts caused damage to the intake pipe on two separate occasions. Since this project is designed to demonstrate the feasibility of using solids removal units in other tributaries, accumulation of fish within the units is thought to represent a likely operating condition which would also occur at other locations. Therefore, further attempts at controlling fish inputs into the units were discontinued.

a. TST Unit.

b. CDS Unit.

Figure 5-15. Photographs of Accumulated Fish in the CDS and TST Units.

5.3.1 Performance Efficiency of the CDS Unit

5.3.1.1 Performance Efficiency During Operation at 1 cfs

5.3.1.1.1 Chemical Characteristics of Inflow and Outflow Samples

Evaluation of the performance efficiency of the CDS and TST units at inflow rates of 1 cfs was conducted on a periodic basis from November 2002-June 2003. Performance efficiency monitoring was performed on 172 separate days, comprising 22 separate monitoring intervals. Chemical characteristics of Lettuce Creek inflow during testing performed at 1 cfs is given in Table 5-6.

Discharges through Lettuce Creek during this monitoring program exhibited a high degree of variability for dissolved organic phosphorus, particulate phosphorus, total phosphorus, particulate nitrogen, and TKN. Approximately 52% of the mean total phosphorus concentration of 953 µg/l measured during this period is comprised of dissolved orthophosphorus, with an additional 19% comprised of dissolved organic phosphorus. Only 30% of the phosphorus discharging through the creek during this testing period was particulate in nature. Only approximately 10% of the mean total nitrogen concentration of 4037 µg/l is comprised of particulate species.

Measured concentrations of both TSS and turbidity within the creek were relatively low during this monitoring program, with a mean of 6.1 mg/l for TSS and 5.4 NTU for turbidity. In contrast, measured concentrations of TOC and DOC were relatively stable during this monitoring period. Approximately 96% of the total organic carbon discharging through the creek was in a dissolved state.

Chemical characteristics of discharges from the CDS unit during operation at 1 cfs are summarized in Table 5-7. Similar to the trends observed in the Lettuce Creek samples, discharges from the CDS unit are characterized by a high degree of variability in measured concentrations of dissolved organic phosphorus, particulate phosphorus, total phosphorus, particulate nitrogen, and TKN. A relatively low degree of variability was observed in discharge concentrations of orthophosphorus, TSS, turbidity, TOC, and DOC.

TABLE 5-6

CHEMICAL CHARACTERISTICS OF LETTUCE CREEK INFLOW DURING TESTING AT 1 cfs

Start	End	No. of Days	Flow (cfs)	pH (s.u.)	Temp (°C)	Ortho P (μg/l)	Diss. Org. P μg/l)	Part P (μg/l)	TP (μg/l)	Dis. Org. N (μg/l)	Part N (μg/l)	TKN (μg/l)	TN (μg/l)	TSS (mg/l)	Turbidity (NTU)	TOC (mg/l)	DOC (mg/l)
11/15/02	11/19/02	4	6.9	7.83	23.82	308	54	63	425	1,217	142	1,444	2,054	4.7	5.1	26.61	24.60
11/19/02	11/21/02	2	6.6	7.67	23.79	381	59	44	484	1,529	360	2,010	2,507	4.4	4.4	26.62	25.06
11/21/02	11/26/02	5	5.2	7.72	22.87	255	323	35	613	1,964	129	2,146	3,036	2.5	4.4	27.97	27.83
11/26/02	12/03/02	7	6.7	7.41	21.54	376	69	50	495	1,223	106	1,433	2,461	5.6	5.5	29.79	27.06
12/03/02	12/06/02	3	3.3	7.51	21.47	387	74	58	519	1,151	105	1,496	3,115	3.6	4.7	27.58	25.96
12/06/02	12/11/02	5	4.6	7.20	21.23	356	82	54	492	965	174	1,279	1,665	6.6	5.9	28.34	28.31
12/11/02	12/17/02	6	9.9	7.21	20.46	352	67	56	475	1,029	132	1,327	1,614	8.3	6.6	30.78	29.03
12/17/02	12/26/02	9	8.2	7.65	19.72	262	83	35	380	3,074	248	4,150	4,381	3.9	5.2	34.60	34.01
12/26/02	01/07/03	12	8.4	7.46	18.23	227	219	53	499	1,479	1,048	2,603	3,575	6.8	7.1	28.33	26.51
01/07/03	01/16/03	9	5.9	7.15	20.10	318	49	57	424	969	223	1,387	2,179	3.0	3.0	27.49	26.30
01/16/03	01/23/03	7	4.1	7.34	18.90	394	60	169	623	959	225	2,416	3,557	4.9	4.8	26.23	23.60
01/23/03	01/30/03	7	2.7	7.25	19.80	625	314	499	1,438	1,097	987	11,072	12,582	6.5	11.6	29.13	28.32
01/30/03	02/12/03	13	2.3	6.96	22.80	691	1,039	3,845	5,575	6,396	1,355	9,147	9,733	3.8	3.7	22.70	22.35
02/19/03	03/12/03	21	2.0	6.99	27.40	710	708	247	1,665	2,388	420	4,743	6,885	10.6	7.8	26.38	26.34
03/20/03	03/28/03	8	8.5	6.96	26.30	955	116	169	1,240	1,532	245	2,864	4,155	9.5	7.1	35.10	33.93
03/28/03	04/04/03	7	5.2	7.99	26.00	471	84	92	647	1,158	269	1,586	2,649	5.5	2.7	30.54	29.68
04/04/03	04/15/03	11	1.9	7.37	27.70	529	147	149	825	922	437	1,474	2,261	4.8	5.5	22.35	22.09
04/29/03	05/09/03	10	4.8	7.49	32.40	594	7	49	650	1,480	268	2,443	3,536	3.6	3.5	29.07	28.29
05/09/03	05/14/03	5	1.7	7.54	31.60	756	141	287	1,184	1,008	523	1,945	4,336	14.7	8.5	28.70	27.97
05/29/03	06/06/03	8	3.7	7.28	32.10	854	39	168	1,061	2,090	147	4,439	5,381	12.6	7.2	27.68	27.41
06/13/03	06/19/03	6	1.7	7.39	32.50	417	170	39	626	767	799	1,957	2,250	4.2	2.4	21.65	21.10
06/19/03	06/26/03	7	6.5	7.33	32.30	588	17	22	627	3,086	176	4,166	4,909	4.1	3.1	26.58	23.03
Mean			5.0	7.40	24.68	491	178	284	953	1,704	387	3,069	4,037	6.1	5.4	27.9	26.8
Min			1.7	6.96	18.23	227	7	22	380	767	105	1,279	1,614	2.5	2.4	21.7	21.1
Max			9.9	7.99	32.50	955	1,039	3,845	5,575	6,396	1,355	11,072	12,582	14.7	11.6	35.1	34.0
C.V.			49.2	3.7	19.9	41.6	138	283	115	72.6	89.9	82.7	66.4	52.5	40.3	11.8	12.5
95% Confidence Interval			4.1-5.9	7.30-7.50	22.95-26.41	419-563	92-264	1-567	569-1,337	1,268-2,140	264-510	2,176-3,962	3,093-4,981	5.0-7.2	4.6-6.2	26.7-29.1	25.6-28.0

TABLE 5-7

CHEMICAL CHARACTERISTICS OF DISCHARGES FROM THE CDS UNIT DURING OPERATION AT 1 cfs

Start	End	No. of Days	Flow (cfs)	pH (s.u.)	Temp (°C)	Ortho P (µg/l)	Diss. Org. P µg/l)	Part P (µg/l)	TP (µg/l)	Dis. Org. N (µg/l)	Part N (µg/l)	TKN (µg/l)	TN (µg/l)	TSS (mg/l)	Turbidity (NTU)	TOC (mg/l)	DOC (mg/l)
11/19/02	11/21/02	2	6.6	7.67	23.79	422	56	49	527	1,843	115	2,026	2,733	4.9	4.40	28.03	25.74
11/21/02	11/26/02	5	5.2	7.72	22.87	263	260	43	566	1,493	159	1,675	2,925	3.9	3.80	26.42	26.01
11/26/02	12/03/02	7	6.7	7.41	21.54	375	62	80	517	1,207	170	1,661	3,319	4.2	6.80	28.58	28.05
12/03/02	12/06/02	3	3.3	7.51	21.47	361	86	59	506	2,012	983	3,221	3,905	5.3	5.10	26.64	23.87
12/06/02	12/11/02	5	4.6	7.20	21.23	343	95	54	492	853	216	1,198	1,720	6.1	6.90	28.98	28.95
12/11/02	12/17/02	6	9.9	7.21	20.46	363	59	49	471	1,321	611	1,982	2,209	7.9	6.60	30.43	29.85
12/17/02	12/26/02	9	8.2	7.65	19.72	249	81	40	370	3,584	229	4,248	4,472	3.0	4.40	34.59	32.50
12/26/02	01/07/03	12	8.4	7.46	18.23	214	219	37	470	1,377	1,020	2,457	3,358	3.1	4.50	27.89	26.12
01/07/03	01/16/03	9	5.9	7.15	20.10	320	49	41	410	1,122	299	1,547	2,320	3.2	3.10	27.41	25.39
01/16/03	01/23/03	7	4.1	7.34	18.90	408	50	179	637	1,129	326	2,777	3,856	4.0	4.70	24.91	23.98
01/23/03	01/30/03	7	2.7	7.25	19.80	593	254	642	1,489	903	1,048	10,610	11,968	7.7	11.70	29.50	29.30
01/30/03	02/12/03	13	2.3	6.96	22.80	724	800	4,434	5,958	7,075	1,426	10,550	11,266	7.8	5.50	23.60	22.79
02/19/03	03/12/03	21	2.0	6.99	27.40	720	717	343	1,780	2,502	700	5,580	7,210	10.4	8.20	26.45	24.72
03/20/03	03/28/03	8	8.5	6.96	26.30	1,020	157	88	1,265	1,330	175	3,051	4,425	10.5	8.00	34.57	34.47
03/28/03	04/04/03	7	5.2	7.79	26.00	728	132	131	991	1,833	119	2,093	3,480	5.0	4.30	29.87	29.12
04/04/03	04/15/03	11	1.9	7.31	27.70	562	149	86	797	936	222	1,276	2,201	4.3	4.00	23.07	22.57
04/29/03	05/09/03	10	4.8	7.50	32.40	556	11	52	619	1,539	38	1,875	3,415	3.8	2.40	28.66	28.22
05/09/03	05/14/03	5	1.7	7.55	31.60	790	189	302	1,281	930	422	1,568	4,731	8.2	5.30	29.21	28.32
05/29/03	06/06/03	8	3.7	7.20	32.10	797	22	217	1,036	1,932	166	3,467	4,801	14.0	6.50	26.20	25.80
06/13/03	06/19/03	6	1.7	7.54	32.50	443	190	19	652	714	1,121	2,333	2,666	3.7	2.10	21.70	20.96
06/19/03	06/26/03	7	6.5	6.82	32.30	550	69	37	656	3,310	221	3,961	4,455	3.8	3.10	25.80	23.66

Statistic	Flow (cfs)	pH (s.u.)	Temp (°C)	Ortho P (µg/l)	Diss. Org. P µg/l)	Part P (µg/l)	TP (µg/l)	Dis. Org. N (µg/l)	Part N (µg/l)	TKN (µg/l)	TN (µg/l)	TSS (mg/l)	Turbidity (NTU)	TOC (mg/l)	DOC (mg/l)
Mean	5.0	7.34	24.72	514	177	332	1,023	1,855	466	3,293	4,354	5.9	5.3	27.7	26.7
Min	1.7	6.82	18.23	214	11	19	370	714	38	1,198	1,720	3.0	2.1	21.7	21.0
Max	9.9	7.79	32.50	1,020	800	4,434	5,958	7,075	1,426	10,610	11,968	14.0	11.7	34.6	34.5
C.V.	50.6	3.7	20.3	41.2	177	286	117	76.5	88.6	80.7	62.1	49.9	42.3	11.6	12.6
95% Confidence Interval	4.1-5.9	7.24-7.44	22.95-26.49	438-590	104-250	0-667	602-1,444	1,356-2,354	321-611	2,357-4,229	3,402-5,306	4.9-6.9	4.5-6.1	26.6-28.8	25.5-27.9

In general, the characteristics of discharges from the CDS are similar to the characteristics of discharges through Lettuce Creek. Approximately 50% of the mean total phosphorus concentration of 1023 μg/l is comprised of dissolved orthophosphorus, with an additional 17% comprised of dissolved organic phosphorus. Only 32% of the phosphorus discharges from the CDS unit consist of particulate phosphorus species. A graphical comparison of phosphorus species in the inflow and outflow of the CDS unit during operation at 1 cfs is given in Figure 5-16.

In contrast to the trends observed for phosphorus species, a majority of nitrogen in discharges from the CDS unit consisted of dissolved species. Only 11% of the discharges from the CDS unit consisted of particulate nitrogen. A graphical comparison of nitrogen species in the inflow and outflow of the CDS unit during operation at 1 cfs is given in Figure 5-17.

Discharge concentrations of TSS and turbidity from the CDS unit were relatively low in value and exhibited a low degree of variability in measured concentrations, with a mean TSS concentration of 5.9 mg/l and a mean turbidity of 5.3 NTU. Approximately 96% of the total carbon discharging from the unit consisted of dissolved organic carbon. A graphical comparison of TSS, turbidity, DOC, and TOC in the inflow and outflow of the CDS unit during operation at 1 cfs is given in Figure 5-18.

A comparison of mean chemical characteristics of Lettuce Creek inflow and CDS outflow at a flow rate of 1 cfs is given in Table 5-8. Inflow and outflow concentrations into the CDS unit appear to be virtually identical for all measured species. In fact, slight increases in measured concentrations of some nitrogen and phosphorus species may have occurred during migration through the CDS unit, although the differences are not statistically significant.

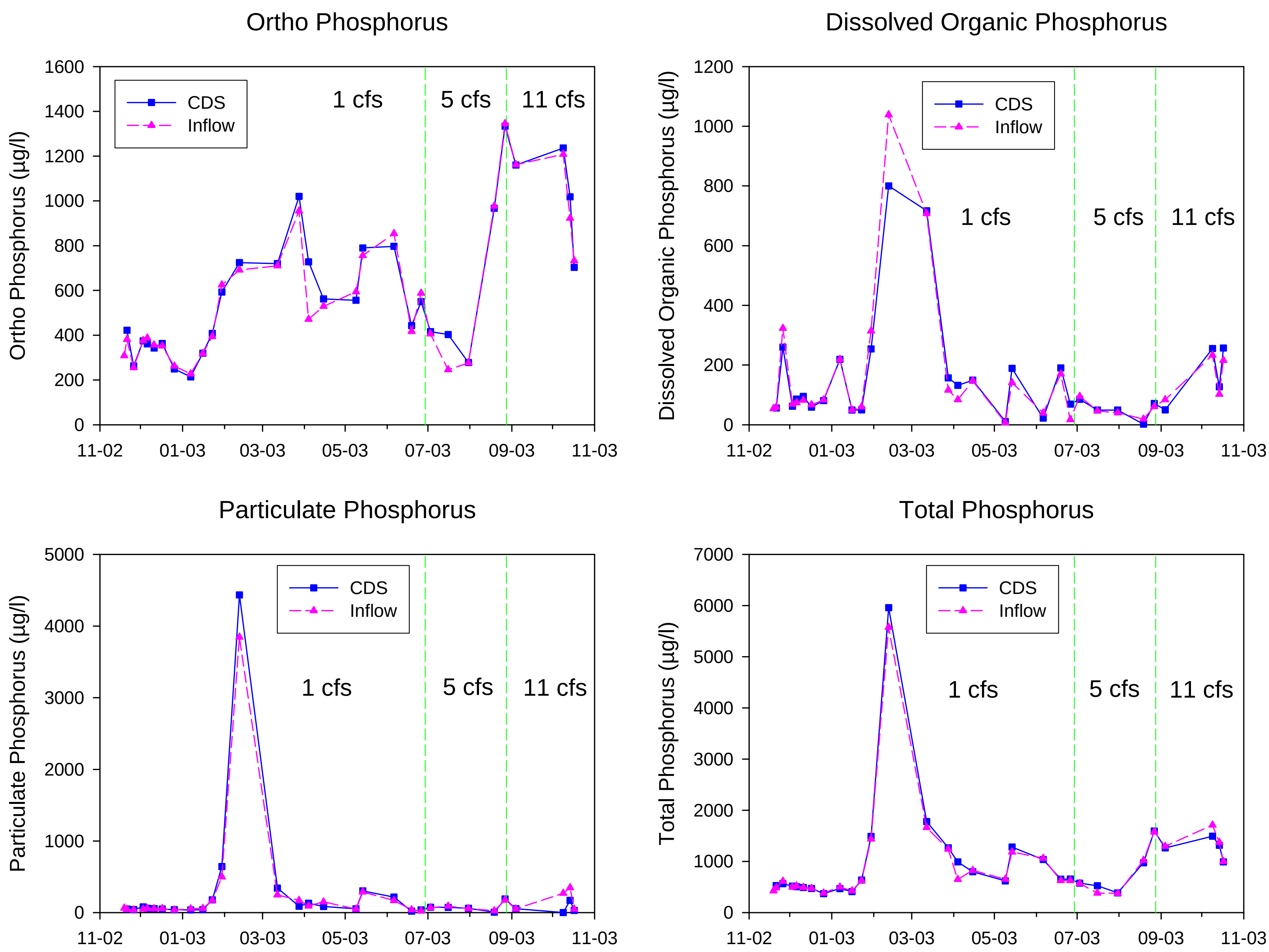


Figure 5-16. Concentrations of Phosphorus Species in Inflow and Outflow of the CDS Unit.

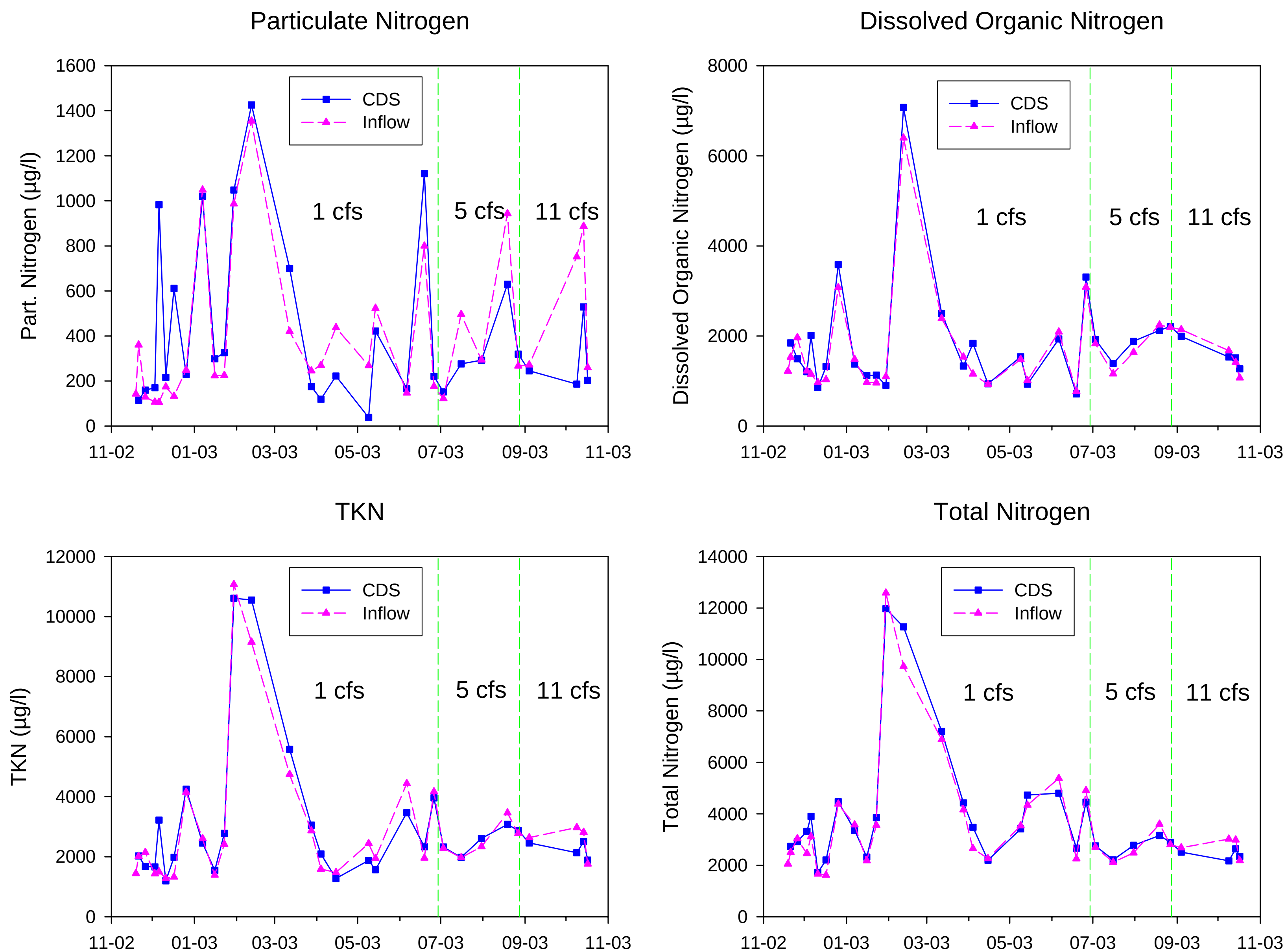


Figure 5-17. Concentrations of Nitrogen Species in Inflow and Outflow of the CDS Unit.

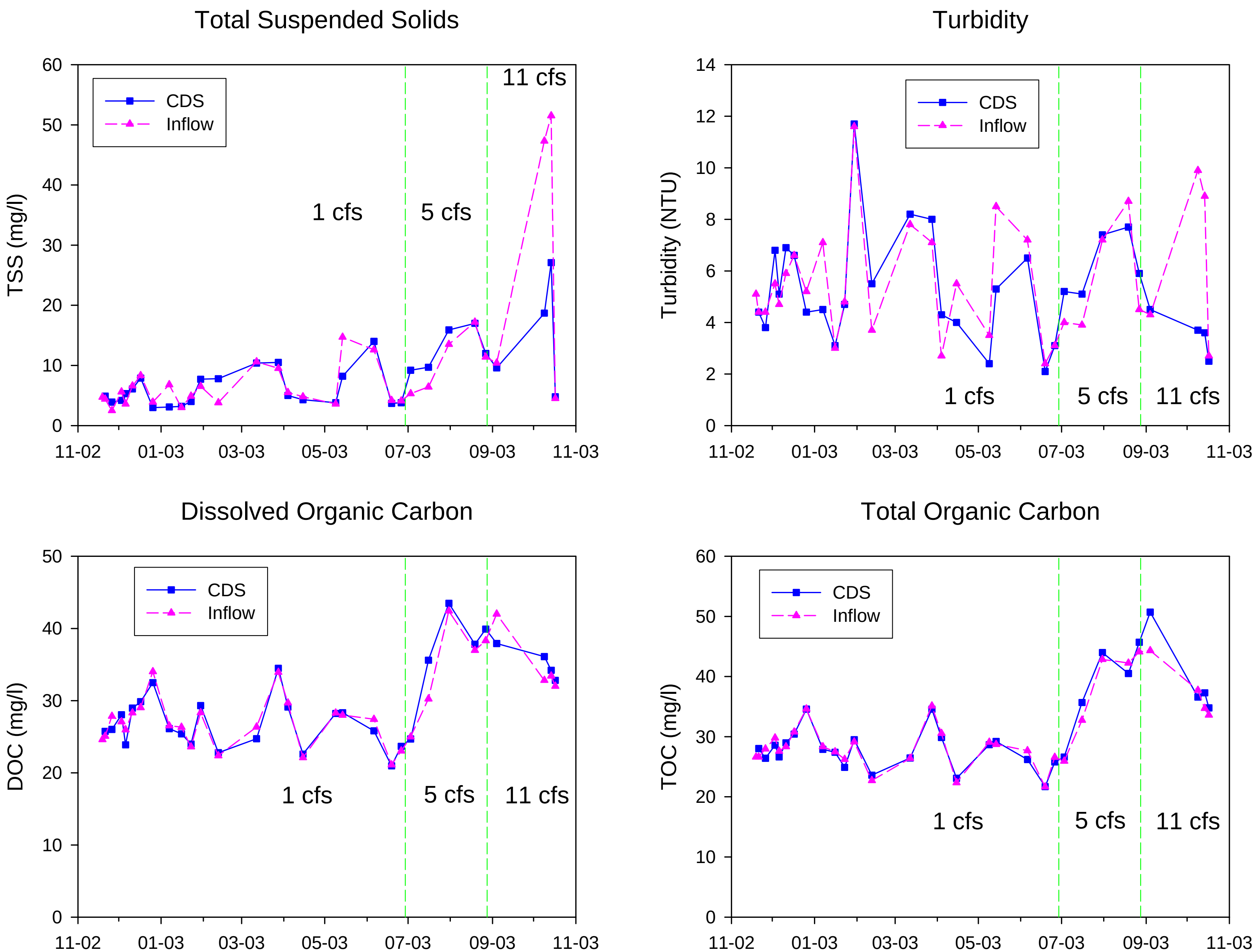


Figure 5-18. Concentrations of TSS, Turbidity, DOC and TOC in Inflow and Outflow of the CDS Unit.

TABLE 5-8

COMPARISON OF MEAN CHEMICAL CHARACTERISTICS OF LETTUCE CREEK INFLOW AND CDS OUTFLOW AT A FLOW RATE OF 1 cfs

PARAMETER	UNITS	MEAN CONCENTRATION	
		LETTUCE CREEK INFLOW	CDS OUTFLOW
pH	s.u.	7.40	7.34
TKN	µg/l	3069	3293
Diss. Organic N	µg/l	1704	1855
Particulate N	µg/l	387	466
Total N	µg/l	4037	4354
Ortho-P	µg/l	491	514
Diss. Organic P	µg/l	178	177
Particulate P	µg/l	284	332
Total P	µg/l	953	1023
TSS	mg/l	6.1	5.9
Turbidity	NTU	5.4	5.3
TOC	mg/l	27.9	27.7
DOC	mg/l	26.8	26.7

5.3.1.1.2 Concentration-Based Efficiencies

Concentration-based removals for the CDS unit during operation at 1 cfs are summarized in Table 5-9 for each of the 21 monitoring periods conducted at this flow rate. Increases in concentrations, indicated by negative signs for any of the calculated removals, were observed for many species of nitrogen and phosphorus during individual monitoring periods. Increases in concentrations were observed during 12 of the 21 monitoring periods for dissolved organic nitrogen, 13 of the monitoring periods for particulate nitrogen, 14 of the monitoring periods for total nitrogen, 12 of the monitoring periods for orthophosphorus, 10 of the monitoring periods for dissolved organic phosphorus, 14 of the monitoring periods for particulate phosphorus, and 11 of the monitoring periods for total phosphorus. Concentration-based efficiencies for nutrient species were also highly variable, particularly for nitrogen species. In contrast, a substantially lower degree of variability in concentration-based removals was observed for TOC and DOC, with increases in TOC observed during 6 of the 21 events and increases in TOC observed during 11 of the 21 events.

TABLE 5-9

CONCENTRATION-BASED REMOVALS FOR THE CDS UNIT DURING OPERATION AT 1 cfs

PERIOD OF OPERATION	DISS ORG N	PART N	TN	ORTHO P	DISS ORG P	PART P	TP	TSS	TURB	TOC	DOC
11/19-11/21/02	-21	68	-9	-11	5	-11	-9	-11	0	-5	-3
11/21-11/26/02	24	-23	4	-3	20	-23	8	-56	14	6	7
11/26-12/3/02	1	-60	-35	0	10	-60	-4	25	-24	4	-4
12/3-12/6/02	-75	-836	-25	7	-16	-2	3	-47	-9	3	8
12/6-12/11/02	12	-24	-3	4	-16	0	0	8	-17	-2	-2
12/11-12/17/02	-28	-363	-37	-3	12	13	1	5	0	1	-3
12/17-12/26/02	-17	8	-2	5	2	-14	3	23	15	0	4
12/26/02-1/7/03	7	3	6	6	0	30	6	54	37	2	1
1/7-1/16/03	-16	-34	-6	-1	0	28	3	-7	-3	0	3
1/16-1/23/03	-18	-45	-8	-4	17	-6	-2	18	2	5	-2
1/23-1/30/03	18	-6	5	5	19	-29	-4	-18	-1	-1	-3
1/30-2/12/03	-11	-5	-16	-5	23	-15	-7	-105	-49	-4	-2
2/19-3/12/03	-5	-67	-5	-1	-1	-39	-7	2	-5	0	6
3/20-3/28/03	13	29	-6	-7	-35	48	-2	-11	-13	2	-2
3/28-4/4/03	-58	56	-31	-55	-57	-42	-53	9	-59	2	2
4/4-4/15/03	-2	49	3	-6	-1	42	3	10	27	-3	-2
4/29-5/9/03	-4	86	3	6	-57	-6	5	-6	31	1	0
5/9-5/14/03	8	19	-9	-4	-34	-5	-8	44	38	-2	-1
5/29-6/6/03	8	-13	11	7	44	-29	2	-11	10	5	6
6/13-6/19/03	7	-40	-18	-6	-12	51	-4	12	13	0	1
6/19-6/26/03	-7	-26	9	6	-306	-68	-5	7	0	3	-3

5.3.1.1.3 <u>Mass Removal Efficiencies</u>

Mass removal efficiencies for the CDS unit during operation at 1 cfs are summarized in Table 5-10. A high degree of variability is apparent in measured mass removals for individual monitoring periods for virtually all measured parameters. However, on an overall basis, increases in mass were observed for dissolved organic nitrogen, particulate nitrogen, and total nitrogen between the inflow and outflow of the CDS unit. Increases in mass between inflow and outflow were also observed for orthophosphorus, particulate phosphorus, and total phosphorus, with a net mass retention for dissolved organic phosphorus.

TABLE 5-10

MASS REMOVAL FOR THE CDS UNIT DURING OPERATION AT 1 cfs

PERIOD OF OPERATION	DISS ORG N	PART N	TN	ORTHO P	DISS ORG P	PART P	TP	TSS	TURB	TOC	DOC
11/19-11/21/02	-21	68	-9	-11	5	-11	-9	-11	0	-5	-3
11/21-11/26/02	24	-23	4	-3	20	-23	8	-56	14	6	7
11/26-12/3/02	1	-60	-35	0	10	-60	-4	25	-24	4	-4
12/3-12/6/02	-75	-836	-25	7	-16	-2	3	-47	-9	3	8
12/6-12/11/02	12	-24	-3	4	-16	0	0	8	-17	-2	-2
12/11-12/17/02	-28	-363	-37	-3	12	13	1	5	0	1	-3
12/17-12/26/02	-17	8	-2	5	2	-14	3	23	15	0	4
12/26/02-1/7/03	7	3	6	6	0	30	6	54	37	2	1
1/7-1/16/03	-16	-34	-6	-1	0	28	3	-7	-3	0	3
1/16-1/23/03	-18	-45	-8	-4	17	-6	-2	18	2	5	-2
1/23-1/30/03	18	-6	5	5	19	-29	-4	-18	-1	-1	-3
1/30-2/12/03	-11	-5	-16	-5	23	-15	-7	-105	-49	-4	-2
2/19-3/12/03	-5	-67	-5	-1	-1	-39	-7	2	-5	0	6
3/20-3/28/03	13	29	-6	-7	-35	48	-2	-11	-13	2	-2
3/28-4/4/03	-58	56	-31	-55	-57	-42	-53	9	-59	2	2
4/4-4/15/03	-2	49	3	-6	-1	42	3	10	27	-3	-2
4/29-5/9/03	-4	86	3	6	-57	-6	5	-6	31	1	0
5/9-5/14/03	8	19	-9	-4	-34	-5	-8	44	38	-2	-1
5/29-6/6/03	8	-13	11	7	44	-29	2	-11	10	5	6
6/13-6/19/03	7	-40	-18	-6	-12	51	-4	12	13	0	1
6/19-6/26/03	-7	-26	9	6	-306	-68	-5	7	0	3	-3
Average	-5	-12	-4	-1	6	-14	-4	4	5	3	3

In contrast, an overall reduction in mass was observed between the inflow and outflow for TSS, turbidity, TOC, and DOC. Overall retention of TSS within the unit was approximately 4%, with a 5% retention of turbidity and 3% retention for TOC and DOC.

In general, it appears that the CDS unit exhibited poor mass retention for all measured species of nitrogen and phosphorus. This lack of retention is related to several factors, including the general lack of particulate matter in Lettuce Creek water, the relatively large size of particles which exist within Lettuce Creek, and the presence of fish species within the units which released waste products into the water column on a continuous basis.

5.3.1.2 Performance Efficiency During Operation at 5 cfs

5.3.1.2.1 Chemical Characteristics of Outflow Samples

Chemical characteristics of CDS outflow samples with the system operating at 5 cfs are given in Table 5-11. Chemical characteristics of inflow samples are provided in Table 5-4. Discharges from the CDS unit are characterized by a high degree of variability in measured concentrations of particulate nitrogen. A substantially lower degree of variability is apparent in measured concentrations of TKN, dissolved organic nitrogen, and total nitrogen. On an average basis, approximately 88% of the total nitrogen discharging from the CDS unit consists of dissolved species, with only 12% contributed by particulate nitrogen. A graphical comparison of nitrogen species in the inflow and outflow from the CDS unit during operation at 5 cfs is included in Figure 5-17.

TABLE 5-11

CHEMICAL CHARACTERISTICS OF CDS OUTFLOW SAMPLES WITH SYSTEM OPERATING AT 5 cfs

PERIOD OF OPERATION	PARAMETER													
	pH (s.u.)	Temp (EC)	TKN (μg/l)	Diss. Org N (μg/l)	Part N (μg/l)	TN (μg/l)	OP (μg/l)	Org P (μg/l)	Part P (μg/l)	TP (μg/l)	TSS (mg/l)	Turb (NTU)	TOC (mg/l)	DOC (mg/l)
6/27-7/3/03	6.99	32.1	2324	1920	152	2752	416	85	75	576	9.2	5.2	26.6	24.7
7/10-16/03	6.95	31.9	1979	1392	276	2212	403	49	74	526	9.7	5.1	35.7	35.6
7/31-8/6/03	7.23	32.4	2613	1882	292	2777	278	89	59	386	15.9	7.4	44.0	43.5
8/12-19/03	6.96	31.5	3075	2126	630	3162	967	2	6	975	17.0	7.7	40.5	37.8
8/21-27/03	7.23	30.8	2870	2211	319	2896	1334	71	190	1595	12.0	5.9	45.7	39.9
Mean	7.07	31.7	2572	1906	334	2760	680	59	81	812	12.8	6.3	38.5	36.3
95% C.I.	6.89-7.25	31.0-32.5	1880-3102	1525-2327	58-570	2329-3190	118-1241	15-103	8-175	247-1415	8.4-17.2	4.7-7.8	29.0-48.0	27.5-45.1

A relatively high degree of variability is also apparent in measured phosphorus species discharging from the CDS unit, including orthophosphorus, organic phosphorus, and particulate phosphorus, as well as total phosphorus. On an average basis, discharges from the CDS unit, operating at a flow rate of 5 cfs, are approximately 90% dissolved and 10% particulate. Mean discharge concentrations from the CDS unit are greater than discharge concentrations from the TST unit for all measured species with the system operating at 5 cfs. A graphical comparison of phosphorus species in the inflow and outflow from the CDS unit during operation at 5 cfs is included in Figure 5-16.

A relatively low degree of variability is apparent in measured TSS and turbidity concentrations discharging from the CDS unit. Measured TSS concentrations range from 9.2-17.0 mg/l, with turbidity ranging from 5.1-7.7 NTU. A relatively high degree of variability is also apparent in measured TOC and DOC concentrations in discharges from the CDS unit. On an average basis, approximately 94% of the total organic carbon measured is present in a dissolved form. A graphical comparison of TSS, turbidity, DOC, and TOC in the inflow and outflow from the CDS unit during operation at 5 cfs is included in Figure 5-18.

5.3.1.2.2 Concentration-Based Efficiencies

Changes in concentrations for the CDS unit between the inflow and outflow during operation at 5 cfs are summarized in Table 5-12. Increases in concentrations were observed for dissolved organic nitrogen during four of the five monitoring intervals. In contrast, decreases in concentrations were observed for particulate nitrogen during three of the five monitoring intervals. However, on an overall basis, total nitrogen concentrations increase slightly during a majority of the experimental tests.

TABLE 5-12

CONCENTRATION-BASED REMOVAL FOR THE CDS UNIT DURING OPERATION AT 5 cfs

PERIOD OF OPERATION	REMOVAL (%)										
	Diss Org N	Part N	TN	OP	Diss Org P	Part P	TP	TSS	Turb	TOC	DOC
6/27-7/3/03	-5	-25	-2	-2	11	-10	-1	-74	-30	-3	1
7/10-16/03	-20	44	-4	-64	-7	17	-38	-52	-31	-9	-18
7/31-8/6/03	-15	0	-12	-1	-23	-5	-4	-18	-3	-3	-2
8/12-19/03	5	33	12	1	89	76	5	1	11	4	-2
8/21-27/03	-1	-20	-3	1	-16	-9	-1	-5	-31	-4	-4

Concentrations of phosphorus species at the inflow and outflow from the CDS unit were highly variable during the testing at 5 cfs. Increases in concentrations of orthophosphorus, dissolved organic phosphorus, and particulate phosphorus were observed during a vast majority of the monitoring events, with substantial increases in concentrations observed during several monitoring events. Overall, total phosphorus concentrations increased between the inflow and outflow of the CDS unit for a majority of the monitoring events. Increases in concentrations of TSS and turbidity were also observed during migration through the CDS unit for a majority of the monitoring events. These experiments were performed during a period when fish were observed to be accumulating within both the baffle box and CDS units which may be partly responsible for the poor performance of the units during these tests.

5.3.1.2.3 Mass Removal Efficiencies

Mass removal efficiencies for the CDS unit during operation at 5 cfs are summarized in Table 5-13. On an overall basis, a slight increase in mass was observed for dissolved organic nitrogen during migration through the CDS unit. However, a 22% decrease in mass of particulate nitrogen was observed within the unit. Overall, total nitrogen was unchanged during migration through the CDS unit.

TABLE 5-13

MASS REMOVAL FOR THE CDS UNIT DURING OPERATION AT 5 cfs

PERIOD OF OPERATION	MASS REMOVAL (%)										
	Diss Org N	Part N	TN	OP	Diss Org P	Part P	TP	TSS	Turb	TOC	DOC
6/27-7/3/03	-5	-25	-2	-2	11	-10	-1	-74	-30	-3	1
7/10-16/03	-20	44	-4	-64	-7	17	-38	-52	-31	-9	-18
7/31-8/6/03	-15	0	-12	-1	-23	-5	-4	-18	-3	-3	-2
8/12-19/03	5	33	12	1	89	76	5	1	11	4	-2
8/21-27/03	-1	-20	-3	1	-16	-9	-1	-5	-31	-4	-4
Overall	-5	22	0	-4	3	3	-3	-18	-10	-2	-5

Increases in mass were observed within the CDS unit for all measured phosphorus species from the inflow to the outflow. Overall, total phosphorus increased by approximately 3% during migration through the CDS unit. This poor performance is likely influenced by the large number of fish which continued to accumulate within the CDS unit. The mass of TSS increased by approximately 18% from the inflow to the outflow of the CDS unit.

5.3.1.3 Performance Efficiency During Operation at 11 cfs

5.3.1.3.1 Chemical Characteristics of Outflow Samples

Chemical characteristics of CDS outflow samples with the system operating at 11 cfs are summarized in Table 5-14. A relatively high degree of variability is apparent in discharge concentrations of particulate nitrogen in the CDS outflow, with substantially lower degrees of variability present for the remaining nitrogen species. On an average basis, approximately 88% of the total nitrogen discharging from the CDS unit at 11 cfs consists of dissolved nitrogen species, with 12% comprised of particulate nitrogen species. A graphical comparison of nitrogen species in the inflow and outflow from the CDS unit during operation at 11 cfs is included in Figure 5-17.

TABLE 5-14

CHEMICAL CHARACTERISTICS OF CDS OUTFLOW SAMPLES WITH SYSTEM OPERATING AT 11 cfs

PERIOD OF OPERATION	PARAMETER													
	pH (s.u.)	Temp (EC)	TKN (µg/l)	Diss. Org N (µg/l)	Part N (µg/l)	TN (µg/l)	OP (µg/l)	Org P (µg/l)	Part P (µg/l)	TP (µg/l)	TSS (mg/l)	Turb (NTU)	TOC (mg/l)	DOC (mg/l)
8/27-9/4/03	6.99	31.4	2461	1991	245	2511	1160	50	54	1264	9.6	4.5	50.7	37.9
10/6-9/03	6.80	31.7	2132	1532	186	2175	1236	255	101	1492	18.7	3.7	36.6	36.1
10/9-14/03	7.04	30.1	2506	1512	529	2639	1018	127	172	1317	27.1	3.6	37.3	34.2
10/14-17/03	7.04	31.3	1889	1271	203	2344	703	257	30	990	4.8	2.5	34.8	32.8
Mean	6.97	31.1	2247	1577	291	2417	1029	172	89	1266	15.1	3.6	39.9	35.3
95% C.I.	6.79-7.15	30.0-32.2	1823-2501	1098-2055	175-287	2121-3064	655-1404	11-283	0-189	935-1597	0-30.8	2.3-4.9	28.2-51.5	31.7-38.8

A high degree of variability is apparent in measured phosphorus concentrations discharging from the CDS unit at a flow rate of 11 cfs, particularly for dissolved organic phosphorus as well as particulate phosphorus. Mean phosphorus concentrations from the CDS unit appear to be relatively similar to phosphorus concentrations in discharges from the baffle box when operating at the same flow rate. On an average basis, approximately 95% of the phosphorus discharging from the CDS unit is dissolved in nature, with only 5% comprised of particulate phosphorus species. A graphical comparison of phosphorus species in the inflow and outflow from the CDS unit during operation at 11 cfs is included in Figure 5-16.

A relatively high degree of variability is apparent in TSS concentrations discharging from the CDS unit, with measured concentrations ranging from 4.8-27.1 mg/l. However, turbidity concentrations discharging from the CDS unit appear to be relatively low in value, ranging from 2.5-4.5 NTU. Approximately 88% of the total organic carbon discharging from the CDS unit consists of dissolved organic carbon. A graphical comparison of TSS, turbidity, DOC, and TOC in the inflow and outflow from the CDS unit during operation at 11 cfs is included in Figure 5-18.

5.3.1.3.2 Concentration-Based Efficiencies

Changes in concentrations from the inflow to the outflow of the CDS unit at a flow rate of 11 cfs are summarized in Table 5-15. Decreases in concentrations of nitrogen species were observed during migration through the CDS unit for the majority of the measured nitrogen species. Concentration decreases were observed during two of the four monitoring events for dissolved organic nitrogen, with concentration decreases observed during three of the four events for particulate nitrogen and total nitrogen. For phosphorus species, increases in concentrations were typically observed for orthophosphorus and dissolved organic phosphorus, with decreases in concentrations observed for particulate phosphorus and total phosphorus. Decreases in concentrations were also observed for TSS and turbidity.

TABLE 5-15

CONCENTRATION-BASED REMOVAL FOR THE CDS UNIT DURING OPERATION AT 11 cfs

PERIOD OF OPERATION	REMOVAL (%)										
	Diss Org N	Part N	TN	OP	Diss Org P	Part P	TP	TSS	Turb	TOC	DOC
8/27-9/4/03	7	10	6	0	40	-6	2	8	-5	-14	10
10/6-9/03	8	75	28	-2	-9	100	13	60	63	3	-10
10/9-14/03	-7	40	12	-10	-25	51	4	47	60	-7	-2
10/14-17/03	-19	22	-7	4	-19	39	1	-7	7	-4	-2

5.3.1.3.3 Mass Removal Efficiencies

Overall mass removal efficiencies for the CDS unit operating at 11 cfs are summarized in Table 5-16. On an overall basis, a mass reduction of approximately 2% was observed for dissolved organic nitrogen, 40% reduction for particulate nitrogen, and a 10% reduction for total nitrogen. The mass of orthophosphorus and dissolved organic phosphorus within the CDS unit increased by approximately 2%. However, the mass of particulate phosphorus was reduced by 55%, with an overall 5% reduction in total phosphorus. A 43% reduction in TSS concentrations and a 38% reduction in turbidity were also observed within the CDS unit while operating at a flow rate of 11 cfs.

TABLE 5-16

MASS REMOVAL FOR THE CDS UNIT DURING OPERATION AT 11 cfs

PERIOD OF OPERATION	MASS REMOVAL (%)										
	Diss Org N	Part N	TN	OP	Diss Org P	Part P	TP	TSS	Turb	TOC	DOC
8/27-9/4/03	7	10	6	0	40	-6	2	8	-5	-14	10
10/6-9/03	8	75	28	-2	-9	100	13	60	63	3	-10
10/9-14/03	-7	40	12	-10	-25	51	4	47	60	-7	-2
10/14-17/03	-19	22	-7	4	-19	39	1	-7	7	-4	-2
Overall	2	40	10	-2	-2	55	5	43	38	-9	2

5.3.2 Performance Efficiency of the TST Unit

5.3.2.1 Performance Efficiency During Operation at 1 cfs

5.3.2.1.1 Chemical Characteristics of Outflow Samples

Chemical characteristics of discharges from the TST unit during operation at 1 cfs are given in Table 5-17. In general, a high degree of variability is apparent in discharges from the TST unit for organic phosphorus, particulate phosphorus, total phosphorus, dissolved organic nitrogen, particulate nitrogen, and TKN. A substantially lower degree of variability is apparent in discharge concentrations of orthophosphorus, TSS, turbidity, TOC, and DOC.

Approximately 49% of the mean total phosphorus concentration of 951 μg/l is comprised of dissolved orthophosphorus, with an additional 17% contributed by dissolved organic phosphorus. The remaining 34% of the total phosphorus is contributed by particulate phosphorus. In contrast, the vast majority of nitrogen species exist in a dissolved state, with only 9% of the measured total nitrogen concentration of 4076 μg/l contributed by particulate nitrogen. A graphical comparison of inflow and outflow concentrations of phosphorus and nitrogen species for the TST unit at a flow rate of 1 cfs is given in Figures 5-19 and 5-20, respectively.

In general, measured concentrations of both TSS and turbidity were low in value in discharges from the TST unit, with a mean TSS concentration of 5.6 mg/l and mean turbidity of 5.5 NTU. Approximately 97% of the TOC measured was in a dissolved form.

TABLE 5-17

CHEMICAL CHARACTERISTICS OF DISCHARGES FROM THE TST UNIT DURING OPERATION AT 1 cfs

Start	End	No. of Days	Flow (cfs)	pH (s.u.)	Temp (°C)	Ortho P (µg/l)	Diss. Org. P µg/l)	Part P (µg/l)	TP (µg/l)	Diss. Org. N (µg/l)	Part N (µg/l)	TKN (µg/l)	TN (µg/l)	TSS (mg/l)	Turbidity (NTU)	TOC (mg/l)	DOC (mg/l)
11/15/02	11/19/02	4	6.9	7.83	23.82	356	52	72	480	1,436	79	1,597	2,283	4.60	4.9	26.0	24.3
11/19/02	11/21/02	2	6.6	7.67	23.79	386	44	44	474	1,379	119	1,553	2,020	4.50	4.5	27.3	26.0
11/21/02	11/26/02	5	5.2	7.72	22.87	251	317	37	605	2,035	164	2,213	3,153	1.70	5.2	29.2	28.9
11/26/02	12/03/02	7	6.7	7.41	21.54	371	66	65	502	1,186	157	1,456	2,650	5.40	6.2	28.8	26.5
12/03/02	12/06/02	3	3.3	7.51	21.47	398	71	57	526	1,156	105	1,531	3,194	4.60	5.5	27.5	26.7
12/06/02	12/11/02	5	4.6	7.20	21.23	352	45	68	465	1,126	136	1,412	1,917	6.60	6.2	25.0	24.9
12/11/02	12/17/02	6	9.9	7.21	20.46	422	65	50	537	1,345	150	1,758	2,112	6.60	4.2	31.9	31.7
12/17/02	12/26/02	9	8.2	7.65	19.72	262	94	39	395	3,491	236	4,430	4,779	4.90	5.9	34.2	34.2
12/26/02	01/07/03	12	8.4	7.46	18.23	225	207	39	471	1,282	1,079	2,459	3,393	2.40	4.1	27.8	25.8
01/07/03	01/16/03	9	5.9	7.15	20.10	327	46	50	423	825	226	1,187	1,959	3.00	4.1	27.3	26.0
01/16/03	01/23/03	7	4.1	7.34	18.90	384	73	131	588	970	202	2,554	3,565	4.40	5.0	25.9	24.3
01/23/03	01/30/03	7	2.7	7.25	19.80	599	234	571	1,404	496	525	10,038	11,336	7.90	11.4	30.2	29.1
01/30/03	02/12/03	13	2.3	6.96	22.80	722	816	4,426	5,964	7,551	1,891	10,880	11,443	5.00	4.9	22.3	20.7
02/19/03	03/12/03	21	2.0	6.99	27.40	685	685	355	1,725	2,978	200	6,246	7,940	8.20	9.5	26.7	26.5
03/20/03	03/28/03	8	8.5	6.96	26.30	737	243	125	1,105	1,543	315	2,932	4,260	3.50	4.7	34.3	33.6
03/28/03	04/04/03	7	5.2	7.89	26.00	491	67	111	669	1,384	371	1,909	3,039	3.10	2.9	29.2	29.0
04/04/03	04/15/03	11	1.9	7.51	27.70	521	131	233	885	859	374	1,347	2,150	6.00	9.0	22.4	22.1
04/29/03	05/09/03	10	4.8	7.56	32.40	570	5	41	616	1,444	145	1,740	3,285	4.20	3.6	28.9	28.7
05/09/03	05/14/03	5	1.7	7.70	31.60	761	124	172	1,057	894	434	1,381	4,347	11.50	6.1	29.8	29.0
05/29/03	06/06/03	8	3.7	7.08	32.10	494	27	266	787	1,869	121	2,961	4,030	17.80	8.0	26.4	25.5
06/13/03	06/19/03	6	1.7	7.58	32.50	422	160	43	625	704	823	1,944	2,240	3.60	2.0	22.2	21.4
06/19/03	06/26/03	7	6.5	7.37	32.30	566	27	25	618	3,380	206	3,943	4,575	4.30	3.3	24.2	23.0
Mean			5.0	7.41	24.68	468	164	319	951	1,788	366	3,067	4,076	5.6	5.5	27.6	26.7
Min			1.7	6.96	18.23	225	5	25	395	496	79	1,187	1,917	1.7	2.0	22.2	20.7
Max			9.9	7.89	32.50	761	816	4,426	5,964	7,551	1,891	10,880	11,443	17.8	11.4	34.3	34.2
C.V.			49.2	3.8	19.9	34.2	127	290	123	85.0	115	87.5	67.0	61.8	40.9	12.2	13.4
95% Confidence Interval			4.1-5.9	7.31-7.51	22.95-26.41	412-524	91-237	0-645	539-1,363	1,263-2,323	218-514	2,122-4,012	3,115-5,037	4.4-6.8	4.7-6.3	26.4-27.8	25.4-28.0

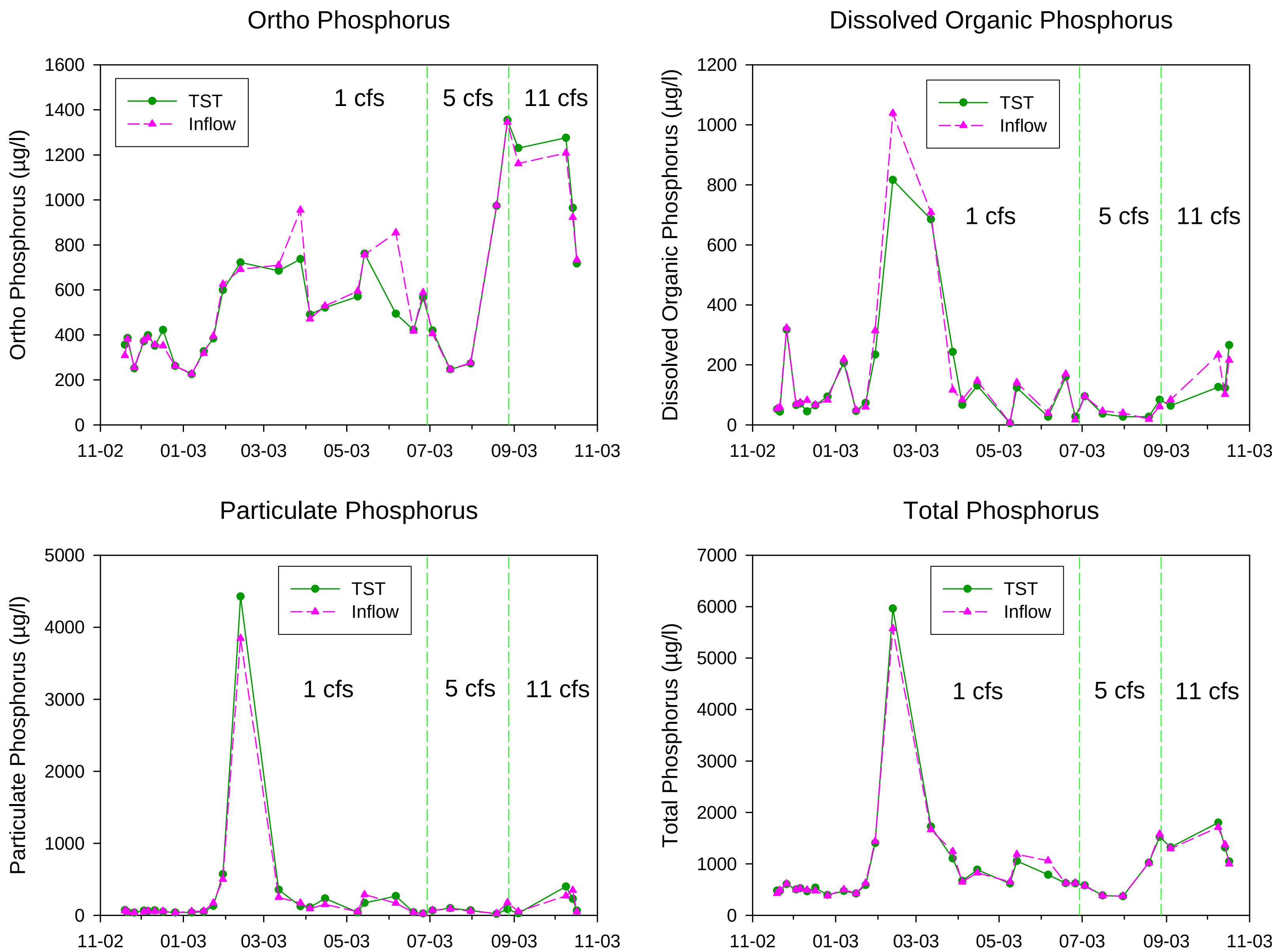


Figure 5-19. Concentrations of Phosphorus Species in Inflow and Outflow of the TST Unit.

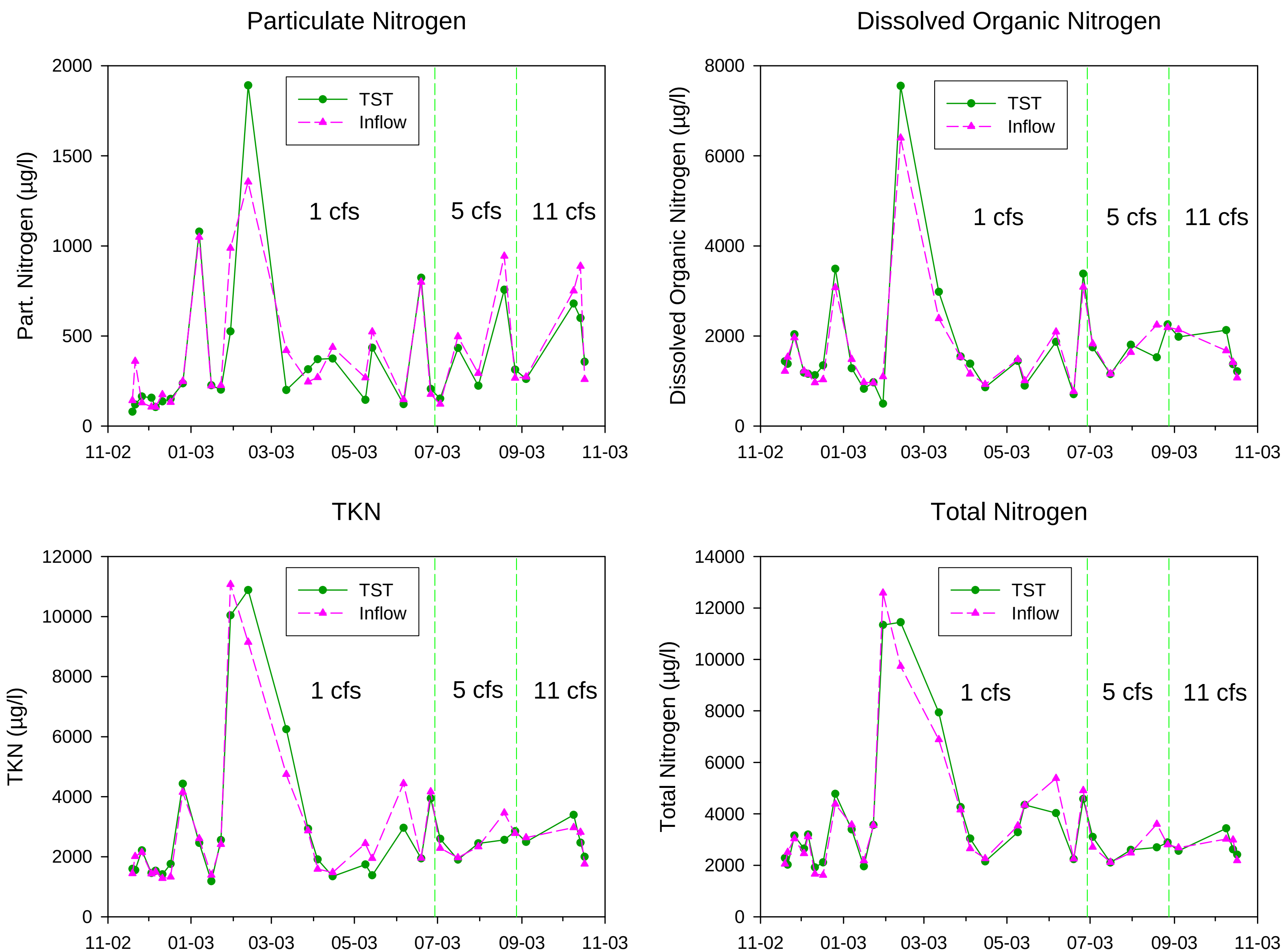


Figure 5-20. Concentrations of Nitrogen Species in Inflow and Outflow of the CDS Unit.

A comparison of mean chemical characteristics of Lettuce Creek inflow and TST outflow at a flow rate of 1 cfs is given in Table 5-18. Mean inflow and outflow characteristics for the TST unit are virtually identical for all of the measured parameters. This is in contrast to the apparent slight increase in chemical characteristics observed between the inflow and outflow within the CDS unit. A graphical comparison of inflow and outflow concentrations of TSS, turbidity, DOC, and TOC for the TST unit at a flow rate of 1 cfs is given in Figure 5-21.

TABLE 5-18

COMPARISON OF MEAN CHEMICAL CHARACTERISTICS OF LETTUCE CREEK INFLOW AND TST OUTFLOW AT A FLOW RATE OF 1 cfs

PARAMETER	UNITS	MEAN CONCENTRATION	
		LETTUCE CREEK INFLOW	TST OUTFLOW
pH	s.u.	7.40	7.41
TKN	µg/l	3069	3067
Diss. Organic N	µg/l	1704	1788
Particulate N	µg/l	387	366
Total N	µg/l	4037	4076
Ortho-P	µg/l	491	468
Diss. Organic P	µg/l	178	164
Particulate P	µg/l	284	319
Total P	µg/l	953	951
TSS	mg/l	6.1	5.6
Turbidity	NTU	5.4	5.5
TOC	mg/l	27.9	27.6
DOC	mg/l	26.8	26.7

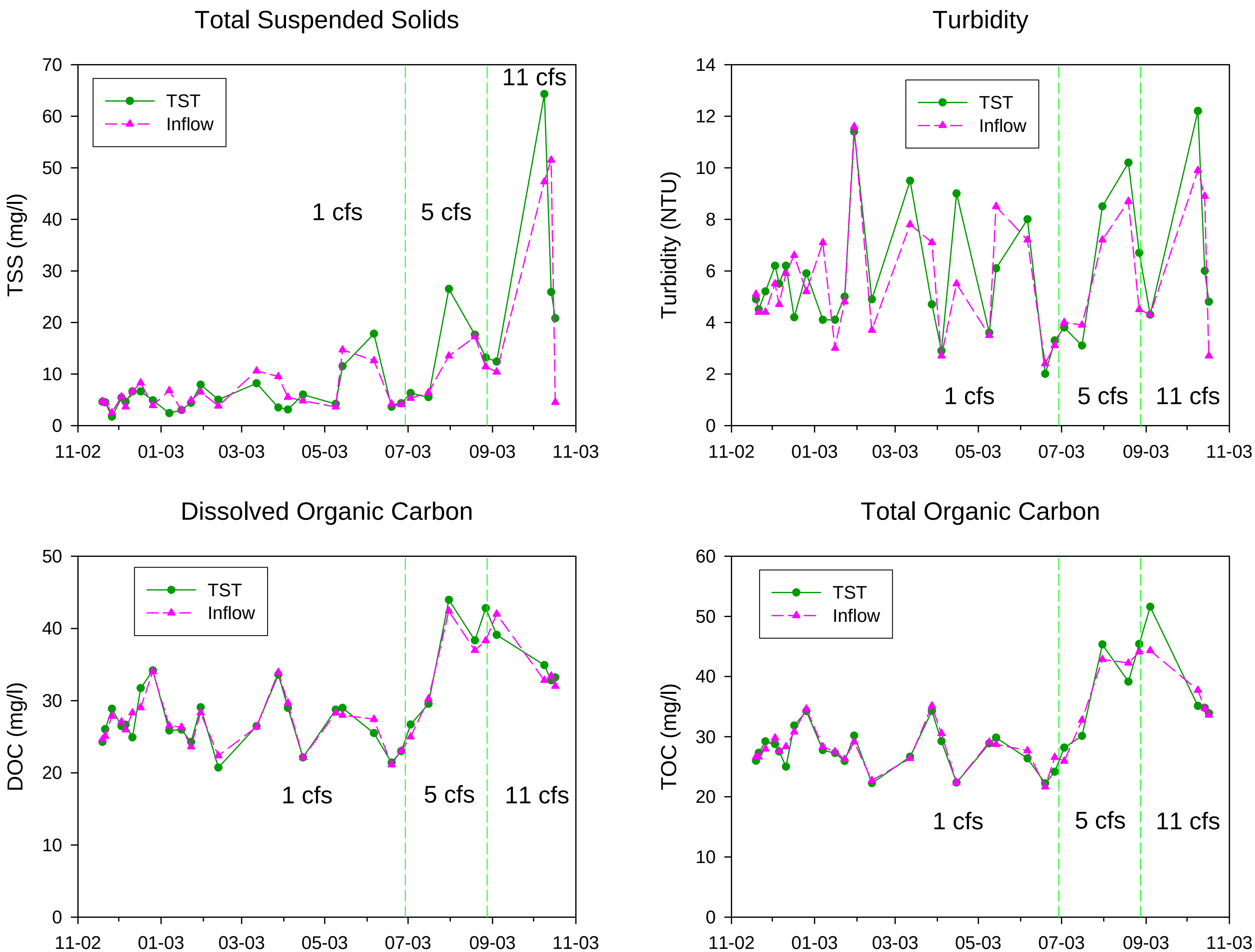


Figure 5-21. Concentrations of TSS, Turbidity, DOC and TOC in Inflow and Outflow of the TST Unit.

5.3.2.1.2 Concentration-Based Efficiencies

Concentration-based removals between the inflow and outflow of the TST during operation at 1 cfs are summarized in Table 5-19. A high variability is apparent in concentration-based removal for virtually all measured parameters with the exceptions of TOC and DOC. Approximately half of the measured concentrations of nitrogen and phosphorus species exhibit decreases during migration through the TST unit, while the remaining half exhibit increases in concentrations.

TABLE 5-19

CONCENTRATION-BASED REMOVALS FOR THE TST UNIT DURING OPERATION AT 1 cfs

PERIOD OF OPERATION	DISS ORG N	PART N	TN	ORTHO P	DISS ORG P	PART P	TP	TSS	TURB	TOC	DOC
11/15-11/19/02	-18	44	-11	-16	4	-14	-13	2	4	2	1
11/19-11/21/02	10	67	19	-1	25	0	2	-2	-2	-3	-4
11/21-11/26/02	-4	-27	-4	2	2	-6	1	32	-18	-4	-4
11/26-12/3/02	3	-48	-8	1	4	-30	-1	4	-13	3	2
12/3-12/6/02	0	0	-3	-3	4	2	-1	-28	-17	0	-3
12/6-12/11/02	-17	22	-15	1	45	-26	5	0	-5	12	12
12/11-12/17/02	-31	-14	-31	-20	3	11	-13	20	36	-3	-9
12/17-12/26/02	-14	5	-9	0	-13	-11	-4	-26	-13	1	0
12/26/02-1/7/03	13	-3	5	1	5	26	6	65	42	2	3
1/7-1/16/03	15	-1	10	-3	6	12	0	0	-37	1	1
1/16-1/23/03	-1	10	0	3	-22	22	6	10	-4	1	-3
1/23-1/30/03	55	47	10	4	25	-14	2	-22	2	-4	-3
1/30-2/12/03	-18	-40	-18	-4	21	-15	-7	-32	-32	2	7
2/19-3/12/03	-25	52	-15	4	3	-44	-4	23	-22	-1	0
3/20-3/28/03	-1	-29	-3	23	-109	26	11	63	34	2	1
3/28-4/4/03	-20	-38	-15	-4	20	-21	-3	44	-7	4	2
4/4-4/15/03	7	14	5	2	11	-56	-7	-25	-64	0	0
4/29-5/9/03	2	46	7	4	29	16	5	-17	-3	1	-2
5/9-5/14/03	11	17	0	-1	12	40	11	22	28	-4	-4
5/29-6/6/03	11	18	25	42	31	-58	26	-41	-11	5	7
6/13-6/19/03	8	-3	0	-1	6	-10	0	14	17	-3	-1
6/19-6/26/03	-10	-17	7	4	-59	-14	1	-5	-6	9	0

Although a high degree of variability is apparent in concentration-based removals presented in Table 5-19 for the TST unit, the variability for the evaluated parameters in the TST unit appears to be less than the variability in concentration-based removals observed in the CDS unit. These differences may be partly related to the accumulation of fish within the two units, since the fish could not escape from the CDS unit compared with the TST unit where fish could escape over the interior baffle structures.

5.3.2.1.3 Mass Removal Efficiencies

Overall mass removal efficiencies for the TST unit during operation at 1 cfs are given in Table 5-20. A high degree of variability is apparent in removal efficiencies measured throughout the monitoring program, with both positive and negative removals observed for all measured parameters. However, on an overall basis, the TST unit had a net export of approximately 8% for dissolved organic nitrogen, with a 3% retention for particulate nitrogen and a 4% export for total nitrogen. The mass of orthophosphorus within the TST unit was decreased by approximately 5%, with a corresponding 8% decrease in dissolved organic phosphorus. However, particulate phosphorus increased from the inflow to the outflow of the unit by approximately 16%. Overall, no net removal of phosphorus was achieved within the TST unit during operation at 1 cfs.

On an overall basis, approximately 10% of the suspended solids entering the TST unit were retained, although a net export of 5% was observed for turbidity. Relatively little change occurred in mass inputs of TOC and DOC during migration through the TST unit.

TABLE 5-20

MASS REMOVAL FOR THE TST UNIT DURING OPERATION AT 1 cfs

PERIOD OF OPERATION	DISS ORG N	PART N	TN	ORTHO P	DISS ORG P	PART P	TP	TSS	TURB	TOC	DOC
11/15-11/19/02	-18	44	-11	-16	4	-14	-13	2	4	2	1
11/19-11/21/02	10	67	19	-1	25	0	2	-2	-2	-3	-4
11/21-11/26/02	-4	-27	-4	2	2	-6	1	32	-18	-4	-4
11/26-12/3/02	3	-48	-8	1	4	-30	-1	4	-13	3	2
12/3-12/6/02	0	0	-3	-3	4	2	-1	-28	-17	0	-3
12/6-12/11/02	-17	22	-15	1	45	-26	5	0	-5	12	12
12/11-12/17/02	-31	-14	-31	-20	3	11	-13	20	36	-3	-9
12/17-12/26/02	-14	5	-9	0	-13	-11	-4	-26	-13	1	0
12/26/02-1/7/03	13	-3	5	1	5	26	6	65	42	2	3
1/7-1/16/03	15	-1	10	-3	6	12	0	0	-37	1	1
1/16-1/23/03	-1	10	0	3	-22	22	6	10	-4	1	-3
1/23-1/30/03	55	47	10	4	25	-14	2	-22	2	-4	-3
1/30-2/12/03	-18	-40	-18	-4	21	-15	-7	-32	-32	2	7
2/19-3/12/03	-25	52	-15	4	3	-44	-4	23	-22	-1	0
3/20-3/28/03	-1	-29	-3	23	-109	26	11	63	34	2	1
3/28-4/4/03	-20	-38	-15	-4	20	-21	-3	44	-7	4	2
4/4-4/15/03	7	14	5	2	11	-56	-7	-25	-64	0	0
4/29-5/9/03	2	46	7	4	29	16	5	-17	-3	1	-2
5/9-5/14/03	11	17	0	-1	12	40	11	22	28	-4	-4
5/29-6/6/03	11	18	25	42	31	-58	26	-41	-11	5	7
6/13-6/19/03	8	-3	0	-1	6	-10	0	14	17	-3	-1
6/19-6/26/03	-10	-17	7	4	-59	-14	1	-5	-6	9	0
Average	-8	3	-4	5	8	-16	-1	10	-5	1	1

5.3.2.2 Performance Efficiency During Operation at 5 cfs

5.3.2.2.1 Chemical Characteristics of Outflow Samples

Chemical characteristics of TST outflow samples with the system operating at 5 cfs are given in Table 5-21. A moderate to relatively high degree of variability was observed for measured nitrogen species in discharges from the TST unit. On an average basis, approximately 86% of the total nitrogen measured in discharges from the TST was in a dissolved form, with only 14% present as particulate nitrogen. A graphical comparison of nitrogen species in the inflow and outflow for the TST unit at a flow rate of 5 cfs is included in Figure 5-20.

TABLE 5-21

CHEMICAL CHARACTERISTICS OF TST OUTFLOW SAMPLES WITH SYSTEM OPERATING AT 5 cfs

PERIOD OF OPERATION	PARAMETER													
	pH (s.u.)	Temp (EC)	TKN (µg/l)	Diss. Org N (µg/l)	Part N (µg/l)	TN (µg/l)	OP (µg/l)	Org P (µg/l)	Part P (µg/l)	TP (µg/l)	TSS (mg/l)	Turb (NTU)	TOC (mg/l)	DOC (mg/l)
6/27-7/3/03	7.39	32.1	2597	1744	152	3102	419	95	66	580	6.3	3.8	28.2	26.7
7/10-16/03	7.22	31.9	1902	1151	433	2108	247	37	100	384	5.5	3.1	30.1	29.5
7/31-8/6/03	7.19	32.4	2442	1803	223	2598	273	27	68	368	26.5	8.5	45.3	44.0
8/12-19/03	6.93	31.5	2558	1525	756	2696	973	27	19	1019	17.6	10.2	39.1	38.3
8/21-27/03	7.21	30.8	2849	2254	313	2889	1354	84	86	1524	13.2	6.7	45.4	42.8
Mean	7.19	31.7	2470	1695	375	2679	653	54	68	775	13.8	6.5	37.6	36.3
95% C.I.	6.98-7.39	31.0-32.5	1886-2910	1194-2196	48-703	2249-3088	63-1264	16-84	26 110	161-1389	3.0-24.6	2.7-10.2	27.5-47.8	26.6-45.9

Measured concentrations of phosphorus species were also found to be highly variable in discharges from the TST unit. Outflow concentrations of orthophosphorus range from 247-1354 µg/l, with an overall mean of 653 µg/l. Measured concentrations of dissolved organic phosphorus were found to be relatively low, ranging from 27-95 µg/l. However, on an average basis, the majority of phosphorus present in discharges from the TST unit was in a dissolved state, with approximately 88% of the mean total phosphorus concentration of 775 µg/l comprised of dissolved phosphorus species (orthophosphorus + organic phosphorus). A graphical comparison of phosphorus species in the inflow and outflow for the TST unit at a flow rate of 5 cfs is included in Figure 5-19.

A relatively moderate degree of variability was observed in measured concentrations of TSS and turbidity in discharges from the TST unit at a flow rate of 5 cfs, with a mean TSS concentration of 13.8 mg/l and a mean turbidity of 6.5 NTU. A moderate degree of variability is also apparent in measured concentrations for TOC and DOC, with a mean TOC of 37.6 mg/l and a mean DOC of 36.3 mg/l. A graphical comparison of TSS, turbidity, DOC, and TOC in the inflow and outflow for the TST unit at a flow rate of 5 cfs is included in Figure 5-21.

5.3.2.2.2 Concentration-Based Removal Efficiencies

A summary of changes in concentrations within the TST unit during operation at 5 cfs is given in Table 5-22. A high degree of variability is apparent for inflow and outflow concentrations in the TST unit for many of the measured parameters. Decreases in concentrations were observed for dissolved organic nitrogen and particulate nitrogen for most events. However, overall removal of total nitrogen within the baffle box ranged from -15% to 25% during the testing performed at 5 cfs.

TABLE 5-22

CONCENTRATION-BASED REMOVAL FOR THE TST UNIT DURING OPERATION AT 5 cfs

PERIOD OF OPERATION	REMOVAL (%)										
	Diss Org N	Part N	TN	OP	Diss Org P	Part P	TP	TSS	Turb	TOC	DOC
6/27-7/3/03	5	-25	-15	-3	0	3	-2	-19	5	-9	-7
7/10-16/03	1	13	0	0	20	-12	-1	14	21	8	2
7/31-8/6/03	-10	24	-5	1	33	-21	1	-96	-18	-6	-4
8/12-19/03	32	20	25	0	-42	24	0	-2	-17	7	-4
8/21-27/03	-3	-18	-3	-1	-38	51	4	-16	-49	-3	-12

A similar pattern is apparent for measured phosphorus species within the baffle box structure. Relatively little change was observed in orthophosphorus concentrations during a majority of the monitoring events. However, substantial reductions in concentrations of dissolved organic phosphorus and particulate phosphorus were observed during some events, with increases in concentrations observed during other events. Overall, changes in total phosphorus concentrations within the baffle box at a flow rate of 5 cfs ranged from -2% to 4%.

A high degree of variability is also apparent in concentrations of TSS and turbidity during migration through the baffle box structure. TSS concentrations increased from the inflow to the outflow during four of the five events, with turbidity increasing during three of the five events.

These increases are probably due to resuspension of previously accumulated materials within the baffle box at the higher flow rate of 5 cfs. Relatively little change was observed in measured concentrations of TOC or DOC during migration through the baffle box.

5.3.2.2.3 Mass Removal Efficiencies

A summary of calculated mass removal efficiencies for the TST unit during operation at 5 cfs is given in Table 5-23. Overall, migration through the baffle box resulted in a 7% increase in mass of dissolved organic nitrogen and a 12% decrease in mass of particulate nitrogen. Total nitrogen was reduced by approximately 4% during migration through the TST unit. For phosphorus species, the mass of orthophosphorus remained unchanged, with a 4% increase in mass of dissolved organic phosphorus, and an 18% decrease in mass of particulate phosphorus. However, since the majority of phosphorus species are present as dissolved orthophosphorus, the removal of total phosphorus within the TST unit is estimated to be approximately 1%. The mass of TSS increased by approximately 27% during migration through the baffle box, presumably resulting from washout of accumulated pollutants from previous studies.

TABLE 5-23

MASS REMOVAL FOR THE TST UNIT DURING OPERATION AT 5 cfs

PERIOD OF OPERATION	MASS REMOVAL (%)										
	Diss Org N	Part N	TN	OP	Diss Org P	Part P	TP	TSS	Turb	TOC	DOC
6/27-7/3/03	5	-25	-15	-3	0	3	-2	-19	5	-7	-7
7/10-16/03	1	13	0	0	20	-12	-1	14	21	2	2
7/31-8/6/03	-10	24	-5	1	33	-21	1	-96	-18	-4	-4
8/12-19/03	32	20	25	0	-42	24	0	-2	-17	-4	-4
8/21-27/03	-3	-18	-3	-1	-38	51	4	-16	-49	-12	-12
Overall	7	12	4	0	-4	18	1	-27	-14	-5	-5

5.3.2.3 Performance Efficiency During Operation at 11 cfs

5.3.2.3.1 Chemical Characteristics of Outflow Samples

Chemical characteristics of TST outflow samples with the system operating at 11 cfs are given in Table 5-24. Similar to the trends discussed for discharges at 5 cfs, discharges from the TST unit at 11 cfs are characterized by a moderate degree of variability for nitrogen species. Approximately 83% of the total nitrogen measured in discharges from the TST at 11 cfs consists of dissolved nitrogen species, with 17% contributed by particulate nitrogen species. A graphical comparison of nitrogen species in the inflow and outflow for the TST unit at a flow rate of 11 cfs is included in Figure 5-20.

TABLE 5-24

CHEMICAL CHARACTERISTICS OF TST OUTFLOW SAMPLES WITH SYSTEM OPERATING AT 11 cfs

PERIOD OF OPERATION	PARAMETER													
	pH (s.u.)	Temp (EC)	TKN (µg/l)	Diss. Org N (µg/l)	Part N (µg/l)	TN (µg/l)	OP (µg/l)	Org P (µg/l)	Part P (µg/l)	TP (µg/l)	TSS (mg/l)	Turb (NTU)	TOC (mg/l)	DOC (mg/l)
8/27-9/4/03	7.03	31.4	2495	1979	261	2561	1230	64	27	1321	12.4	4.3	51.6	39.1
10/6-9/03	6.73	31.7	3394	2129	680	3437	1276	126	399	1801	64.3	12.2	35.1	34.9
10/9-14/03	6.84	30.1	2469	1371	599	2619	964	123	229	1316	25.9	6.0	34.8	32.8
10/14-17/03	6.93	31.3	1995	1213	356	2412	717	266	64	1047	20.8	4.8	33.9	33.2
Mean	6.88	31.1	2588	1673	474	2757	1047	145	180	1371	30.9	6.8	38.9	35.0
95% C.I.	6.68-7.09	30.0-32.2	1812-3422	959-2387	159-789	2023-3491	634-1459	53-187	0-451	872-1870	0-67.4	1.0-12.6	25.3-52.4	30.4-39.6

The dominant phosphorus species in discharges from the TST unit at 11 cfs appears to be orthophosphorus, with substantially smaller contributions from organic phosphorus and particulate phosphorus. Orthophosphorus concentrations in discharges from the TST unit were found to be somewhat elevated, ranging from 717-1276 µg/l. Concentrations of particulate phosphorus ranged from 27-399 µg/l. On an average basis, approximately 85% of the total phosphorus discharging from the TST unit was dissolved in nature, with 15% consisting of particulate phosphorus species. A graphical comparison of phosphorus species in the inflow and outflow for the TST unit at a flow rate of 5 cfs is included in Figure 5-19.

A relatively high degree of variability was observed in concentrations of both TSS and turbidity in discharges from the TST unit at 11 cfs. Measured TSS concentrations in the discharge range from 12.4-64.3 mg/l, with an overall mean of 30.9 mg/l. Measured turbidity values range from 4.3-12.2 NTU, with an overall mean of 6.8 NTU. A graphical comparison of TSS, turbidity, DOC, and TOC in the inflow and outflow for the TST unit at a flow rate of 5 cfs is included in Figure 5-21.

5.3.2.3.2 Concentration-Based Efficiencies

Changes in concentrations during migration through the baffle box at a flow rate of 11 cfs are summarized in Table 5-25. Concentration changes for nitrogen species appear to be highly variable, with concentration increases observed for some sampling events and decreases in concentration observed during other sampling events. For phosphorus species, orthophosphorus concentrations appear to increase during three of the four monitoring intervals, with decreases in dissolved organic phosphorus during three of the four monitoring intervals, and equal numbers of increases and decreases for particulate phosphorus. Overall, total phosphorus concentrations in the outflow from the baffle box increased slightly during three of the four monitoring events. Similarly, concentrations of TSS and turbidity also increased during a majority of the monitored events during migration through the TST unit.

TABLE 5-25

CONCENTRATION-BASED REMOVAL FOR THE TST UNIT DURING OPERATION AT 11 cfs

PERIOD OF OPERATION	REMOVAL (%)										
	Diss Org N	Part N	TN	OP	Diss Org P	Part P	TP	TSS	Turb	TOC	DOC
8/27-9/4/03	7	4	4	-6	24	47	-2	-19	0	-16	7
10/6-9/03	-27	9	-14	-6	46	-48	-5	-36	-23	7	-6
10/9-14/03	3	32	12	-4	-21	34	4	50	33	0	2
10/14-17/03	-14	-37	0	2	23	-31	-5	-362	-78	-1	-4

5.3.2.3.3 Mass Removal Efficiencies

Mass removal efficiencies during migration through the baffle box are indicated on Table 5-26. On a mass basis, no significant change was observed for input mass of dissolved organic nitrogen within the TST unit. However, a 12% reduction in the mass of particulate nitrogen was observed, resulting in an overall decrease of 1% in mass of total nitrogen within the unit. For phosphorus species, a 5% increase in mass was observed for orthophosphorus, with a 21% decrease for dissolved organic phosphorus and a 2% decrease for particulate phosphorus. Overall, the mass of total phosphorus increased by approximately 1% during migration through the TST unit. No significant changes in mass of TSS or DOC were observed within the TST unit during operation at 11 cfs.

TABLE 5-26

MASS REMOVAL FOR THE TST UNIT DURING OPERATION AT 11 cfs

PERIOD OF OPERATION	MASS REMOVAL (%)										
	Diss Org N	Part N	TN	OP	Diss Org P	Part P	TP	TSS	Turb	TOC	DOC
8/27-9/4/03	7	4	4	-6	24	47	-2	-19	0	-16	7
10/6-19/03	-27	9	-14	-6	46	-48	-5	-36	-23	7	-6
10/9-14/03	3	32	12	-4	-21	34	4	50	33	0	2
10/14-17/03	-14	-37	-10	2	-23	-31	-5	-362	-78	-1	-4
Overall	-1	15	2	-5	9	11	-1	2	1	-7	2

5.3.3 Comparative Removal Efficiencies for the CDS and TST Units

A graphical comparison of mass removal efficiencies for phosphorus species at flow rates of 1, 5, and 11 cfs in the CDS and TST units is given in Figure 5-22. For orthophosphorus, the CDS unit exhibited negative mass removal efficiencies ranging from approximately -1% to -4% at each of the three evaluated flow rates. The TST unit exhibited a positive mass removal of approximately 5% for orthophosphorus at a flow rate of 1 cfs, with negative removals observed at higher flow rates.

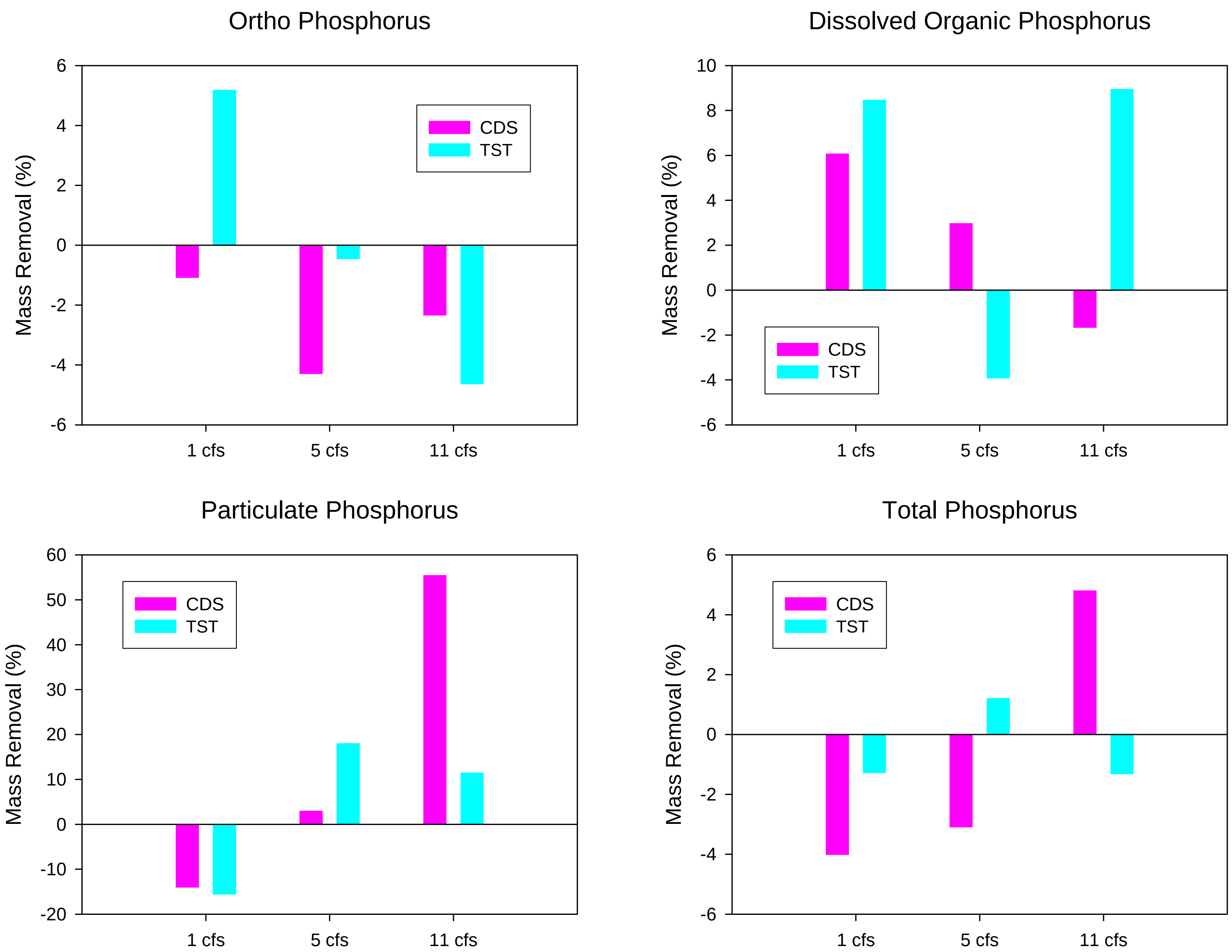


Figure 5-22. Comparative Mass Removal Efficiencies for Phosphorus Species in the CDS and TST Units.

However, differences between the observed flow rates are not statistically significant. Mass removal for dissolved organic phosphorus species also exhibited both positive and negative removal efficiencies in both the CDS and TST units. None of the observed removals for dissolved organic phosphorus are statistically significant.

Particulate phosphorus species exhibited a negative mass removal of approximately 15% in both the CDS and TST units during operation at 1 cfs. However, at higher flow rates, positive mass removals were observed in each unit, with a mass removal of approximately 55% for particulate phosphorus observed in the CDS unit at a flow rate of 11 cfs. However, removal of total phosphorus was highly variable within each of the two units. Total phosphorus removal ranged from -4% to 5% in the CDS unit, with removals ranging from approximately -1% to 1% in the TST unit. However, none of the observed total phosphorus mass removals are statistically significant, indicating that neither of the two units exhibited a statistically significant phosphorus removal.

Comparative mass removal efficiencies for nitrogen species in the CDS and TST units are illustrated in Figure 5-23. Mass removal for dissolved organic nitrogen was found to be highly variable in each of the two units, with mass removal efficiencies ranging from -8% to approximately 8%, depending upon the flow rate. Mass removal for particulate nitrogen in the two test units appears to be similar to that observed for particulate phosphorus, with no significant removal efficiency observed at 1 cfs and higher removal efficiencies observed at 5 cfs and 11 cfs. Overall, the CDS unit appeared to exhibit a higher degree of particulate nitrogen removal than the TST unit, although the differences between the CDS and TST removal efficiencies for particulate nitrogen are not statistically significant. Overall, each of the two units exhibited a small negative mass removal efficiency for total nitrogen at 1 cfs, with positive mass removal efficiencies observed at 5 cfs and 11 cfs. However, differences between the CDS and TST units indicated in Figure 5-23 are not statistically significant.

Comparative mass removal efficiencies for TSS and turbidity in the CDS and TST units are illustrated on Figure 5-24. The CDS and TST units exhibited a slight positive mass removal efficiency at 1 cfs, with a negative removal efficiency observed at 5 cfs and a positive removal

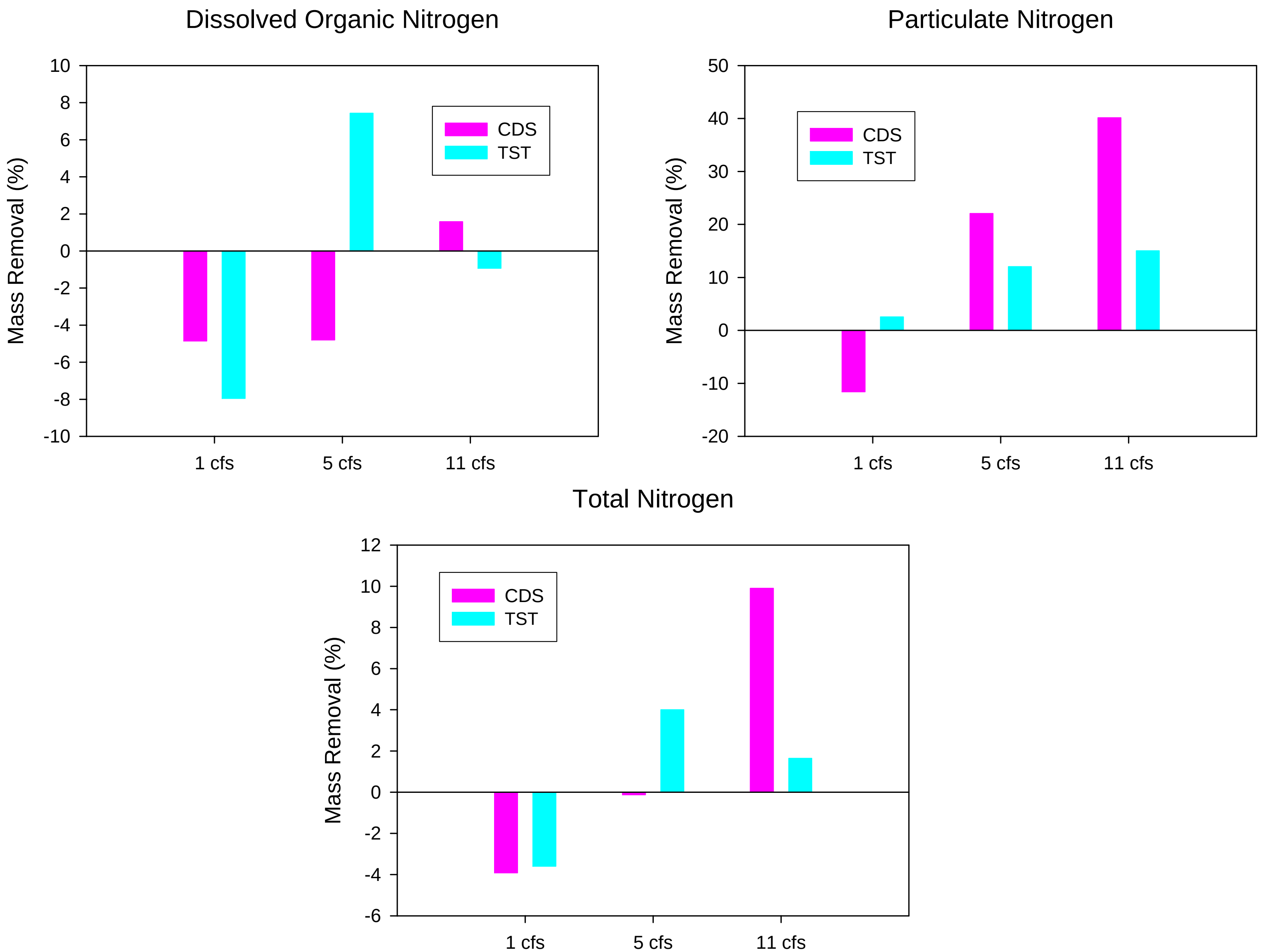


Figure 5-23. Comparative Mass Removal Efficiencies for Nitrogen Species in the CDS and TST Units.

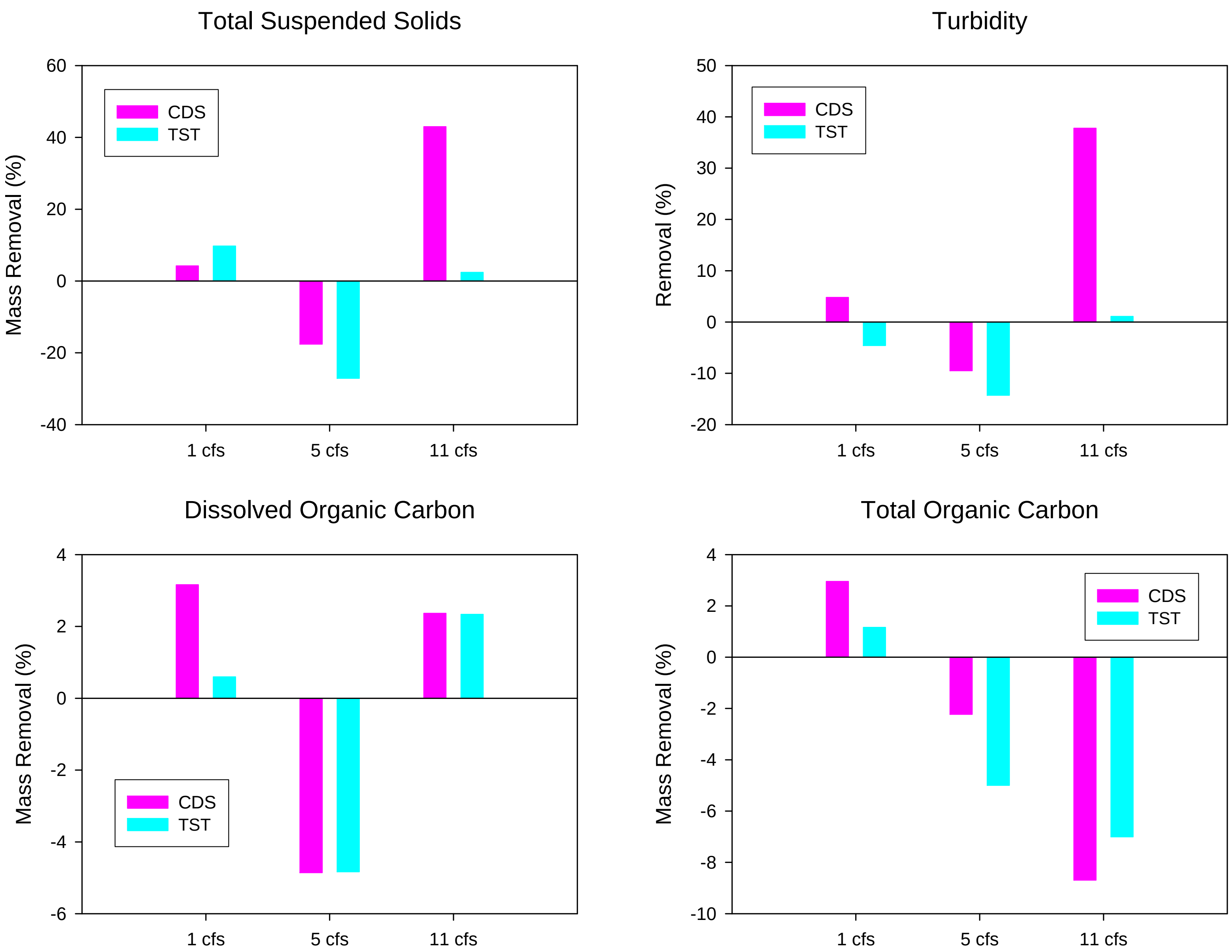


Figure 5-24. Comparative Mass Removal Efficiencies for TSS, Turbidity, DOC and TOC in the CDS and TST Units.

efficiency observed at 11 cfs. A similar pattern of mass removal is apparent for turbidity. In general, the observed differences in removal efficiencies for TSS and turbidity between the CDS and TST units are not statistically significant.

Highly variable mass removal efficiencies were observed for both DOC and TOC each of the two units. Positive mass removal efficiencies were observed for DOC in each of the two units at 1 cfs and 11 cfs, with a negative removal efficiency observed at 5 cfs. Positive mass removal efficiencies were observed for TOC at 1 cfs, with negative mass removal efficiencies observed at 5 cfs and 11 cfs. However, in general, the differences in observed mass removal efficiencies between the two units are not statistically significant.

5.4 Characteristics of Collected TST and CDS Sediments

Accumulated sediments were removed from the TST and CDS units on a periodic basis. Sediment removal was performed on the TST unit on June 13 and August 19-21, 2003. Sediment removal from the CDS unit was performed on three separate occasions, including June 13, August 19-21, and September 9, 2003. During each cleaning operation, the quantity of sediments removed from both the TST and CDS units was quantified, and a representative sample was returned to the ERD Laboratory for further evaluation.

Sediment removal in the TST and CDS units was conducted manually by ERD personnel. During a typical clean-out operation, the inflow and outflow to the TST and CDS units would be closed using the inflow and outflow sluice gates. The water within each unit was pumped down to leave approximately 6-12 inches. A field technician then entered the unit and collected the accumulated sediments using a broad flat shovel. The accumulated sediments were placed into a plastic 5-gallon bucket which was lifted to the surface by rope. The collected sediments from each unit were placed into separate 150-gallon polyethylene containers for quantification of the volume of material collected and collection of a well-mixed sub-sample for subsequent laboratory analyses. Photographs of typical sediment clean-out operations in the CDS and TST units are given in Figure 5-25.

a. TST Unit.

b. CDS Unit.

Figure 5-25. Sediment Clean-Out Operations.

Material removed from the TST unit had a mean moisture content of approximately 34.5% and a wet density of 1.96 kg/liter. After drying, a total of 68.4 kg of dry material was removed from the TST unit on June 13, 2003, with 340.4 kg of dry material removed on August 20, 2003. Material removed from the CDS unit was characterized by a moisture content of 39.3% and a wet density of 1.82 kg/liter. After drying, approximately 91.2 kg of dry solids was removed from the CDS unit on June 13, with 281.4 kg of dry solids removed from August 19-21, and 393.6 kg of dry solids removed on September 9, 2003.

From a maintenance perspective, removal of sediments from the TST unit was somewhat easier than removal of sediments from the CDS unit due to the larger working area, easier access, and the straight sidewalls which made sediment removal by shovel easier. In contrast, the sump of the CDS unit was approximately 25 ft below the land surface, making access substantially more difficult. This depth also made pumping more difficult, particularly when the water level was near the bottom of the unit. In addition, the circular walls of the unit made manual sediment removal substantially more difficult. However, manual removal of sediment was necessary so that the volume and characteristics of collected sediments could be quantified. In a real-world installation, sediment removal would probably be achieved using a vacuum-type truck which would minimize these differences, although the vacuum trucks may still have difficulty removing sediments from the deep sump of the CDS unit.

Characteristics of sediment fractions removed from the TST unit during June and August 2003 are given in Table 5-27. Analyses performed on the collected sediment samples include particle size, organic content, and nutrient content. As seen in Table 5-27, the majority of samples collected within the TST unit are within the range of 100-250 microns. Removal efficiencies for particles less than 100 microns appear to drop-off rapidly. Particles larger than 250 microns collected within the TST unit primarily reflect vegetation which has been trapped within the unit. Particles in the range of 100-250 microns exhibit the lowest organic content and lowest concentrations of nitrogen and phosphorus of any particles collected within the unit. Substantially larger concentrations for organic content, total nitrogen, and total phosphorus are present in larger and smaller particles which are collected at a relatively low percentage within the unit. Material collected from the TST unit on June 13 contained 0.073 kg of total phosphorus, with 0.491 kg of total phosphorus collected on August 20, 2003.

TABLE 5-27

CHARACTERISTICS OF SEDIMENT FRACTIONS REMOVED FROM THE TST UNIT DURING JUNE AND AUGUST 2003

COLLECTION DATE	PARTICLE SIZE (microns)	SEDIMENT FRACTION (% by weight)	SEDIMENT WEIGHT (kg dry weight)	ORGANIC CONTENT (%)	TOTAL PHOSPHORUS		TOTAL NITROGEN	
					(µg/g dry)	(kg)	(µg/g dry)	(kg)
6/13/03	2000	0.5	0.34	69.7	5,954	0.002	24,080	0.008
	850	0.6	0.40	27.2	6,677	0.003	24,781	0.010
	425	2.8	1.93	13.8	3,441	0.007	10,571	0.020
	250	3.1	2.12	3.9	2,343	0.005	5,207	0.011
	180	3.5	2.41	0.7	146	0.000	469	0.001
	150	51.5	35.20	1.6	15	0.001	39	0.001
	100	28.9	19.75	33.0	54	0.001	86	0.002
	60	3.0	2.02	28.7	250	0.001	1,450	0.003
	30	1.2	0.80	28.9	2,396	0.002	7,684	0.006
	11	2.2	1.50	29.3	6,733	0.010	1,333	0.002
	< 11	2.8	1.92	28.9	22,043	0.042	39,971	0.077
		TOTALS:	68.40			0.073		0.142
8/20/03	2000	0.8	2.83	75.1	3,003	0.009	14,322	0.041
	850	1.5	5.19	26.0	9,973	0.052	15,667	0.081
	425	3.7	12.63	18.0	6,086	0.077	5,250	0.066
	250	25.1	85.28	1.7	1,389	0.118	732	0.062
	180	48.1	163.64	2.6	935	0.153	676	0.111
	150	7.2	24.60	2.1	887	0.022	606	0.015
	100	11.1	37.81	0.5	32	0.001	28	0.001
	60	1.2	4.17	3.7	476	0.002	357	0.001
	30	0.4	1.32	19.4	3,219	0.004	3,387	0.004
	11	0.1	0.48	31.8	1,793	0.001	9,456	0.004
	< 11	0.7	2.46	32.6	21,424	0.053	9,221	0.023
		TOTALS:	340.40			0.491		0.410

Characteristics of sediment fractions removed from the CDS unit in June, August, and September 2003 are given in Table 5-28. The vast majority of particles collected within the CDS unit are in the 100-425 micron range, with relatively few particles above and below this range. Similar to the trends observed within the TST unit, particles within the 100-425 micron range are characterized by relatively low organic content and low concentrations of total nitrogen and total phosphorus. Substantially higher concentrations of nutrients are present in particles larger and smaller than the optimum range. Particles larger than the optimum range reflect primarily

TABLE 5-28

CHARACTERISTICS OF SEDIMENT REMOVED FROM THE CDS UNIT DURING JUNE, AUGUST, AND SEPTEMBER 2003

COLLECTION DATE	PARTICLE SIZE (microns)	SEDIMENT FRACTION (% by weight)	SEDIMENT WEIGHT (kg dry weight)	ORGANIC CONTENT (%)	TOTAL PHOSPHORUS		TOTAL NITROGEN	
					(µg/g dry)	(kg)	(µg/g dry)	(kg)
6/13/03	2000	3.0	2.76	68.2	8,788	0.024	22,616	0.063
	850	4.8	4.41	26.6	3,160	0.014	31,876	0.140
	425	31.0	28.28	15.6	2,974	0.084	9,122	0.258
	250	3.5	3.23	2.6	2,481	0.008	7,273	0.024
	180	13.7	12.51	0.9	1,116	0.014	1,831	0.023
	150	13.3	12.10	0.6	874	0.011	1,406	0.017
	100	25.4	23.16	0.5	19	0.000	82	0.002
	60	1.3	1.21	5.3	573	0.001	961	0.001
	30	0.6	0.53	30.4	1,535	0.001	3,035	0.002
	11	1.6	1.50	25.1	8,252	0.012	12,157	0.018
	< 11	1.7	1.51	33.7	11,752	0.018	15,896	0.024
		TOTALS:	91.20			0.187		0.571
8/19-21/03	2000	1.8	5.10	65.2	7,479	0.038	28,571	0.146
	850	4.5	12.57	30.0	10,877	0.137	28,637	0.360
	425	10.8	30.53	15.0	5,244	0.160	19,324	0.590
	250	19.8	55.70	4.3	2,079	0.116	7,181	0.400
	180	35.5	99.97	0.1	834	0.083	2,378	0.238
	150	10.5	29.42	0.5	820	0.024	1,553	0.046
	100	13.5	37.88	0.5	22	0.001	28	0.001
	60	1.1	3.08	3.6	193	0.001	368	0.001
	30	0.5	1.45	14.5	1,034	0.002	1,782	0.003
	11	0.9	2.51	18.2	3,171	0.008	5,897	0.015
	< 11	1.1	3.19	31.0	9,213	0.029	13,016	0.041
		TOTALS:	281.40			0.599		1.840
9/9/03	2000	< 0.1	0.18	75.1	6,402	0.001	38,402	0.007
	850	1.0	4.00	26.0	5,366	0.021	28,497	0.114
	425	50.0	196.87	18.0	696	0.137	2,714	0.534
	250	28.5	112.34	1.7	1,062	0.119	1,937	0.218
	180	9.7	38.37	2.6	458	0.018	1,328	0.051
	150	2.5	9.92	2.1	454	0.005	1,166	0.012
	100	6.5	25.69	0.6	8	0.000	37	0.001
	60	0.7	2.57	5.0	231	0.001	584	0.001
	30	0.2	0.72	14.7	1,742	0.001	2,270	0.002
	11	0.3	1.35	25.0	4,057	0.005	10,099	0.014
	< 11	0.4	1.59	34.1	7,048	0.011	13,474	0.021
		TOTALS:	393.60			0.320		0.975

vegetation and detritus which settles within the unit. Material collected from the CDS unit on June 13 contained 0.187 kg of total phosphorus, with 0.599 kg collected on August 19-21, and 0.320 kg collected on September 9, 2003.

A particle size distribution of suspended solids removed from the CDS and TST units is given in Figure 5-26. Solids collected from the CDS unit were primarily in the 100-425 µm size range. Relatively little of the collected solids from the CDS unit were either above or below this particle size. Suspended solids removed from the TST unit were primarily located in the 100-250 µm range, with little accumulation of solids either above or below these values.

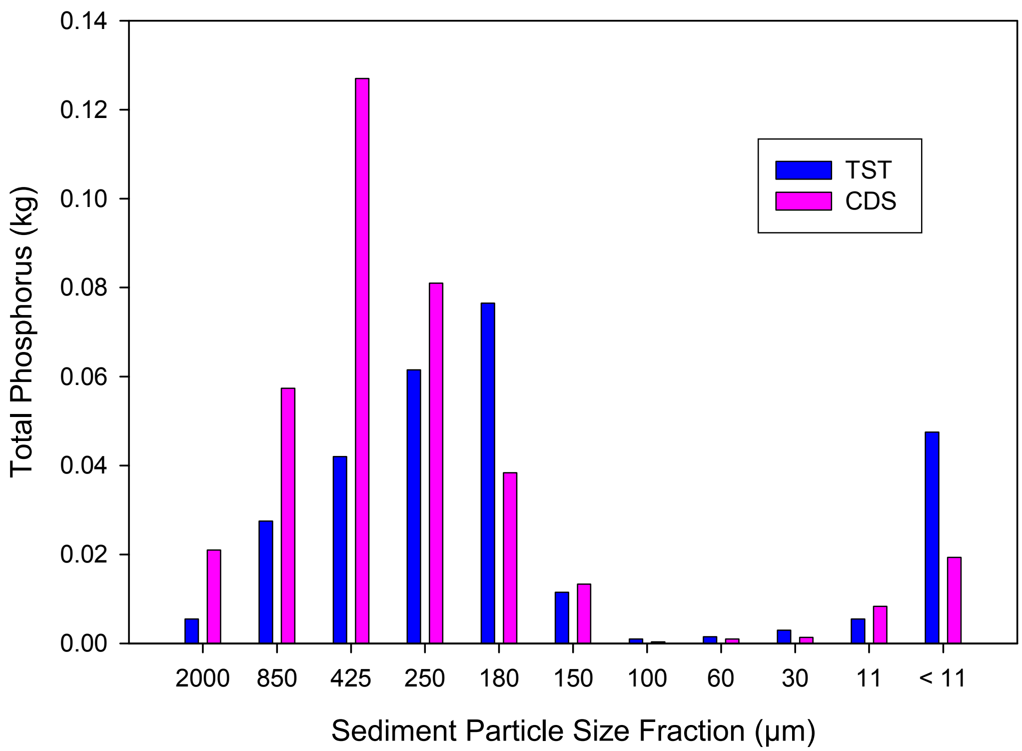


Figure 5-26. Particle Size Distribution of Suspended Solids Removed from the CDS and TST Units.

Based upon this information, it appears that the units are approximately equal in terms of collecting particles less than 100 µm in size and greater than 850 µm in size. However, between these ranges, the CDS unit appears to collect a wider range of particles, while the TST unit collects a smaller range of particle sizes.

Size distributions of phosphorus particles removed from the CDS and TST units are illustrated on Figure 5-27. Virtually all of the phosphorus particles removed from the two units were located in the 150->2000 µm range and in the less than 11 µm range. The CDS unit collected a substantially larger quantity of sediments in the >2000, 850, 425, 250, 150, and 11 µm ranges, while the TST unit collected more solids in the 180 and < 11 µm ranges.

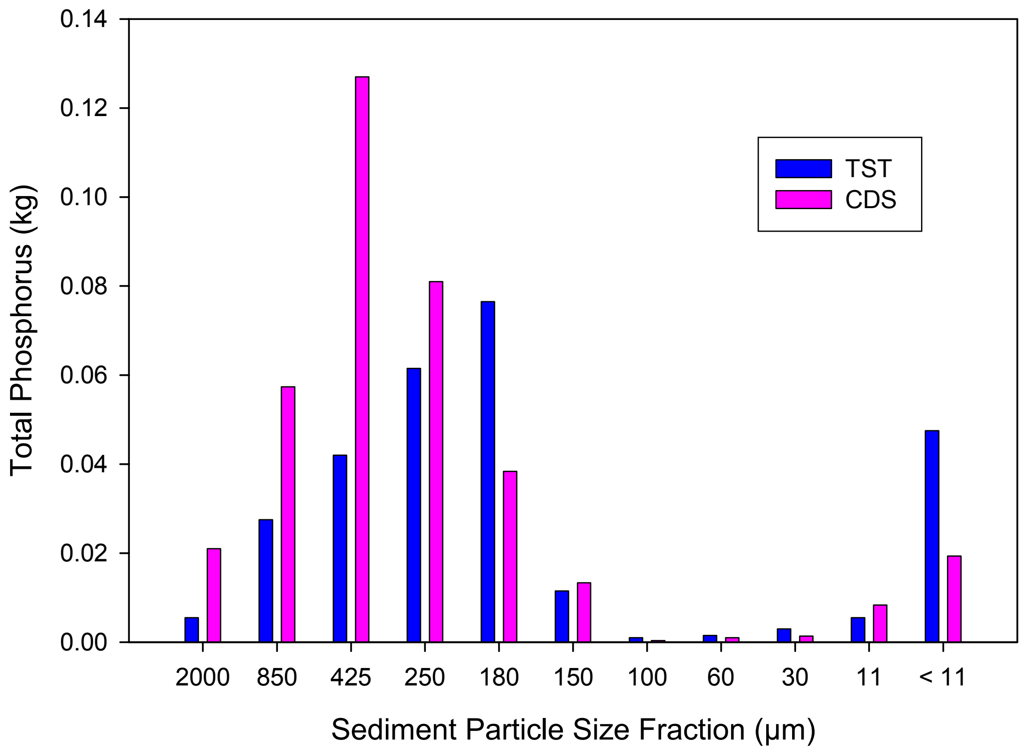


Figure 5-27. Size Distribution of Phosphorus Particles Removed from the CDS and TST Units.

Size distributions of nitrogen particles removed from the CDS and TST units are given in Figure 5-28. With the exception of the <11 μm range, the CDS unit removed substantially more nitrogen mass than the TST unit in each of the evaluated particle size fractions.

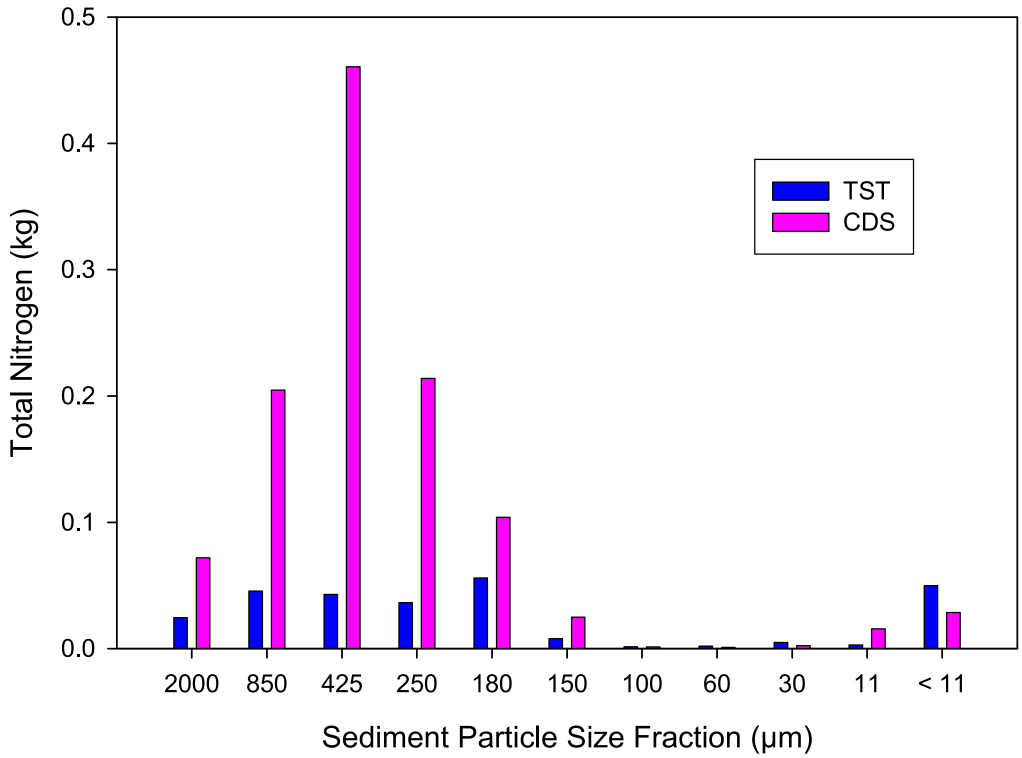


Figure 5-28. Size Distribution of Nitrogen Particles Removed from the CDS and TST Units.

A summary of the total mass of solids, phosphorus, and nitrogen removed from the TST and CDS units during the field monitoring program is given in Table 5-29. A total of 408.8 kg of dry solids was removed from the TST unit on the two occasions when sediment was removed. This removed sediment contained approximately 0.564 kg of total phosphorus and 0.552 kg of total nitrogen, equivalent to approximately 0.14% total phosphorus by weight and 0.14% total nitrogen by weight.

TABLE 5-29

SUMMARY OF TOTAL MASS OF SOLIDS REMOVED FROM THE TST AND CDS UNITS

UNIT	TOTAL SOLIDS (kg dry weight)	TOTAL P (kg dry weight)	TOTAL N (kg dry weight)
TST			
6/13/03	68.4	0.073	0.142
8/20/03	340.4	0.491	0.410
Totals:	408.8	0.564 (0.14% by weight)	0.552 (0.14% by weight)
CDS			
6/13/03	91.2	0.187	0.571
8/19-21/03	281.4	0.599	1.840
9/9/03	393.6	0.320	0.975
Totals:	766.2	1.106 (0.14% by weight)	3.386 (0.44% by weight)

A total of 766.2 kg of dry solids was removed from the CDS unit. The solids contained approximately 1.106 kg of total phosphorus and 3.386 kg of total nitrogen. On a percentage basis, the collected total solids contained 0.14% total phosphorus and 0.44% total nitrogen. It is interesting to note that the percentage of total phosphorus contained in solids collected by the two units is identical.

During the field monitoring program, the CDS unit collected almost twice as much total solids as the TST unit. This difference is probably related to differences in the physical design of each of the two units, as well as the slightly longer accumulation time within the CDS unit. In addition, solids which accumulate in the TST unit can be resuspended when the flow rate discharging through the unit is increased substantially, and solids which were previously collected may be remobilized and discharged from the structure. In contrast, solids collected by the CDS unit are retained in a deep sump area. It is extremely unlikely that solids within the sump could ever be resuspended and discharged from the CDS unit following collection. As a result, the solids retention capability of the CDS unit appears to be superior to that of the TST unit.

A summary of mean removal characteristics of the CDS and TST units is given in Table 5-30. Initial field experimentation at the Lettuce Creek site was initiated on November 15, 2002. Between this date and the final date of sediment collection from the CDS unit (September 9, 2003), a total of 815.2 ac-ft of water from Lettuce Creek had passed through the CDS unit, and a total of 766.2 kg of dry solids was collected. These solids contained a total of 1.106 kg of total phosphorus and 3.306 kg of total nitrogen. These values equate to a mean TSS removed concentration of 0.76 mg/l, with a mean total phosphorus concentration removal of 1.1 μg/l and mean total nitrogen concentration removal of 3.4 μg/l. These calculated concentrations are extremely low in value and are at or below the limits of detection for the TSS, total nitrogen, and total phosphorus tests. These findings are consistent with the lack of significant removals for TSS, total phosphorus, or total nitrogen measured within the CDS unit.

TABLE 5-30

MEAN REMOVAL CHARACTERISTICS OF THE CDS AND TST UNITS

PARAMETER	CDS UNIT	TST UNIT
Total Flow Through Unit	815.2[1] ac-ft 1,006,307 m^3	581.2[2] ac-ft 717,451 m^3
Mean TSS Concentration Removed	0.76 mg/l	0.57 mg/l
Mean Total Phosphorus Concentration Removed	1.1 μg/l 0.001 mg/l	0.79 μg/l 0.00079 mg/l
Mean Total Nitrogen Concentration Removed	3.4 μg/l 0.0034 mg/l	0.77 μg/l 0.00077 mg/l

1. Total flow through CDS unit from 11/15/02-9/9/03
2. Total flow through TST unit from 11/15/02-8/20/03

From the initiation of experimentation on 11/15/02 to the final sediment clean-out date of 8/20/03, approximately 581.2 ac-ft of water from Lettuce Creek was discharged through the TST unit. Over this period, the TST unit removed approximately 408.8 kg of dry solids, 0.564 kg of total phosphorus, and 0.552 kg of total nitrogen. These mass removals correspond to a mean removed TSS concentration of 0.57 mg/l, with a mean total phosphorus removed concentration of 0.79 μg/l and a mean total nitrogen removal of 0.77 μg/l. Each of these values is substantially lower than the minimum detection limits for the expected laboratory analyses. As a result, it would be virtually impossible to detect these differences in concentrations between the inflow and outflow of the TST unit.

5.5 Lettuce Creek Sediment Characteristics

Sediment core samples were collected along three separate transects in upstream portions of Lettuce Creek during July, August, and October 2003 to evaluate general sediment characteristics and to investigate the potential for sediment migration during periods of high flow within Lettuce Creek. Locations of sediment core collection sites in Lettuce Creek are indicated on Figure 3-6. The monitoring sites indicated on Figure 3-6 are the same sites utilized by ERD for collection of Lettuce Creek sediment core samples throughout this project.

Characteristics of sediment core samples collected in upstream portions of Lettuce Creek during July, August, and October are summarized in Table 5-31. Analyses were conducted for measurements of sediment pH, moisture content, organic content, total nitrogen, and total phosphorus. Separate analyses were conducted for the 0-1 inch layer and the 1-6 inch layer for the four monitoring events performed at each site. In general, sediments within Lettuce Creek are characterized by pH values ranging from approximately 5.5-6.5, with relatively low levels of both moisture content and organic content. The characteristics summarized in Table 5-31 are typical of sediments which are primarily inorganic in nature.

Substantial reductions in measured total phosphorus concentrations were observed in the 0-1 inch layer at each of the three sites during the period from July-October 2003. During this period, sediment phosphorus concentrations at Site 1 decreased from 1732 μg/g to 127 μg/g, with a reduction from 701 μg/g to 197 μg/g at Site 3. Surficial sediment concentrations at Site 2 decreased from 292 μg/g to 209 μg/g from July 24 to August 27 before increasing to 246 μg/g on October 9,

2003. These decreases in sediment phosphorus concentrations in the 0-1 inch layer suggest mobilization and transport of surficial phosphorus within the sediments over this period. As seen in Figure 5-3, Lettuce Creek flow rates increased to approximately 50 cfs between the July 24 and July 31 monitoring events, with flow rates of approximately 150 cfs between the July 31 and August 27 monitoring dates, and flows in excess of 450 cfs between the August 27 and October 9 monitoring dates. It appears that these flows mobilized substantial quantities of previously deposited sediment phosphorus over this period. This trend is also apparent for sediment nitrogen concentrations at monitoring Sites 1 and 3, although the reverse trend appears to be present at Site 2.

TABLE 5-31

CHARACTERISTICS OF SEDIMENT CORE SAMPLES COLLECTED IN UPSTREAM PORTIONS OF LETTUCE CREEK DURING JULY, AUGUST, AND OCTOBER 2003

SEDIMENT DEPTH (inches)	SITE	DATE	pH (s.u.)	MOISTURE CONTENT (%)	ORGANIC CONTENT (%)	TN (µg/g wet wt)	TP (µg/g wet wt)
0-1	1	7/24/03	6.18	38.4	3.3	7206	1732
		7/31/03	6.03	42.0	3.2	3405	668
		8/27/03	6.07	24.2	1.0	1782	366
		10/9/03	6.27	23.1	0.2	236	127
	2	7/24/03	6.43	21.6	0.7	929	292
		7/31/03	6.18	26.2	0.3	572	222
		8/27/03	5.67	27.0	0.6	1028	209
		10/9/03	6.32	39.7	1.2	1488	246
	3	7/24/03	6.33	31.0	1.7	3202	702
		7/31/03	6.25	29.8	0.9	1492	432
		8/27/03	5.64	43.6	3.0	1412	267
		10/9/03	6.50	42.0	0.9	636	197
1-6	1	7/24/03	6.29	25.1	1.3	2246	807
		7/31/03	6.28	27.0	1.4	1660	349
		8/27/03	6.53	26.8	1.1	1746	361
		10/9/03	6.18	20.6	0.2	1170	111
	2	7/24/03	6.21	24.1	0.1	191	130
		7/31/03	6.49	25.8	0.2	333	168
		8/27/03	5.38	26.8	1.1	2170	409
		10/9/03	6.36	32.3	2.4	4183	584
	3	7/24/03	6.52	18.8	0.1	212	100
		7/31/03	6.08	29.2	1.2	1504	359
		8/27/03	5.66	28.4	1.9	2629	413
		10/9/03	6.58	60.3	2.2	1549	145

A significant trend of decreasing sediment nutrient concentrations is not apparent in the 1-6 inch sediment layer. This behavior suggests that sediment transport may be limited to the top 0-1 inch layer of sediments within Lettuce Creek.

5.6 Economic Analysis

An economic analysis was performed to estimate the cost per mass removal for suspended solids, total phosphorus, and total nitrogen in the CDS and TST units installed at the Lettuce Creek site. Approximate construction costs for the CDS and TST units are given in Table 5-32. The installed cost for the CDS structure unit is approximately $67,310, while the installed cost for the TST unit is approximately $38,300. Additional miscellaneous connecting structures, gate valves, and labor is estimated to be $49,374 for the CDS unit and $32,916 for the TST unit. The total installed cost for the two units, as utilized in this project, is approximately $116,684 for the CDS unit and $71,216 for the TST unit.

TABLE 5-32

APPROXIMATE CAPITAL CONSTRUCTION COSTS FOR THE CDS AND TST UNITS

ITEM	COST ($)	
	CDS UNIT	TST UNIT
Installed Structure Cost	67,310	38,300
Miscellaneous Structures, Valves, Labor, etc.	49,374	32,916
TOTALS:	**$ 116,684**	**$ 71,216**

Estimates of costs per mass pollutant removal are typically based upon life-cycle costs which include the initial capital costs plus maintenance activities over a period of years, generally considered to be 20 years. A summary of estimated O&M costs for the CDS and TST units is given in Table 5-33. During an operational period of 207 days, the CDS unit collected approximately 766.2 kg of dry solids. The extrapolation of this value to an annual period of 365 days indicates that the CDS unit would collect approximately 1351 kg of dry solids during an annual period. Based on the measured moisture content of 39.3%, this equates to approximately 2226 kg/yr of wet solids or 2.45 tons of wet material. At a disposal cost of $100/ton, annual disposal of the material collected within the CDS unit would be approximately $245.

TABLE 5-33

ESTIMATED O&M COSTS FOR THE CDS AND TST UNITS

UNIT	PARAMETER	ASSUMPTIONS	ANNUAL COST ($)
CDS	Vactor Fee	a. $200/hr including travel b. 1 cleaning/year @ 4 hours/cleaning, including travel	800
	Solids Generation/ Disposal	a. Assume 1351 kg of dry solids/yr @ 39.3% moisture = 2226 kg/yr wet solids = 2.45 tons/yr wet solids b. Disposal costs of $100/ton	245
	Mowing	a. Mowing in vicinity of structure once per month b. Cost of $75/month	900
		TOTAL:	$ 1945/yr
TST	Vactor Fee	a. $200/hr including travel b. 1 cleaning/year @ 4 hours/cleaning, including travel	800
	Solids Generation/ Disposal	a. Assume 773 kg of dry solids/yr @ 34.5% moisture = 1180 kg/yr wet solids = 1.3 tons/yr wet solids b. Disposal costs of $100/ton	130
	Mowing	a. Mowing in vicinity of structure once per month b. Cost of $75/month	900
		TOTAL:	$ 1830/yr

Based on the measured solids density of 1.82 kg/liter, the annual volume of collected solids is approximately 1223 liters or 43.2 ft^3/yr. Assuming a lower sump volume of 176 ft^3, solid removal from the CDS unit would be required approximately once every four years. However, solids removal should be performed at least once per year to minimize decomposition and subsequent release of collected phosphorus. Therefore, for purposes of this analysis, a cleaning frequency of once/year is assumed. It is assumed that one cleaning per year will be required using a standard vactor truck with 4 hours allotted per cleaning, including travel. Assuming $200/hour for a vactor truck, the cleaning fee will be approximately $800/year. Mowing costs are also included for the area immediately in the vicinity of the structure at a cost of approximately $75/month or $900/year. Total annual O&M cost for the CDS unit is estimated to be $1945/year.

During an operational period of 192 days, the TST unit removed 408.8 kg of dry solids. Based on an average moisture content of 34.5%, this equates to 1180 kg/yr of wet solids or 1.3 tons/yr of wet material. At a disposal cost of $100/ton, disposal of the collected solids will cost approximately $130/yr. Based on the measured solids density of 1.96 kg/liter, the annual volume of collected solids in the TST unit is approximately 602 liters or 21.26 ft^3/yr. Assuming an available sediment storage volume of 200 ft^3 (25% of the tank volume), solids removal from the TST unit would be required once every 9.4 years. However, solids removal should be performed at least once per year to minimize decomposition and subsequent release of collected phosphorus. Similar to the assumptions made for the CDS unit, one cleaning per year is assumed using a vactor-type vehicle, with 4 hours per cleaning, including travel. Estimated total vactor fee is approximately $800/yr. Mowing in the vicinity of the structure is also assumed at a cost of $75/month, for an annual cost of $900. Estimated annual O&M cost for the TST unit is approximately $1830.

Calculated present worth costs for the CDS and TST units are given in Table 5-34 based upon a 20-year life-cycle cost and an interest rate of 4% per year. The calculated 20-year present worth cost for the CDS unit is approximately $143,117, with a present worth cost of $96,086 for the TST unit.

TABLE 5-34

CALCULATED PRESENT WORTH COSTS FOR SOLIDS REMOVAL USING THE CDS AND TST UNITS (n = 20 year, i = 4%)

UNIT	CAPITAL COST ($)	ANNUAL O&M COST ($)	PRESENT WORTH ($)
CDS	116,684	1,945	143,117
TST	71,216	1,830	96,086

The summary of total solids, phosphorus, and nitrogen removed from the CDS unit, given in Table 5-29, reflects a period of operation of 207 days, while the estimated mass removal for the TST unit covers a period of 193 days of system operation. The estimated mass of solids, total phosphorus, and total nitrogen removed by the two units was extrapolated to a 20-year period by first extrapolating the measured removals to an annual period and then multiplying that estimate by 20 years. These values reflect the estimated total removal of solids, phosphorus, and nitrogen by the two units over the 20-year life-cycle period.

Estimated costs per mass removal for the CDS and TST units, based upon the 20-year present worth costs summarized in Table 5-34, are given in Table 5-35. Over a 20-year period, the CDS unit is estimated to remove approximately 27,021 kg of solids containing 39.0 kg of total phosphorus and 119.4 kg of total nitrogen. Based upon the 20-year present worth cost of $143,117, the 20-year life-cycle cost for mass removal in the CDS unit is approximately $5.30/kg of solids, $3670/kg of total phosphorus, and $1199/kg total nitrogen.

TABLE 5-35

ESTIMATED COST PER MASS REMOVAL FOR THE CDS AND TST UNITS (20-year period)

ITEM	CDS UNIT	TST UNIT
Estimated Removal Over 20-year Period	27,021 kg solids 39.0 kg TP 119.4 kg TN	15,462 kg solids 21.3 kg TP 20.9 kg TN
Cost per kg Removed[1]	$5.30/kg solids $3670/kg TP $1199/kg TN	$6.21/kg solids $4511/kg TP $4597/kg TN

1. Based on 20-year present worth costs

Extrapolation of the measured mass removals for the TST unit indicates that over a 20-year period, the TST unit will remove approximately 15,462 kg of solids containing 21.3 kg of total phosphorus and 20.9 kg of total nitrogen. Based upon the 20-year present worth cost of $96,086, this equates to a 20-year life-cycle cost of $6.21/kg of dry solids, $4511/kg of total phosphorus, and

$4597/kg of total nitrogen. The calculated life-cycle values for the CDS and TST units reflect low estimates of the actual life-cycle costs, since the calculated values do not include additional costs for unforeseen maintenance activities.

A comparison of life-cycle costs per mass of pollutant removed for recent stormwater retrofit projects completed by ERD is given in Table 5-36. Typical costs for removal of suspended solids range from approximately $1-11/kg. Therefore, in terms of solids removal, the life-cycle costs for the CDS and TST units appears to be in line with other similar stormwater retrofit projects.

TABLE 5-36

COMPARISON OF LIFE CYCLE COST PER MASS POLLUTANT REMOVED FOR TYPICAL STORMWATER RETROFIT PROJECTS[1]

PROJECT	LIFE CYCLE COST ($)	COST PER MASS POLLUTANT REMOVED ($/kg)		
		TP	TN	TSS
Alum Treatment				
Largo Regional STF	2,044,780	253	65	4
Lake Maggiore STF	4,086,060	200	71	2
Gore Street Outfall STF	1,825,280	87	12	1
East Lake Outfall TF	1,223,600	135	17	1
Wet Detention				
Melburne Blvd. STF	1,069,000	371	125	2
Clear Lake Ponds STF	1,091,600	658	237	2
Wetland Treatment				
McIntosh Park ETW	4,207,807	106	168	11

1. Does not consider cost of land purchase

Typical costs per mass pollutant removed for phosphorus has ranged from $87-658/kg compared with values ranging from $3670/kg of total phosphorus for the CDS unit to $4511/kg of total phosphorus for the TST unit. It is apparent that the CDS and TST units are less efficient in terms of cost per kg of phosphorus removed than other stormwater retrofit projects. However, the apparent high cost of phosphorus removal for the CDS and TST units may be due largely to the fact that little sediment phosphorus was present in Lettuce Creek rather than a failure of the units to provide significant removal.

Costs per kg of total nitrogen removal for stormwater retrofit projects range from $17-237/kg of total nitrogen removed. Costs per kg of total nitrogen removal in the CDS and TST units range from $1199-4597/kg. It appears clear that the CDS and TST units are not economically attractive in terms of removing total nitrogen. However, this conclusion may again be impacted by the lack of significant particulate nitrogen in Lettuce Creek rather than an inability of the units to capture and retain particulate nitrogen.

SECTION 6

EVALUATION OF ALUM COAGULATION TO IMPROVE PERFORMANCE EFFICIENCY OF CDS AND TST UNITS

6.1 Background

Monitoring performed at the Lettuce Creek site during the period from November 2002-March 2003 indicated poor removal efficiencies for all measured parameters in both the CDS and TST units. Virtually no removal of either phosphorus or nitrogen was observed in either unit.

The inability of the units to capture particulate phosphorus appears to be related to the physical characteristics of sediment particles contained in water within Lettuce Creek. A summary of physical-chemical characteristics of sediment particles contained in water samples collected from Lettuce Creek during August and September 2001 was previously given in Tables 4-1 and 4-2. The majority of particles contained in Lettuce Creek water are approximately 100 microns or less in size. These particles also contain the vast majority of phosphorus associated with particulate matter. However, CDS and TST units are designed to provide effective removal for sediment particles of approximately 1000 microns or more. Therefore, the settling velocities of the particles present within Lettuce Creek are too slow to allow capture of the particles within the relatively short residence times provided by the two test units. The effectiveness of the units can only be improved by increasing the residence time within the systems by constructing substantially larger units, or by enhancing the settling velocity of the particles.

After reviewing the results from the initial monitoring performed at the Lettuce Creek site, it was decided to attempt to enhance the settling velocities of the particles using a common flocculating agent. For purposes of this project, it was decided to use alum since alum not only enhances settling of particulate matter, but also provides adsorption and removal of dissolved phosphorus species as well.

When aluminum sulfate (alum), $Al_2(SO_4)_3 \cdot 18H_2O$, is added to water, free Al^{+3} ions are formed. These ions are quickly coordinated by six water molecules in an octahedral configuration which can be represented by the formula $Al(H_2O)_6^{+3}$. The Al^{+3} ion has a considerably smaller ionic radius than other commonly encountered trivalent metal ions and polarizes solvated water ions very strongly. Alum removes phosphorus from water by the following net reaction:

$$Al^{+3} + PO_4^{-3} \text{ -----> } AlPO_4 \text{ (ppt)}$$

where $Al(PO_4)$ is a milky precipitate which settles from the water column relatively slowly. Solids, heavy metals, bacteria, and additional phosphorus are removed by this net reaction:

$$Al^{+3} + 3H_2O \text{ -----> } Al(OH)_3 \text{ (ppt)} + 3H^+$$

The aluminum hydroxide precipitate, $Al(OH)_3$, is a large gelatinous floc which attracts and adsorbs colloidal particles onto the growing floc, rapidly clarifying the water.

Phosphorus is removed from alum treated water by three primary mechanisms: (1) formation of insoluble $AlPO_4$; (2) adsorption on the surface of $Al(OH)_3$ floc; and (3) entrapment by phosphorus-containing particulate matter in the $Al(OH)_3$ floc (Cooke and Kennedy, 1981). Phosphorus removal or entrapment can occur by several mechanisms, depending on the solution pH. At lower pH values and higher inorganic phosphorus concentrations, the formation of $AlPO_4$ is favored. Inorganic phosphorus is also effectively removed by adsorption to the $Al(OH)_3$ floc. Removal of particulate phosphorus is most effective in the pH range of 6-8 when maximum floc occurs (Cooke and Kennedy, 1981). At higher pH values, OH^- begins to compete with phosphate ions for aluminum ions and aluminum hydroxide-phosphate complexes begin to form. Suspended solids, heavy metals, bacteria, and additional phosphorus are removed by only two of the primary mechanisms: (1) by adsorption on the surface of $Al(OH)_3$ floc and (2) by entrapment of particulate matter in the $AlPO_4$ or $Al(OH)_3$ floc.

After formation, the alum precipitate can be collected in a small settling basin, or allowed to settle in receiving waterbodies. Alum precipitates are exceptionally stable in sediments and will not redissolve due to changes in redox potential or under pH conditions normally found in surface waters. Over time, the freshly precipitated alum floc ages into even more stable complexes. The solubility of dissolved aluminum in the treated water is regulated entirely by chemical equilibrium. As long as the pH of the treated water is maintained within the range of 5.5-7.0, dissolved aluminum concentrations will be minimal. In many instances, the concentration of dissolved aluminum in the treated water will be less than the concentration in the raw untreated water due to adjustment of the pH into the range of minimum solubility.

6.2 Initial Testing

6.2.1 Jar Test Procedures

A series of laboratory jar tests were conducted using alum on composite surface water samples collected from Lettuce Creek to evaluate the water quality impacts of alum coagulation at various doses on removal of both dissolved and particulate phosphorus from the creek water. Composite surface water samples were collected from Lettuce Creek on December 17, 2002 and May 19, 2003 for use in laboratory testing. Each of the samples was collected in a 20-liter polyethylene container which was returned, on ice, to the ERD Laboratory for testing.

Jar tests were conducted on the December 17, 2002 sample using alum doses of 5, 7.5, 10, 12.5, and 15 mg Al/liter. To begin each jar test, the appropriate amount of alum was added to a 2-liter water sample contained in a polycarbonate beaker. Following addition of the alum, the mixture was agitated for approximately 60 seconds. Measurements of pH were conducted initially in the raw sample and approximately one minute after addition of the selected alum dose. Additional measurements of pH were conducted at periods of one hour and 24 hours after addition of the alum coagulant to document changes in pH which typically occur after alum addition. In general, minimum pH levels in alum treated water typically occur immediately following addition of the coagulant. The pH value of the treated water continues to increase steadily following addition of the alum for a period of approximately 24 hours.

The alum treated samples were then allowed to settle for a period of 24 hours. At the end of the 24-hour settling period, the clear supernatant was decanted from each jar test container for subsequent laboratory analyses. Each of the samples generated during the laboratory jar test procedures was analyzed for a wide variety of chemical constituents, including general parameters, chlorophyll-a, nutrients, and dissolved aluminum.

6.2.2 Results of Initial Testing

The results of laboratory jar tests using alum on a composite surface water sample collected from Lettuce Creek on December 17, 2002 are given in Table 6-1.

TABLE 6-1

RESULTS OF LABORATORY JAR TESTS USING ALUM ON THE COMPOSITE SURFACE WATER SAMPLE COLLECTED FROM LETTUCE CREEK ON DECEMBER 17, 2002

PARAMETER	UNITS	RAW WATER CHARACTERISTICS	APPLIED ALUM DOSE (mg Al/liter)				
			5.0	7.5	10.0	12.5	15.0
pH (initial)	s.u.	7.13	7.13	7.13	7.13	7.13	7.13
pH (after 1 min)	s.u.	7.13	6.66	6.39	6.25	5.55	5.07
pH (after 1 hr)	s.u.	7.15	6.67	6.44	6.29	5.53	5.09
pH (after 24 hr)	s.u.	7.30	7.27	7.03	6.93	6.17	5.14
Alkalinity	mg/l	81.8	64.2	51.3	38.2	9.7	3.8
NH_3-N	µg/l	< 5	49	< 5	< 5	< 5	< 5
NO_x-N	µg/l	500	2	6	80	328	334
Particulate N	µg/l	126	193	194	116	56	46
Diss. Organic N	µg/l	1220	1032	830	799	531	483
Total N	µg/l	1848	1276	1032	997	917	865
Diss. Ortho-P	µg/l	159	2	< 1	< 1	< 1	< 1
Diss. Organic P	µg/l	162	23	16	16	15	15
Particulate P	µg/l	56	41	11	2	1	1
Total P	µg/l	377	66	28	19	17	17
TSS	mg/l	6.4	11.4	5.6	4.0	1.5	1.1
Turbidity	NTU	5.1	8.2	2.9	1.2	1.0	0.8
Color	Pt-Co	184	88	45	9	7	4
		Floc Characteristics:	Small, milky floc	Small, milky floc	Small floc	Good floc after 1 min.	Good floc after 1 min.

During these experiments, total phosphorus concentrations were reduced from 377 µg/l in the raw water sample to 66 µg/l at an alum dose of 5 mg Al/liter, 28 µg/l at an alum dose of 7.5 mg Al/liter, 19 µg/l at an alum dose of 10 mg Al/liter, and 17 µg/l at an alum dose of 12.5 mg Al/liter. Reductions were also achieved in measured concentrations of particulate and total nitrogen, TSS, turbidity, and color.

Although the addition of alum was effective in reducing concentrations of phosphorus species in Lettuce Creek water, the resulting floc produced after addition of the alum exhibited poor settling characteristics. At alum doses of 5 and 7.5 mg Al/liter, a small milky floc is produced which requires 24-48 hours for complete clarification. At an alum dose of 10 mg Al/liter, a relatively small floc is formed which settles in approximately 12 hours. At more elevated alum dose of 12.5 and 15 mg Al/liter, a large floc is generated, but a period of approximately 1-2 hours is still required for complete settling of the floc particles.

For alum to be effective in enhancing the settling and removal characteristics of particles in Lettuce Creek water, settling processes must be complete in a matter of minutes rather than hours. Detention times within the baffle box and CDS units are a function of the water volume contained within each of the two units and the flow rate of water through the unit. Water levels within the two units are regulated primarily by tailwater conditions rather than water elevations in Lettuce Creek. At a tailwater elevation of approximately 18.0 ft, the baffle box contains a water volume of approximately 560 ft^3, with a water volume of approximately 373 ft^3 in the CDS unit. Calculated detention times for the CDS and baffle box units as a function of water flow rates are given in Table 6-2. At a flow rate of 1 cfs through each unit, the CDS unit has a detention time of approximately 6.2 minutes, with a detention time of 9.3 minutes in the baffle box units. At a flow rate of 2 cfs, detention time in the CDS unit decreases to 3.1 minutes, with a detention time of 4.7 minutes in the baffle box.

TABLE 6-2

CALCULATED DETENTION TIMES FOR THE CDS AND BAFFLE BOX UNITS AS A FUNCTION OF WATER FLOW RATES

PARAMETER	CDS UNIT	BAFFLE BOX UNIT
Water Volume at El. 18.0 ft	373 ft^3	560 ft^3
Water Detention Time 1 cfs 2 cfs 3 cfs 4 cfs	 6.2 minutes 3.1 minutes 2.1 minutes 1.6 minutes	 9.3 minutes 4.7 minutes 3.1 minutes 2.3 minutes

A variety of flocculent aids and polymers were evaluated by ERD to increase the settling rate of the alum floc resulting from addition of alum to Lettuce Creek water. Approximately 10 different polymers were evaluated with respect to settling characteristics and phosphorus removal efficiencies. Based upon this evaluation, a polymer blend designated as product APS #605, also called Silt Stop, manufactured by Applied Polymer Systems, Inc., was selected. This product is an anionic water soluble copolymer emulsion which is milky white in appearance and has a pH of approximately 6-8. The LC-50 for fathead minnows and algae is in excess of 1000 mg/l, with a 48-hour LC-50 for daphnia species of 15 mg/l.

A series of laboratory jar tests were conducted using alum and APS #605 on composite Lettuce Creek samples collected on May 19, 2003. Visual floc formation and settling characteristics for these tests are given in Table 6-3. Tested alum doses included 7.5, 10, and 12.5 mg Al/liter, with polymer doses of 5, 7.5, and 10 ppm. At an alum dose of 7.5 mg Al/liter, the addition of polymer created large floc particles which settled relatively rapidly from the water column. With a polymer dose of 7.5 ppm, floc settling was virtually complete in approximately 13 minutes. At a polymer dose of 10 ppm, floc settling was visually observed to be complete in approximately 6-7 minutes.

TABLE 6-3

FLOC FORMATION AND SETTLING CHARACTERISTICS IN LABORATORY JAR TESTS ON COMPOSITE LETTUCE CREEK SAMPLES COLLECTED ON MAY 19, 2003

ALUM DOSE (mg Al/liter)	POLYMER DOSE (ppm)	FLOC CHARACTERISTICS/ OBSERVATIONS	SETTLING TIME
Raw	--	Water sample clear with moderate organic stain; no visible particles	--
7.5	7.5	Fine floc particles which formed into a round clump	Floc settling initiated in approx. 1 minute; 80% complete in approx. 3 minutes; 100% complete in approx. 13 minutes
7.5	10	Large floc formation immediately which formed into large round clump	Floc settling initiated in approx. 1.5 minute; 80% complete in approx. 2.5 minutes; 100% complete in approx. 6-7 minutes
10	7.5	Large floc formation which rapidly formed into a round clump	Floc settling initiated in 1 minute; 80% complete in approx. 2 minutes; 100% complete in approx. 8 minutes
10	10	Large floc formation which rapidly formed into a round clump	Floc settling initiated in 35 seconds; 80% complete in approx. 1 minute; 100% complete in approx. 7-8 minutes
12.5	5	Small, thick floc formed instantly which clumped together into a round ball	Floc settling initiated in approx. 1 minute; 80% complete in 1 minute; 100% complete in 5 minutes
12.5	7.5	Large floc formation instantly; floc lighter in color than at lower doses	Floc settling initiated in approx. 40 seconds; 80-90% complete in 1 minute; 100% complete in 4 minutes
12.5	10	Large floc formation instantly; floc lighter in color than at lower doses	Floc settling initiated in approx. 40 seconds; 80-90% complete in 1 minute; 100% complete in 3 minutes

At an alum dose of 10 mg Al/liter, floc formation was more rapid, with larger floc particles. Settling of the floc particles from the water column was extremely rapid, with complete settling in approximately 7-8 minutes at the two tested polymer doses. However, at an alum dose of 12.5 mg Al/liter, floc settling was substantially more rapid than at the lower doses. At a polymer dose of 5 ppm, floc settling was 100% complete in 5 minutes. When the polymer dose was increased to 7.5

ppm, floc settling was complete in approximately 4 minutes. At a polymer dose of 10 ppm, a large rapidly settling floc was formed which was completely settled from the water column in less than 3 minutes. Visual characteristics of floc settling at an alum dose of 12.5 mg Al/liter and a polymer dose of 10 ppm are illustrated in Figure 6-1.

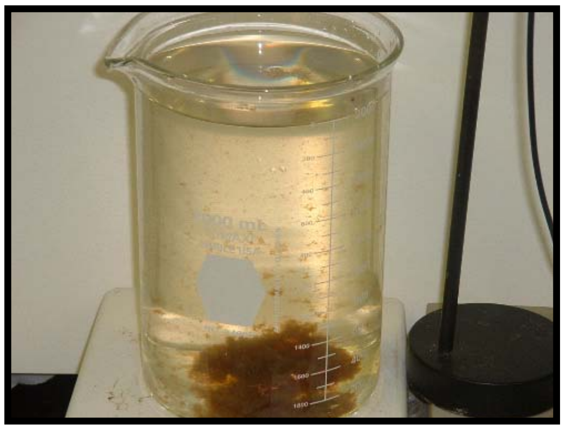
Based on the results summarized in Table 6-3, it appears that at an alum dose of 12.5 mg Al/liter and a polymer dose of 10 ppm can be used to generate a rapidly settling floc which would settle within the residence times provided within the CDS and TST units. This treatment dose would be sufficient to provide complete floc settling within the CDS unit up to a flow rate of 2 cfs and within the baffle box unit up to a flow rate of approximately 3 cfs based upon the calculated detention times summarized in Table 6-2.

A summary of the results of laboratory jar tests on composite Lettuce Creek samples collected on May 19, 2003 is given in Table 6-4. In general, the effectiveness of the alum-polymer mixture increases with increasing doses for the alum and polymer. At a dose of 12.5 mg Al/liter and a polymer dose of 10 ppm, total phosphorus concentrations are reduced from an initial value of 880 μg/l to approximately 10 μg/l after a settling period of 3 minutes. The minimum pH value obtained as a result of this addition is approximately 6.4 which meets the minimum Class III pH criterion of 6.0. This dosage combination also reduced measured concentrations of total nitrogen by approximately 17%, decreasing the raw water concentration of 2585 μg/l down to 2150 μg/l. The addition of alum also resulted in increases in sulfate within the sample, from an initial value of 77 mg/l to 122 mg/l at the highest tested alum-polymer dose.

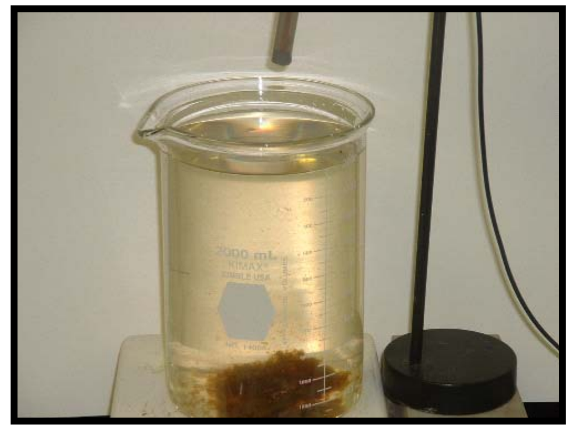
Based upon the results summarized in Tables 6-3 and 6-4, an alum dose of 12.5 mg Al/liter and a polymer dose of 10 ppm was selected for treatment of Lettuce Creek. This chemical combination produces a rapidly settling floc which can be completely removed from the water column in less than 3 minutes. Based on the jar test results, it appeared that this combination will provide sufficient detention time to operate the CDS unit at flow rates up to 2 cfs and the baffle box unit at flow rates up to 3 cfs, while still maintaining containment of floc within the two structures. This treatment combination is sufficient to reduce total phosphorus concentrations by more than 98% from the raw to the treated sample.

Immediately after alum / polymer addition

30 seconds following alum / polymer addition



60 seconds following alum / polymer addition



3 minutes following alum / polymer addition

Figure 6-1. Lettuce Creek Floc Settling at an Alum Dose of 12.5 mg Al/liter and a Polymer Dose of 10 ppm.

TABLE 6-4

RESULTS OF LABORATORY JAR TEST ON COMPOSITE LETTUCE CREEK SAMPLES COLLECTED ON MAY 19, 2003

PARAMETER	UNITS	RAW WATER	7.5 mg Al/liter		10 mg Al/liter		12.5 mg Al/liter		
			7.5 ppm polymer	10 ppm polymer	7.5 ppm polymer	10 ppm polymer	5 ppm polymer	7.5 ppm polymer	10 ppm polymer
pH (initial)	s.u.	7.77	7.77	7.77	7.77	7.77	7.77	7.77	7.77
pH (after 1 min)	s.u.	7.77	6.92	6.83	6.74	6.70	6.47	6.57	6.39
pH (after 24 hr)	s.u.	7.84	7.52	7.58	7.49	7.47	6.49	6.70	6.54
Alkalinity	mg/l	145	110	112	99.0	1030	79.4	86.7	87.1
NO_x-N	µg/l	1542	1405	1391	1431	1371	1438	1487	1426
Total N	µg/l	2585	2345	2355	2220	2240	2055	2110	2150
Ortho-P	µg/l	513	16	9	5	1	2	1	1
Total P	µg/l	880	75	50	40	25	40	35	10
Turbidity	NTU	6.0	1.7	1.7	1.0	1.6	1.0	1.5	1.0
Sulfate	mg/l	77	88	88	95	94	114	113	122

6.3 System Components

System modifications to achieve the alum-polymer addition were performed at the project site. A 1000-gallon HDPE storage tank was installed inside the existing fenced compound which surrounds the test units and monitoring equipment. This storage tank was used to provide bulk storage for liquid alum used during the testing process. A 250-gallon HDPE storage tank was used for storage of the polymer feed. The concentrated raw polymer solution was diluted with Lettuce Creek water to create a 0.25% working solution which was used during the testing. The alum and polymer mixture was fed using separate chemical feed pumps, housed inside an existing equipment shelter. A photograph of the chemical storage tanks and feedlines is given in Figure 6-2. The alum and polymer mixtures were introduced into the inflow chamber which feeds both the CDS and TST units. The treated water constantly flowed into the two units, with settling of the floc particles occurring within each chamber.

Figure 6-2. Storage Tanks for Alum and Polymer.

Operation of the treatment systems at a flow rate of 1 cfs used approximately 138 gallons of alum/unit/day. At a unit cost of approximately $0.55/gallon for liquid alum, the alum cost will be approximately $75.90/unit/day or approximately $530/unit/week. Addition of the required polymer dose will require approximately 4.85 gallons of polymer/unit/day. At an estimated cost of approximately $50/gallon, polymer costs will be $245/unit/day, or approximately $1700/unit/week.

All floc particles retained within the CDS and TST units were removed by ERD following each 24-hour test period. Generated alum floc was disposed of at an adjacent agricultural area owned by the District. Previous research performed by ERD has indicated that alum floc is inert under a wide range of pH and redox conditions, with virtually no potential for leaching of trapped constituents. Alum floc has chemical characteristics similar to a dilute Class I wastewater sludge which can be disposed of on open land and agricultural areas.

6.4 Results of Alum Field Testing

Supplemental field experimentation was performed to evaluate the effectiveness of alum addition for enhancing the performance efficiency of the CDS and TST units. The alum testing was performed using an alum dose of 12.5 mg Al/liter and a polymer dose of 10 ppm to enhance settling of the floc. The recommended doses of alum and polymer were determined through the laboratory jar tests outlined in Section 6.2.

Field testing using alum to enhance phosphorus removal was conducted in both the CDS and TST units at a variety of flow rates ranging from 0.5-2.0 cfs. Testing was conducted at each flow rate for a period of 24 hours. Alum testing was performed from September 22-23, October 23-24, October 29-31, and November 10-14, 2003.

6.4.1 Chemical Characteristics of Alum Treated Discharges

6.4.1.1 TST Unit

A summary of chemical characteristics of alum treated discharges from the TST unit is given in Table 6-5. Inflow characteristics into the TST unit during this testing are given in Table 5-4. In general, the alum treated samples exhibit lower concentrations for virtually all measured parameters compared with characteristics of inflow samples performed on the same dates. Substantial reductions in outflow concentrations are apparent for ammonia, dissolved organic nitrogen, particulate nitrogen, total nitrogen, orthophosphorus, organic phosphorus, total phosphorus, TOC, and DOC. However, increases in concentrations were observed for particulate phosphorus, TSS, and turbidity, presumably resulting from carryover of small amounts of floc which did not settle within the TST unit.

6.4.1.2 CDS Unit

A summary of chemical characteristics of alum treated discharges from the TST unit is given in Table 6-6. Inflow characteristics into the CDS unit during this testing are given in Table 5-4. Substantial reductions in concentrations are also apparent for alum treated discharges from the

TABLE 6-5

CHEMICAL CHARACTERISTICS OF ALUM TREATED DISCHARGES FROM THE TST UNIT

PERIOD OF OPERATION	FLOW RATE (cfs)	PARAMETER														
		pH (s.u.)	Temp (EC)	NH_3 (µg/l)	NO_x (µg/l)	Diss. Org N (µg/l)	Part N (µg/l)	TN (µg/l)	OP (µg/l)	Org P (µg/l)	Part P (µg/l)	TP (µg/l)	TSS (mg/l)	Turb (NTU)	TOC (mg/l)	DOC (mg/l)
11/11-12/03	0.5	6.62	29.5	365	301	615	629	1910	22	18	287	327	7.6	3.7	47.0	16.4
11/10-11/03	0.75	5.69	28.7	212	256	458	148	1074	4	17	113	134	29.2	21.8	22.3	11.2
10/30-31/03	1	5.38	29.6	328	378	244	556	1506	< 1	7	288	296	117	68.8	13.2	9.6
10/29-30/03	2	5.82	29.4	315	390	446	696	1847	17	8	323	348	60.0	27.6	10.8	8.9
Mean		**5.88**	**29.3**	**305**	**331**	**441**	**507**	**1584**	**11**	**13**	**253**	**276**	**53.5**	**30.5**	**23.3**	**11.5**
95% C.I.		5.14-6.61	28.7-29.9	214-396	243-420	230-652	165 849	1052-2117	<1-25	4-21	121-384	141-411	0-119	0-68.6	0.4-46.3	6.8-16.2

TABLE 6-6

CHEMICAL CHARACTERISTICS OF ALUM TREATED DISCHARGES FROM THE CDS UNIT

PERIOD OF OPERATION	FLOW RATE (cfs)	PARAMETER														
		pH (s.u.)	Temp (EC)	NH_3 (µg/l)	NO_x (µg/l)	Diss. Org N (µg/l)	Part N (µg/l)	TN (µg/l)	OP (µg/l)	Org P (µg/l)	Part P (µg/l)	TP (µg/l)	TSS (mg/l)	Turb (NTU)	TOC (mg/l)	DOC (mg/l)
11/12-13/03	0.5	6.61	28.9	218	293	721	1026	2258	16	23	307	346	51.3	38.3	41.9	19.2
11/13-14/03	0.75	7.60	29.3	100	298	426	846	1670	11	27	306	344	60.0	19.5	34.4	18.3
9/22-23/03	1	6.33	32.3	271	352	530	1082	2235	4	20	353	377	86.0	67.6	27.8	15.9
10/23-24/03	2	6.04	29.8	11	411	501	673	1596	10	70	168	248	70.6	39.1	17.4	16.3
Mean		**6.65**	**30.1**	**150**	**277**	**545**	**907**	**1940**	**10**	**35**	**284**	**329**	**67.0**	**41.1**	**30.4**	**17.4**
95% C.I.		5.70-7.59	28.0-32.2	0-269	0-312	370-719	649-1164	1446-2433	3-17	2-68	172-395	251-406	46.2-87.7	13.6-68.7	16.0-44.8	15.2-19.6

CDS unit compared with measured characteristics of inflows. Reductions in concentrations are particularly apparent for inflow concentrations of ammonia, dissolved organic nitrogen, total nitrogen, orthophosphorus, total phosphorus, TOC, and DOC. Increases in concentrations were observed for particulate phosphorus, particulate nitrogen, TSS, and turbidity, presumably resulting from carryover of small amounts of floc from the CDS unit into the outflow during the testing process.

6.4.2 Calculated Removal Efficiencies

Removal efficiencies were calculated for alum treatment performed in the TST and CDS units based upon the chemical characteristics of alum treated discharges from the TST unit presented in Table 6-5 and the chemical characteristics of alum treated discharges from the CDS unit presented in Table 6-6. The characteristics of Lettuce Creek inflow into the units during the field experiments are given in Table 5-4.

Calculated removal efficiencies obtained during alum treatment in the TST unit are summarized in Table 6-7. In general, alum treatment resulted in a slight decrease in pH compared with pH values measured at the inflow. Alum treatment appeared to have a variable effect on ammonia concentrations, with decreases in concentrations observed during three of the four experiments and an increase in concentration observed during one of the four experiments. Slight increases in concentrations were observed for NO_x in all the field tests. Substantial reductions in dissolved organic nitrogen concentrations were observed during all of the field tests, with reductions in particulate nitrogen observed during two of the four tests. However, on an overall basis, a net reduction in total nitrogen was achieved during alum treatment in the TST unit, with measured reductions ranging from 20-58%.

Alum treatment of inflow into the TST unit resulted in substantial reductions in concentrations of dissolved orthophosphorus, with removal efficiencies ranging from 94-99%. Reductions in concentrations of organic phosphorus were also achieved, with removals ranging from 18-70%. However, increases in particulate phosphorus were observed at the outfall during a majority of the field tests. These increases in particulate phosphorus are due to the carryover of

TABLE 6-7

CALCULATED REMOVAL EFFICIENCIES DURING ALUM TREATMENT IN THE TST UNIT

PERIOD OF OPERATION	FLOW RATE (cfs)	REMOVAL (%)												
		NH_3	NO_x	Diss. Org N	Part N	TN	OP	Org P	Part P	TP	TSS	Turb	TOC	DOC
11/11-12/03	0.5	10	-19	36	19	20	95	18	-152	43	88	92	12	57
11/10-11/03	0.75	53	-11	64	67	55	99	61	18	79	1	-235	54	68
10/30-31/03	1	34	-14	83	-19	45	99	65	-188	14	-413	-1198	70	75
10/29-30/03	2	-48	5	86	-32	58	94	70	-413	2	-228	-345	66	70

TABLE 6-8

CALCULATED REMOVAL EFFICIENCIES DURING ALUM TREATMENT IN THE CDS UNIT

PERIOD OF OPERATION	FLOW RATE (cfs)	REMOVAL (%)												
		NH_3	NO_x	Diss. Org N	Part N	TN	OP	Org P	Part P	TP	TSS	Turb	TOC	DOC
11/12-13/03	0.5	53	-31	57	-157	18	93	83	-96	32	-375	-609	24	49
11/13-14/03	0.75	31	-13	40	-149	-15	95	84	-96	36	-823	-117	28	49
9/22-23/03	1	2	-6	91	-455	66	99	68	-651	49	-254	-483	21	50
10/23-24/03	2	90	-1	89	-13	72	98	71	-83	72	-119	-563	42	44

small amounts of alum floc which was visually observed during each experiment. Based on visual observations during both the lab testing and field experimentation, the floc carryover was substantially less than 1% of the generated floc volume. Alum treatment concentrates phosphorus into the floc at a ratio of approximately 10,000 times the concentration in the water column. Although the carryover of floc represented only a small portion of the generated floc, the few floc particles collected in the outflow samples were sufficient to result in an increase in particulate phosphorus. However, even considering the increase in particulate phosphorus, total phosphorus was removed during each experiment, with removal efficiencies ranging from 2-79%. If the increase in particulate phosphorus is not considered, removal of total phosphorus would have exceeded 90% in all experiments.

Decreases in TSS were observed at relatively low flow rates through the TST unit, with increases in TSS observed at higher flow rates, presumably resulting from carryover of particulate material and small amounts of floc. This trend is also apparent in measured concentrations of turbidity. However, relatively good removals were achieved for both TOC and DOC with the alum treatment.

Calculated removal efficiencies during alum treatment in the CDS unit are summarized in Table 6-8. Similar to the trends observed in the TST unit, alum treatment resulted in slight reductions in measured pH values. A net removal of ammonia was achieved during each of the four tests in the CDS unit, with removals ranging from 2-90%. However, in contrast, increases in NO_x concentrations were observed during each test, ranging from 1-31%. Reductions in dissolved organic nitrogen concentrations were also achieved with the alum treatment, with removals ranging from 40-91%. However, increases in particulate nitrogen were observed during each test performed in the CDS unit. On an overall basis, a net removal of total nitrogen was achieved during three of the four experiments, with an increase of 15% observed during the remaining experiment.

The addition of alum to inflow of the CDS unit resulted in substantial reductions in measured concentrations of orthophosphorus, with removals ranging from 93-99%. Excellent removals were also achieved for organic phosphorus, with efficiencies ranging from 68-84%.

However, increases in particulate phosphorus were observed in each test performed in the CDS unit, suggesting carryover of a small portion of the generated floc through the outfall structure. Overall, removal efficiencies for total phosphorus ranged from 32-72% within the CDS unit.

Increases in both TSS and turbidity were observed in the outfall from the CDS unit as a result of carryover of particulate matter from the unit. Relatively good removal efficiencies were achieved for both TOC and DOC during the alum testing.

As indicated previously, carryover of a small amount of alum floc, substantially less than 1% of the total floc volume produced, was observed during testing in both the CDS and TST units. This phenomenon is common during alum treatment when floc particles contain entrapped air or buoyant algal species. In more permanent designs, this floc carryover is prevented using permeable filter fabrics, skimmers, or variations in hydraulic design. If this small amount of floc carryover had not occurred, overall removal of total phosphorus would have been approximately 98%, with a total nitrogen removal of approximately 17%. No visible carryover of floc into the L-63S Canal was observed during any of the field testing.

6.4.3 Florida Department of Environmental Protection (FDEP) Permit Monitoring

The FDEP permit modification for the alum testing portion of this project specified a water quality monitoring program to evaluate potential water quality impacts of the alum treatment process on the L-63 Canal. This permit required that water samples be collected prior to initiation of alum testing to establish background conditions, and on a weekly basis during operation of the alum system. All samples are to be collected mid-way across the canal, with a composite sample formed at each site by combining equal amounts of water collected 0.5 m below the water surface, 0.5 m above the bottom, and mid-way in the water column. Surface water samples are to be collected at three locations in the L-63 Canal:

1. Adjacent to the pipe discharge from Lettuce Creek into the L-63SCanal
2. Approximately 200 ft upstream from the point of inflow for Lettuce Creek
3. Approximately 200 ft downstream from the point of inflow for Lettuce Creek

Each of the composite samples is to be analyzed for pH (field measured), alkalinity, sulfate, dissolved aluminum, and total phosphorus.

The results of FDEP permit monitoring associated with the alum testing program are summarized in Table 6-9. Pre-treatment monitoring was performed on September 22, 2003, with post-treatment monitoring performed at the conclusion of monitoring events ending on September 23, October 24, October 31, November 12, November 13, and November 14, 2003.

TABLE 6-9

RESULTS OF FDEP PERMIT MONITORING ASSOCIATED WITH ALUM TESTING

SAMPLE	DATE	pH (s.u.)	ALKALINITY (mg/l)	TP (µg/l)	DISS. Al (µg/l)	SULFATE (mg/l)
L-63S @ pipe	9/22/03	6.76	69.5	501	201	27
L-63S upstream		6.58	58.9	152	221	27
L-63S downstream		6.80	77.8	532	455	34
L-63S @ pipe	9/23/03	6.87	73.3	279	100	57
L-63S upstream		6.49	57.2	159	161	28
L-63S downstream		7.08	93.1	559	394	29
L-63S @ pipe	10/24/03	6.64	67.9	229	120	82
L-63S upstream		6.66	57.2	176	130	20
L-63S downstream		7.18	94.2	292	80	47
L-63S @ pipe	10/31/03	6.60	46.4	26	191	100
L-63S upstream		6.33	50.9	76	323	21
L-63S downstream		6.61	65.0	597	191	42
L-63S @ pipe	11/12/03	6.71	34.7	51	231	80
L-63S upstream		6.56	51.2	132	343	22
L-63S downstream		6.52	57.1	512	323	46
L-63S @ pipe	11/13/03	6.67	41.0	53	506	80
L-63S upstream		6.75	59.6	96	272	21
L-63S downstream		6.81	68.1	475	302	43
L-63S @ pipe	11/14/03	5.57	21.1	58	661	94
L-63S upstream		6.97	51.1	43	319	21
L-63S downstream		7.11	81.3	380	391	39

Substantial reductions in measured total phosphorus concentrations are apparent for samples collected adjacent to the outflow pipes entering the L-63S Canal during operation of the alum treatment system, compared with pre-treatment characteristics measured on September 22, 2003. Increases in measured sulfate concentrations were observed in the canal immediately adjacent to the pipe discharge. However, at the downstream monitoring location, located approximately 200 ft downstream from the point of inflow for Lettuce Creek, measured post-treatment characteristics appear to be similar to pre-treatment characteristics for each of the measured parameters.

6.5 Economic Analysis

An economic analysis was performed to estimate the cost per mass removal for suspended solids and total phosphorus in the CDS and TST units using supplemental alum coagulation for enhancement of solids and phosphorus removal. Approximate construction costs for the unmodified CDS and TST units are summarized in Table 5-32. Additional components necessary for alum addition, including chemical feed pumps, storage tanks, piping, and metering equipment, would increase the cost by approximately $20,000 for a permanent installation.

A summary of estimated O&M costs for alum treatment of Lettuce Creek flow, using the CDS and TST units, is given in Table 6-10, based upon applied doses of 12.5 mg Al/liter for alum and 10 ppm for polymer. This analysis assumes that alum treatment will occur at a flow rate of 1 cfs to maximize floc retention within each unit. Based upon historical flow records for Lettuce Creek, provided by the District, for the period from February 27, 1997-January 24, 2004, the flow rate in Lettuce Creek was equal to or greater than 1 cfs for a total of 1056 days during the 6.91-year period, or approximately 153 days/year. As a result, estimated O&M costs for alum treatment of Lettuce Creek flow are calculated based on the assumption that the system will operate approximately 153 days/year.

At a flow rate of 1 cfs, alum treatment of Lettuce Creek in either the CDS or TST unit will require approximately 138 gallons of alum per day or 21,114 gallons/year. At a unit cost of $0.55/gallon, annual alum costs will be approximately $11,613. Alum treatment of Lettuce Creek flow will also use approximately 4.85 gallons of polymer per day or 742 gallons/year. At a unit cost of $50/gallon, annual polymer cost will be approximately $37,103.

In general, floc generation at the recommended alum treatment dose for Lettuce Creek will be equal to approximately 0.2% of the treated volume. Based upon a mean flow rate of 1 cfs, floc generation will be approximately 172 ft^3/day at a typical density of 1.05 kg/liter, the generated floc will be approximately 11,270 lbs/day or 5.64 tons/day. At a disposal cost of $100/ton, the annual disposal cost will be approximately $86,292. However, this value is based upon the in-place wet floc volume. Since alum floc is approximately 95-98% water, substantial savings in disposal costs can be achieved by initial dewatering of the floc in a drying bed or other structure prior to disposal.

TABLE 6-10

ESTIMATED O&M COSTS FOR ALUM TREATMENT OF LETTUCE CREEK FLOW (Based on 153 days/year of operation)

PARAMETER	ASSUMPTIONS	ANNUAL COST ($)
Chemical Costs	a. 138 gallons alum/day = 21,114 gallons/yr @ $0.55/gallon b. 4.85 gallons polymer/day = 742 gallons/yr @ $50/gallon	11,613 37,103
Solids Generation/ Disposal	a. Assume 172 ft^3/day of floc @ density = 1.05 = 11,270 lbs/day = 5.64 tons/day b. Disposal costs of $100/ton	86,292
Vactor Fee	a. $200/hr including travel b. 1 cleaning/day @ 4 hours/cleaning	122,400
Mowing	a. Mowing in vicinity of structures once/month b. Cost of $75/mowing event	900
	TOTAL:	$ 258,308

Based upon the assumed generated floc volume of 172 ft^3/day, daily floc removal will be required for both the CDS and TST units. Assuming four hours/day for cleaning, including travel time, and a rate of $200/hour for the vactor vehicle, annual cleaning costs for the CDS or TST unit would be $122,400. Costs are also included in Table 6-10 for monthly mowing in the vicinity of the structures. Based upon a cost of $75/mowing event, annual mowing costs are estimated to be approximately $900. Based upon the costs outlined previously, annual O&M costs for alum treatment of Lettuce Creek in either the TST or CDS unit is approximately $258,308/year.

Calculated present worth costs for alum treatment in the CDS and TST units are given in Table 6-11 based upon a 20-year life-cycle cost and an interest rate of 4%/year. Calculated 20-year present worth cost for the CDS unit is approximately $3,647,090, with a present worth cost of $3,601,621 for the TST unit.

TABLE 6-11

CALCULATED PRESENT WORTH COSTS FOR ALUM TREATMENT IN THE CDS AND TST UNITS

UNIT	CAPITAL COSTS ($)		ANNUAL O&M ($)	PRESENT WORTH ($)
	UNIT	ADD. ALUM COMPONENTS		
CDS	116,684	20,000	258,308	3,647,090
TST	71,216	20,000	258,308	3,601,621

Estimated costs per mass removal for alum treatment in the CDS and TST units are given in Table 6-12. For purposes of this analysis, it is assumed that a flow rate of 1 cfs will be treated for 153 days/year. The average total phosphorus concentration for Lettuce Creek is assumed to be 898 μg/l based upon the inflow monitoring performed from November 2002-November 2003 summarized in Table 5-4. Similarly, a mean inflow TSS concentration of 12.7 mg/l is assumed. Removal of total phosphorus and TSS by the alum treatment is assumed to be approximately 90%, although laboratory testing suggests that the actual removal may be substantially greater than 90%. Based upon these assumptions, alum treatment in either the CDS or TST unit will remove approximately 85,556 kg of TSS over a 20-year period, with a corresponding removal of 6050 kg of total phosphorus.

TABLE 6-12

ESTIMATED COSTS PER MASS REMOVAL FOR ALUM TREATMENT IN THE CDS AND TST UNITS

ITEM	CDS UNIT	TST UNIT
Estimated Removal Over 20-year Period	85,556 kg TSS 6050 kg TP	85,556 kg TSS 6050 kg TP
Cost per kg Removed[1]	$42.63/kg solids $603/kg TP	$42.10/kg solids $595/kg TP

1. Based on 20-year present worth costs

Estimated costs per mass removal for the CDS and TST units, based upon the 20-year present worth costs presented in Table 6-11, are summarized at the bottom of Table 6-12. Based upon the 20-year present worth costs, solids removal in the CDS unit will cost approximately $42.63/kg, with an estimated total phosphorus removal of $603/kg. Removal costs for the TST unit are slightly lower due to the lower initial capital costs. Estimated cost per kg removed in the TST unit is $42.10/kg TSS and $595/kg for total phosphorus.

The cost per mass removal for total phosphorus using alum treatment is substantially lower than the cost for phosphorus removal without alum treatment, as summarized in Table 5-35. However, the phosphorus removal costs, ranging from $595-603/kg, are still substantially greater than similar life-cycle phosphorus removal costs for previous alum treatment projects designed by ERD. The elevated costs for alum treatment in the CDS and TST units are due primarily to the frequent solids handling required by these relatively small units. The most cost-effective method for solids handling in an alum treatment process is to use a larger settling basin which can be dewatered, substantially reducing the floc volume and frequency of disposal.

6.6 Conclusions

Alum treatment of tributary discharges appears to be a feasible alternative for reduction of phosphorus loadings discharging into Lake Okeechobee. Chemical coagulation of tributary inflow not only removes particulate phosphorus but provides the additional benefit of substantial removal of dissolved phosphorus species as well. The field testing performed during this project has clearly demonstrated that significant removal of total phosphorus concentrations can be achieved using this methodology.

However, the design of the CDS and TST units does not appear to be optimum for retaining all of the floc generated during this process. A more complete removal of floc particles could be achieved by extending the detention time to approximately 15-30 minutes. If additional detention time was available, the applied dose of alum and polymer could be reduced substantially while still achieving the same removal effectiveness, since the primary role of the elevated dose of alum and polymer is to create rapid settling within a period of a few minutes.

SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

From the field monitoring and laboratory activities performed as part of the Lake Okeechobee Sediment Removal Demonstration Project, the following specific conclusions have been reached:

1. Discharge rates in Lettuce Creek were found to be highly variable during the monitoring period from November 1, 2002 to December 1, 2003, with discharge regulated primarily by rain events within the watershed. During dry season conditions, approximately 90% of the mean daily discharge rates were less than 10.5 cfs, with 90% less than 95.4 cfs under wet season conditions.

2. Water flowing through Lettuce Creek was found to exhibit a high degree of variability in measured concentrations of dissolved organic phosphorus, particulate phosphorus, total phosphorus, TSS, and turbidity. Measured concentrations of organic phosphorus, particulate phosphorus, and total phosphorus cover several orders of magnitude between the minimum and maximum values, with dissolved organic phosphorus ranging from 7-1039 μg/l, particulate phosphorus ranging from 22-3845 μg/l, and total phosphorus ranging from 345-5575 μg/l. On an average basis, approximately 61% of the total phosphorus measured in Lettuce Creek is comprised of dissolved orthophosphorus, with 16% comprised of dissolved organic phosphorus and 23% contributed by particulate phosphorus.

3. Approximately one-third to one-half of the particulate matter discharging through Lettuce Creek is comprised of particles less than 11 microns (μm) in size. These particles are comprised primarily of organic matter with an elevated concentration of total phosphorus and an extremely slow settling velocity. Much of the remaining particulate matter discharging through Lettuce Creek, particularly under high flow conditions, appears to be comprised of fine sand which has a low organic content and a low phosphorus concentration.

4. Significant correlations between Lettuce Creek flow rates and chemical characteristics of Lettuce Creek water were observed only for orthophosphorus, total phosphorus, and DOC. Discharge rates through Lettuce Creek did not exhibit strong significant relationships with particulate nitrogen, particulate phosphorus, turbidity, or TSS.

5. Sediment core samples collected in upstream portions of Lettuce Creek during July, August, and October 2003 suggest that mobilization and transport of surficial sediments occurs within the creek during periods of high flow conditions. This mobilization and transport carries particles containing total nitrogen and total phosphorus, since substantial decreases in surficial sediment concentrations of these parameters were observed following elevated flow conditions. It appears that sediments accumulate within the creek during low flow conditions and become mobilized during high flow conditions. The analyses suggest that sediment transport is limited to the top 0-1 inch layer of sediments within Lettuce Creek.

6. More than 90% of the sediment particles collected from Lettuce Creek consist of fine and medium sand particles with a diameter in excess of 100 μm. Although these particles are characterized by relatively fast settling velocities, very little total phosphorus is associated with these particles. Extremely elevated total phosphorus concentrations were observed in smaller diameter particles, particularly particles less than 11 μm in size. However, these particles comprise approximately 3% or less of the total sediment mass within Lettuce Creek. A significant decrease in the proportion of these smaller particles was observed in the creek following high flow conditions.

7. Virtually no mass removal was observed in the CDS unit during operation at a flow rate of 1 cfs. Inflow and outflow concentrations from the unit appear to be virtually identical, with a slight increase observed between inflow and outflow for many measured parameters, although the differences are not statistically significant. On an average basis, the mass of particulate phosphorus increased by approximately 14% during migration through the CDS unit, with a 4% increase in total phosphorus, 4% increase in total nitrogen, 4% reduction in TSS, and 5% reduction in turbidity. The lack of mass retention in the CDS unit is related to several factors, including the general lack of particulate matter in Lettuce Creek, the relatively large size of particles which exist within Lettuce Creek, the lack of significant phosphorus associations with particulate matter, and the presence of fish species within the units which released waste products into the water column on a continuous basis.

8. Virtually no significant removals were observed for any measured parameters within the TST unit during operation at the flow rate of 1 cfs. Mean inflow and outflow characteristics for the TST unit are virtually identical for all measured parameters. This is in contrast to the apparent slight increase in chemical characteristics observed between the inflow and outflow within the CDS unit. On an overall mass removal basis, orthophosphorus concentrations were reduced by 5% during migration through the TST unit, with an 8% reduction in dissolved organic phosphorus, 16% increase in particulate phosphorus, and 1% increase in total phosphorus. An overall increase of 4% was observed for total nitrogen. However, approximately 10% of the TSS mass was retained within the system.

9. Large accumulations of fish, primarily catfish, were observed in both the CDS and TST units throughout the monitoring program, numbering in excess of 100 in each of the two units on many occasions. Numerous efforts were undertaken to both remove these fish and prevent them from entering the units. However, these efforts were largely unsuccessful. Accumulation of fish was a particular problem in the CDS unit since the fish had no avenue of escaping the unit once they entered the center sump area. Impacts from fish wastes, from both living and dead organisms, are apparent throughout the monitoring data, particularly for TKN, particulate nitrogen, and particulate phosphorus. However, since this project is designed to demonstrate the feasibility of using solids removal units in tributaries, accumulation of fish within the units is thought to represent a likely operating condition which would also occur at other locations.

10. No significant removal of any measured parameter was observed within the CDS unit during operation at 5 cfs. At this flow rate, nitrogen remained unchanged during migration through the unit, while the mass of phosphorus increased by 3%. However, at a flow rate of 11 cfs, approximately 10% of the total nitrogen was retained within the unit, with 55% of the particulate phosphorus, 5% of the total phosphorus, and 43% of the suspended solids. The operation of the CDS unit appears to be best at the highest flow rate. These findings may be related to operational characteristics within the CDS unit which were visually observed during this project. At low flow rates, the vortex activity, responsible for the removal of suspended solids, was not observed within the CDS unit. However, at more elevated flow rates, the vortex activity was clearly evident. This may partially explain the enhanced removal efficiency at higher flow rates in the CDS unit.

11. Virtually no significant mass removal was observed within the TST unit during operation at either 5 or 11 cfs. At a flow rate of 5 cfs, approximately 4% of the total nitrogen mass was removed, along with 1% of the total phosphorus. A net export of suspended solids was observed at this flow rate. At a flow rate of 11 cfs, approximately 2% of the total nitrogen was retained within the unit, while a net export of 1% was observed for total phosphorus.

12. During an operational period of 207 days, with a total flow-through volume of 815.2 ac-ft, the CDS unit removed approximately 766.2 kg of dry solids from Lettuce Creek. This material was approximately 0.14% total phosphorus by weight and 0.44% total nitrogen by weight. Over the 207-day operation period, the CDS unit exhibited an average TSS removal of 0.76 mg/l, with a mean total phosphorus removal of 1.1 μg/l, and a mean total nitrogen removal of 3.4 μg/l. The TST unit was operated for a period of 193 days, with a total flow-through volume of 581.2 ac-ft, and removed 408.8 kg of dry solids which was 0.14% total phosphorus by weight and 0.14% total nitrogen by weight. On an average basis, the TST unit removed an average of 0.57 mg/l of TSS, 0.79 μg/l of total phosphorus, and 0.77 μg/l of total nitrogen.

13. Sediments collected from the TST and CDS units consisted primarily of fine sand in the 100-850 μm range. In general, the TST unit appears to collect a slightly smaller range of particle sizes, with larger particle sizes collected in the CDS unit.

14. Based upon the results obtained during the monitoring program and extrapolation to a 20-year life-cycle period, the CDS unit is expected to remove 27,021 kg of solids, 39.0 kg of total phosphorus, and 119.4 kg of total nitrogen. Based upon a 20-year present worth cost of $143,117 for the CDS unit, mass removal costs are approximately $5.30/kg ($2.40/lb) of solids, $3670/kg ($1664/lb) of total phosphorus, and $1199/kg ($544/lb) of total nitrogen. The estimated cost per mass removal for TSS is similar to costs exhibited by other stormwater retrofit projects. However, the cost per mass pollutant removed for total phosphorus and total nitrogen in the CDS unit substantially exceeds mass removal costs for other typical stormwater retrofit projects.

15. Over a 20-year life-cycle period, the TST unit is expected to remove 15,462 kg of solids, containing 21.3 kg of total phosphorus and 20.9 kg of total nitrogen. Based upon a 20-year present worth cost of $96,086 for the TST unit, the 20-year life-cycle mass removal cost is approximately $6.21/kg ($2.82/lb) of solids, $4511/kg ($2046/lb) of total phosphorus, and $4597/kg ($2085/lb) of total nitrogen. Although the TSS cost is similar to other stormwater retrofit projects, the cost per mass of total phosphorus and total nitrogen removed substantially exceeds costs achieved by other projects.

16. Alum treatment of tributary discharges resulted in a substantial reduction of phosphorus species discharging through Lettuce Creek. Based on laboratory and field testing performed during this project, chemical coagulation of tributary inflow is expected to remove more than 90% of TSS and total phosphorus. Chemical coagulation of tributary flow not only removes particulate phosphorus but provides removal for dissolved phosphorus species as well. However, chemical coagulation of tributary inflow would be more effective utilizing a settling basin for collection of generated floc rather than attempting to collect the floc in either the CDS or TST units.

17. Using a treatment system designed for 1 cfs, alum coagulation is expected to remove approximately 85,556 kg of TSS and 6050 kg of total phosphorus over a 20-year life-cycle period. Based upon a 20-year present worth cost of $3,647,090 for the CDS unit, the 20-year life-cycle mass removal cost using alum treatment is approximately $42.63/kg of solids ($19.33/lb) and $603/kg of total phosphorus ($273/lb). Using the TST unit and a 20-year present worth cost of $3,601,621, mass removal costs are approximately $42.10/kg ($19.09/lb) of TSS and $595/kg ($270/lb) of total phosphorus. The cost per mass of total phosphorus removed using alum treatment is substantially less than the cost per mass of phosphorus removed using the unmodified CDS and TST units.

7.2 Recommendations

The use of CDS and TST units for removal of particulate phosphorus in tributaries discharging to Lake Okeechobee does not appear to be a feasible nutrient reduction alternative. Only approximately 30% of the total phosphorus discharging through Lettuce Creek is particulate in nature, with less than 10% of the total nitrogen comprised of particulate species. The vast majority of particulate phosphorus is associated with relatively small particles, primarily organic in nature, which have an extremely slow settling rate. The residence time provided by CDS and TST units is clearly insufficient to affect significant settling of these particles.

The use of alum coagulant significantly enhanced the overall performance efficiency of these systems. Alum treatment is effective not only in reducing particulate phosphorus but also for reducing both dissolved inorganic and organic phosphorus species. However, to be an effective treatment alternative, longer residence times would be needed to reduce the required chemical dosage rates and provide for complete settling of the alum floc generated during the precipitation process.

Based upon the extremely small size of the phosphorus-laden particles in Lettuce Creek, combined with the fact that only approximately 23% of the total phosphorus discharging through the tributary is particulate in nature, there appears to be no feasible modifications which could be made to either the CDS or TST units to substantially enhance removal of phosphorus within these units. Significant removal of extremely small diameter particles and dissolved phosphorus species can only be achieved using either chemical coagulation or a relatively long detention time in a pond or reservoir environment. Based on initial characterization studies performed on Lettuce Creek water samples, the vast majority of particulate phosphorus in Lettuce Creek is associated with particles less than 11 microns in size with an estimated settling velocity of approximately 10^{-6} meters/sec. Under perfectly quiescent conditions, settling of these particles in a water column 2 m deep would require approximately 23 days. As a result, any pond system designed to remove particulate phosphorus from tributary inflow would need to have a detention time of approximately 50 days, assuming a safety factor of 2 to account for turbulence within the pond.

The use of CDS and TST technologies appears to be more suited to an urban environment where particle sizes would likely be larger. Although TSS removals may be enhanced in an urban environment, these units may still not be capable of removing a significant quantity of total nitrogen and total phosphorus from runoff flow.