An Evaluation of Innovative Stormwater Treatment Technology Installations Designed to Mitigate Storm Drain Pollution Impacting Shellfish Beds at Wychmere Harbor, Harwich and the Jones River, Gloucester, Massachusetts

Section 319 NPS Project #95-02

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AND

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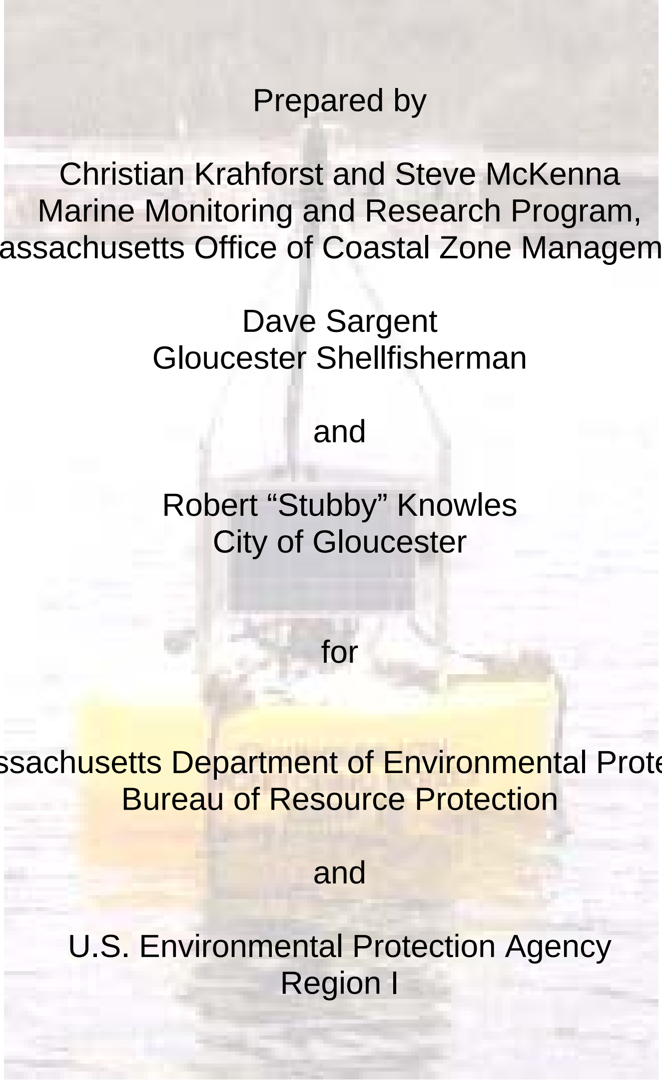
1998 – 1999



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Executive Summary

In 1998, the newly formed Marine Monitoring and Research Program of the Massachusetts Office of Coastal Zone Management, with funding from Section 319 of the Federal Clean Water Act (§ 319), began investigating the performance of StormTreat™ System (STS) installations in treating stormwater runoff at two locations in Massachusetts: along the Jones River, Gloucester, and adjacent to the parking lot of the Wychmere Harbor town pier, Harwich. STS is an innovative stormwater treatment technology that uses a combination of sedimentation, filtration, and constructed wetlands to remove a wide range of contaminants from stormwater runoff.

The installations of STS were performed in 1994 by the towns of Harwich and Gloucester for the purposes of controlling and treating contaminant loading from storm runoff to the local receiving waters. These installations were designed to capture the early portion of stormwater from the immediate impervious surfaces. Generally thought to be the most contaminated portion of a rainstorm, this first flush (FF) entrains and remobilizes contaminants that have accumulated during dry periods between rain events. The monitoring initiated under this project was designed to first evaluate appropriate sampling strategies, utilizing tracer studies to determine FF flow through characteristics of each STS, and then determine the removal efficiencies of contaminants of concern from FF runoff.

This report summarizes the field studies conducted in the fall of 1998 and the spring of 1999 at the STS sites in Gloucester and Harwich. The goals of these studies were to evaluate the variability of FF residence time between locations, to determine when and how to capture FF element of discrete storm events, and evaluate STS in the treatment of fecal coliform, dissolved nutrients (nitrate+nitrite, ammonia, orthophosphate), total Kjeldahl nitrogen, total phosphorous, selected trace metals, and total suspended solids. It is important to note that the main objective of evaluating these systems to remove contaminants from FF runoff was not achieved because these STS were installed and/or sited improperly, rendering their performances to capture, contain, and release treated FF stormwater as ineffectual. These performances were illustrated by tracer dye studies performed during Phase I of this project.

Tracer samples collected in the effluent of the STS units at the Wychmere Harbor town pier in Harwich and two subsites along the Jones River in Gloucester indicate these systems do not perform as designed for the treatment of FF. In Harwich, the STS units are very close to mean high water and are subjected to saltwater intrusion either from infiltration, overwash, or sea spray. Salinity measurements of effluent samples collected during the dye experiment show portions of this system are saturated with salt water and are therefore not able to capture FF as designed. The tracer studies conducted at two subsites along the Jones River in Gloucester gave measurable but very different results for calculating FF residence times. FF stormwater runoff through the Gloucester

systems ranged from fairly rapid (on the order of hours) to several days. Additionally, none of the STS units installed in either Gloucester or Harwich have been able to sustain a viable wetland plant component of the STS design.

Both installations have shown greatly varying flow through characteristics of FF runoff. In each instance, issues associated with installation of STS are thought to be largely responsible for the variability in both the timing and duration of FF as it moves through the STS. The implication from this study is that most installations of stormwater treatment technologies to date may not be uniform in their ability to treat stromwater runoff due in large part to faulty installation designs. The development of meaningful site evaluation criteria and detailed consistent installation protocols for the installation of innovative stormwater technologies would provide benefits in both sound installation practices and the utility of these types of remediation efforts. In addition, future installation practices of these and other innovative stormwater technologies should include a measure of flow through performance as part of the installation certification process. Because of the highly variable FF flow through characteristics and the failure to establish a viable constructed wetland component at each installation studied in this project, further evaluation of the STS effectiveness in contaminant removal would be meaningless since these systems do not perform as designed.

DISCLAIMER

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1.0 INTRODUCTION

This report summarizes an evaluation of StormTreat™ System (STS) installations performed in 1994 in the City of Gloucester and the Town of Harwich, Massachusetts for stormwater pollution remediation. This project has been financed with federal funds from the Environmental Protection Agency (EPA) to the Massachusetts Department of Environmental Protection (DEP) under a Section 319 (§ 319) competitive grant. This project is sponsored under an award to the Massachusetts Bays Program Shellfish Bed Restoration Program (MBP/SBRP) on behalf of the Town of Harwich and the City of Gloucester, Massachusetts.

When the § 319 grant was awarded, the Massachusetts Bays Program (MBP) coordinated an interagency program, the Shellfish Bed Restoration (SBR) Program to help mitigate sources of pollution to contaminated shellfish beds in the communities of Massachusetts and Cape Cod Bays region. The SBR program identified the STS System as a promising technology that could help remedy nonpoint source pollutant problems that contribute to localized shellfish bed closures. The SBR program at MBP dissolved in 1996, and in 1998, the Marine Monitoring and Research Program of the Massachusetts Office of Coastal Zone Management (CZM) carried this project to its completion.

The STS was a new technology (in 1994) and has been installed in a number of locations in Massachusetts. A monitoring program carried out by the manufacturer (StormTreat™ Systems, Inc.) at an installation in Kingston, MA indicates relatively high levels of contaminant removal by STS from stormwater runoff. These systems appear to be appropriate for treating the early portion of stormwater runoff events when sized (i.e., appropriate number of STS units installed) according to the surrounding impervious drainage area. Since the selected sites in Harwich and Gloucester have documented fecal coliform bacteria pollution, the STS was chosen due in part due to demonstrated treatment of fecal coliform. See http://www.stormtreat.com/stsdata.html for a summary of their pollutant removal data. Other reasons for selecting the STS for these locations include its compact size, easy maintenance (see Appendix 2) and demonstrated treatment of a broad range of pollutants (bacteria, metals, nutrients and petroleum hydrocarbons).

1.1 Goals and Objectives:

The project's overarching goals were to:

- ❑ improve coastal water quality,
- ❑ protect and/or help reclassify shellfish beds for increased commercial or recreational harvesting,
- ❑ demonstrate best management practices to mitigate storm drain-related water quality problems impacting living resources, and

- demonstrate the effectiveness of the STS system as an innovative nonpoint source remediation technology.

Little or no independent information existed on the effectiveness of stormwater pollution remediation for the new types of innovative stormwater treatment technologies. A monitoring program was the key objective of the project in achieving these goals. The monitoring program has the specific purpose of determining whether the STS at these installations are effective at removing a wide range of contaminants associated with first flush (FF) stormwater runoff. The project results will provide insight into factors contributing to the effectiveness of the overall technology on stormwater-related pollution.

The project's monitoring plan was designed to produce the data necessary to evaluate the ability of STS in removing contaminants associated with FF. Specific details of the monitoring plan can be found in the project's Quality Assurance Program Plan (QAPP): *Stormwater Quality Sampling and Analysis from the StormTreat™ Systems in Harwich and Gloucester, June 6, 1998.* A copy of the QAPP may be obtained in full from:

Arthur Screpetis,
Dept. of Environmental Protection
627 Main St.
Worcester, MA 01608.

An overview of the QAPP is provided in Section 2, Technical Approach.

1.2 Study Area:

The performance of STS in treating stormwater FF runoff was conducted at the following three sites:

- One site in the Town of Harwich on the Town Pier at Wychmere Harbor - a small road/parking lot-drainage system which discharges directly into Wychmere Harbor. This site is served by a STS installation with six tanks.

- Two sites along the Jones River in the City of Gloucester adjacent to Atlantic Street known as the "Trailer Park". The first site, known as "Paved Road" has two STS Tanks, and the second site, known as the "Snack Bar", consists of four STS Tanks. A third site was originally proposed at the intersection of Atlantic and Concord Streets, but was later withdrawn from the project due to overwhelming complications of groundwater infiltration and the concurrent contamination from septic systems discharges.

The general locations of these two sites are depicted below in Figure 1.

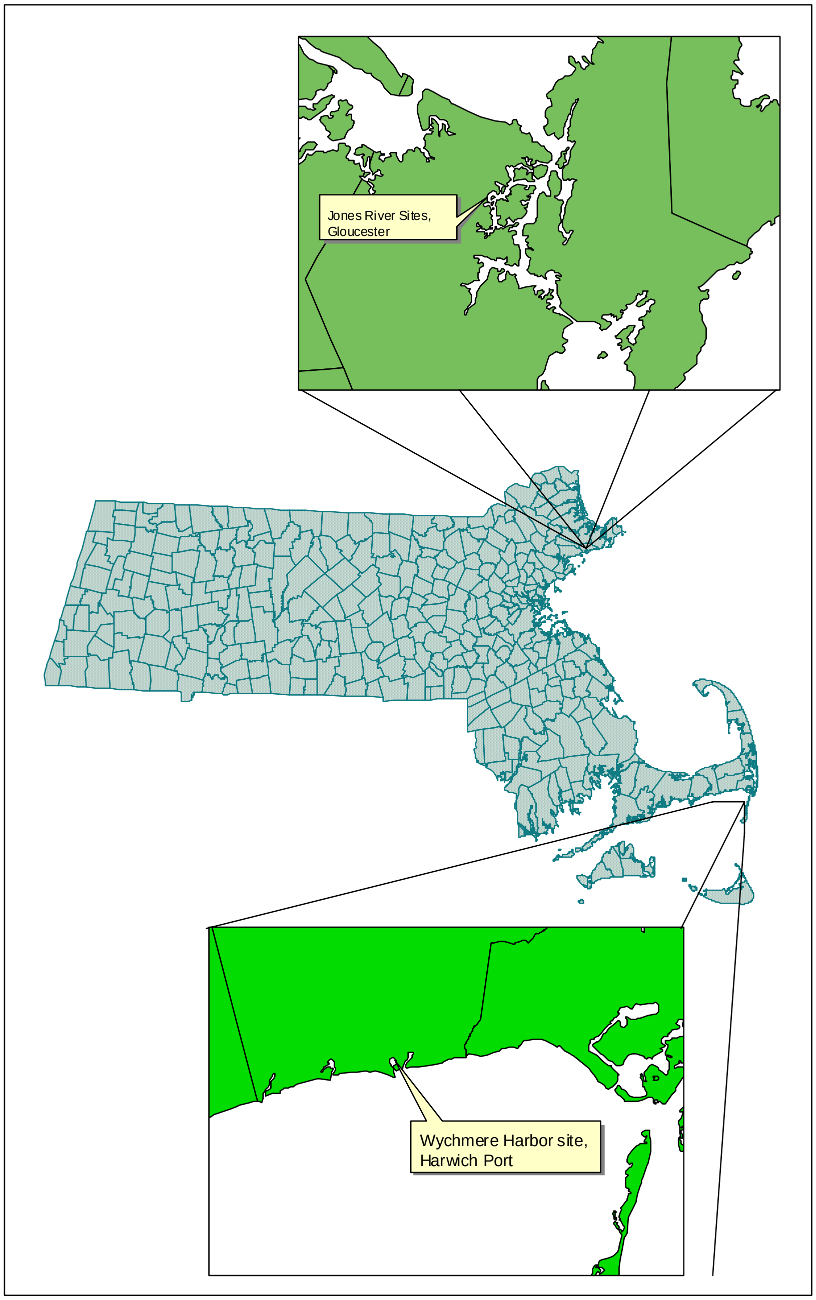

Figure 1. Relative locations of STS installations in Gloucester and Harwich, Massachusetts.

1.3 Background

Nonpoint source (NPS) pollution, unlike pollution from industrial and sewage treatment plants, originates from diffuse sources. Aqueous NPS pollution is caused either by rainfall or snowmelt moving over and through the ground. This runoff carries with it natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and underground sources of drinking water. Typically, the major load of total pollutants occurs shortly after the onset of a rain event. This "first flush" of pollutants occurs when all the pollutants already present in rain and those that have accumulated on streets, gutters, roofs and land between rain events (i.e. dry deposition) are washed off, and essentially “pulsed” into receiving waters such as local creeks, streams, rivers and coastal waters via storm drains *(1)*.

Stormwater runoff is now recognized as a critical component to the degradation of the environmental quality of wetlands and receiving waters in both fresh and coastal environments. Stormwater runoff from impervious and semi-pervious land surfaces often carries substantial amounts contaminants such as solids (branches, paper, plastics, cigarette filters), pathogens (bacteria, viruses), inorganic constituents (heavy metals, especially zinc, copper, and cadmium), organic compounds (e.g., pesticides, PCBs, petroleum hydrocarbons), and nutrients (e.g., nitrogen and phosphates) *(2,3)*. Although these pollutants are not routinely monitored in coastal waters containing shellfish, some these pollutants have been shown to have sub-lethal effects on shellfish and bio-accumulate in fish tissue (*4*). These complex contaminant mixtures are routinely discharged into wetlands, streams, lakes and ultimately, coastal waters.

Many pollutants associated with stormwater runoff are particle-reactive; that is they absorb to particles transported in stormwater runoff and are ultimately deposited in sediments (*5,6*). Some contaminants in runoff, such as oil and grease, are hydrophobic, i.e., they float, degrading valuable habitat at the water/air interface and diminishing aesthetic values as well. Thus, effective stormwater management necessitates a mixture of strategies, e.g., sedimentation as well as filtration and screening, to remove the complex phases that combine to pollute receiving waters.

Several researchers have proposed sedimentation basins and constructed wetlands as effective methods of minimizing stormwater pollution. "The Use of Wetlands for Controlling Stormwater Pollution” summarizes 20 stormwater projects throughout the United States *(7)*. Mitsch and Gosselink discuss the benefits of constructed wetland systems to reduce pollutant impacts *(8)*. However, a common problem in maintaining constructed wetlands has been controlling water levels. Constructed wetlands are typically open-air systems, subject to extensive evaporation, which can desiccate wetland plants, thereby reducing the effectiveness of the constructed wetlands approach in pollutant load attenuation.

1.4 StormTreat™ System Technology

The StormTreat™ System (STS) is an innovative stormwater treatment technology for treatment of FF runoff consistent with Standards 4 and 6 of the Stormwater Management Handbook (*9*). STS operates in principle by controlling the water level in its tanks and in the surrounding constructed wetlands through an enclosed system design. STS uses a pre-fabricated structure to provide stormwater treatment via sedimentation, oil and grease separation, and filtration (by biological filters and sand), together with constructed wetlands that surround each unit's perimeter. A catch basin or other structure upstream from a STS tank collects stormwater runoff from the road surface. Stormwater fills the catch basin to a certain level, above which it overflows into a pipeline connected to the STS tank (Figure 2). STS design optimizes stormwater flow rates through the system to maximize sedimentation rates, filtration efficiency, and biochemical attenuation within the root zone of the constructed wetland. Outflow rates of 0.25 gal. min^{-1} (recommended by STS) results in 5 day residency time if fully charged. Outflow rate can be adjusted by an adjustable valve located in the effluent pipe. Each unit has a storage capacity of approximately 1400 gal. The effluent outlet (from a biofilter) is designed to leave sufficient water (approximately 6 in. water level) for plant growth between storm events.

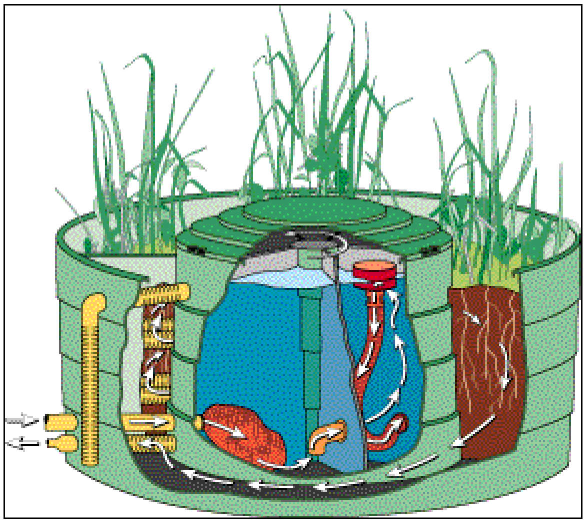

Figure 2. Schematic of StormTreat™ System, reprinted from http://www.stormtreat.com/stsdata.html.

1.5 *Specific Rationale and Installation, Wychmere Harbor, Harwich*

On December 3, 1989, the Massachusetts Division of Marine Fisheries (DMF) completed a Sanitary Survey of Shellfish Classification Area 40 (SC40). SC40 is located in Wychmere Harbor, in Harwich, starting at the breakwaters and extends out into Nantucket Sound. In its report, DMF observed that discharges from a stormdrain pipe at this project site were the major source of elevated counts of fecal coliform. These elevated counts resulted in the closure of shellfish beds in area SC40.

The status of SC:40 has improved. On October 1, 1995, SC:40 was reclassified as conditionally (seasonally) approved with an open status from November 1 through June 30 and a closed status from July 1 through October 30. This stormwater mitigation project is intended to sustain the improvements in water quality recently observed at classification area SC:40.

Recent water quality improvements are probably related both to the remediation of local nonpoint sources and recent changes in land use in the area. There have been several nonpoint source remediation efforts by the town. A new tight tank system was installed for the town-operated restroom facilities at the boat ramp and marina area on Lower County Road in 1994. A mobile pump-out boat was also put into operation in 1994, servicing Allen's Harbor. The Snow Inn Complex has been vacated since the last shoreline survey undertaken by DMF in 1992, with the exception of the some offices. These changes have reduced flows of domestic wastewater to the Harbor.

Funded under the §319 grants program, the STS installation at Harwich was designed and has been built to help remedy pollution loading and subsequent contamination of shellfish beds in Wychmere Harbor from stormwater runoff along the Harbor Road area and the parking lot. Figure 3 displays the general location of the STS installation relative to Wychmere Harbor.

StormTreat™ Systems, Inc. contracted with the Town of Harwich to install and test four units (tanks) of this innovative technology in the parking lot at the Town pier off Harbor Road. The system was first installed in December 1995, and has undergone a number of design changes in order to address problems with control of dry-weather flows and tidal inflow. Figure 4 shows the impervious surface drainage area relative to the location of the STS installation adjacent to the Town pier parking area. The system is designed to capture and treat the FF of stormwater runoff (defined here as the runoff associated with the first one-half inch of rain). The impervious area of the drainage area on Harbor Road is estimated at 24,000 square feet. One-half inch of runoff over this area generates approximately 8,400 gallons of stormwater, the amount to be stored by the overall STS installation.

Runoff from the storm drain pipe on Harbor Road is directed to a catch basin in the parking lot (Catch Basin #2, Figure 5), which also receives flow from a second catch basin draining the parking lot (Catch Basin #1). Flow from Catch Basin #2 is then directed to two 1500-gallon septic tanks preceding the four STS tanks. The addition of septic tanks to this design increases the holding capacity of FF and provides some measure of total suspend solid pretreatment. The four STS tanks each have a capacity of 5,600 gallons, and the two catch basins each a capacity of 1,000 gallons. Flow from the FF is diverted from Catch Basin #1 until the STS tanks are full. Once the tanks are full, the remaining runoff bypasses the STS tanks and flows directly to Wychmere Harbor.

Figure 3. Location of the STS units relative to Wychmere Harbor in Harwich.

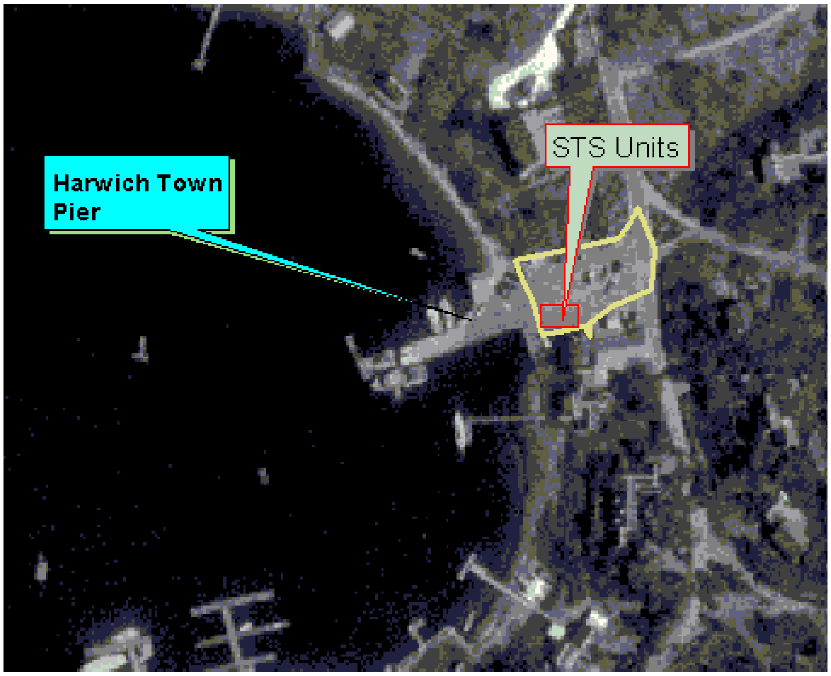

Figure 4. Relative location of STS installations to the Wychmere Town Pier and adjacent drainage area.

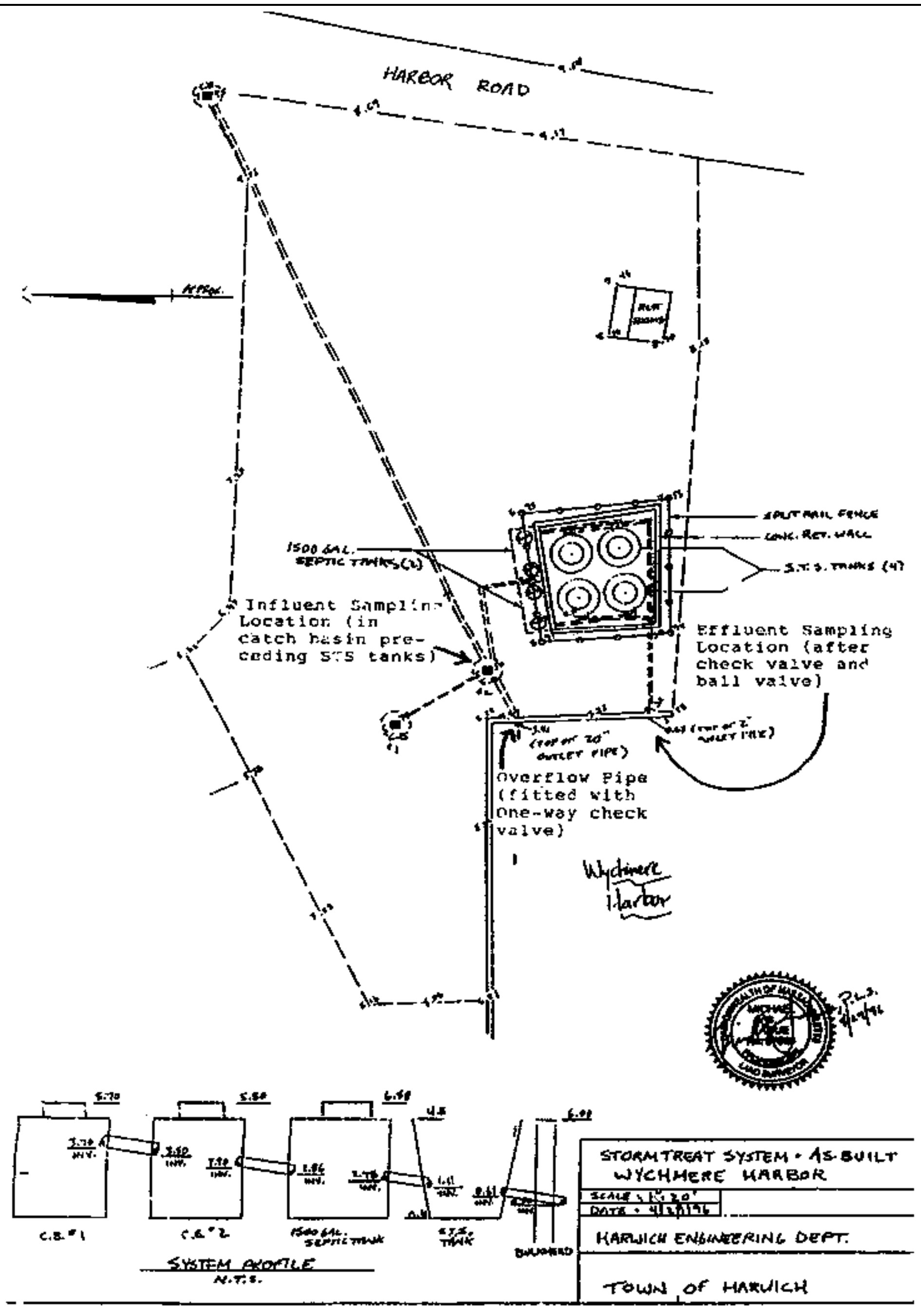

Figure 5. Schematic of the Wychmere Harbor StormTreat System and Sampling Locations.

1.6 Specific Rationale and Installation, Jones River, Gloucester

Along the Jones River in Gloucester, stormwater runoff, animal waste, and failing septic systems are suspected as significant pollution sources contributing to the shellfishing closure of highly productive shellfish beds. Over the past several years, increasing acreage within shellfish classification area N 9.8 (formerly designated as areas N: 9.4 CP and N: 9.4 JR) has been added to DMF's closure list. In 1994, all areas within the Jones River were posted off-limits to shellfishing. Adjacent areas are also threatened with closure. Municipal and state authorities are concerned that closures in the area will continue to spread unless measures to mitigate pollution associated with stormwater runoff at Atlantic Street are implemented.

In the immediate vicinities of Atlantic Street and Cedarwood Road, investigations by the Gloucester Engineering Department and Robert Knowles, Shellfish Officer of the City of Gloucester, have documented onsite wastewater disposal in this area influence both stormwater runoff and groundwater and is most likely contributing to elevated fecal coliform levels. In 1999, the DMF re-classified the Jones River area from Prohibited to Conditional Approved (Seasonal) and is now open for harvesting from December 1 to April 1. DMF credits this improvement to local efforts that corrected failed septic systems.

In June 1994, the City of Gloucester, under a grant from the Section 319 of the Clean Water Act, installed STS to address stormwater runoff from impervious surfaces to the Jones River, in the vicinity of Atlantic Street and Cedarwood Road. Six STS tanks were installed to treat 0.6 acres (~26,000 ft^2) of impervious surface at Atlantic Street, across from the "Trailer Park" area adjacent to the Jones River. The installations along Atlantic Street actually involve two subsites, a few hundred feet apart. Figure 6 displays the location of the two subsites. Two STS units have been installed across from the "Paved Road" (PR) in front of the trailer park; four (4) will treat stormwater collected via catch basins in the vicinity of the "Snack Bar" (SB). Figure 7 provides schematics of the installation at each subsite, and the sampling locations. The design is similar to that describe for the Wychmere Harbor, Harwich installation, but does not have any enhanced FF holding capacity (no septic tanks) and the effluent discharge here is subterranean, in an area evacuated and filled with crushed stone below the adjacent marsh.

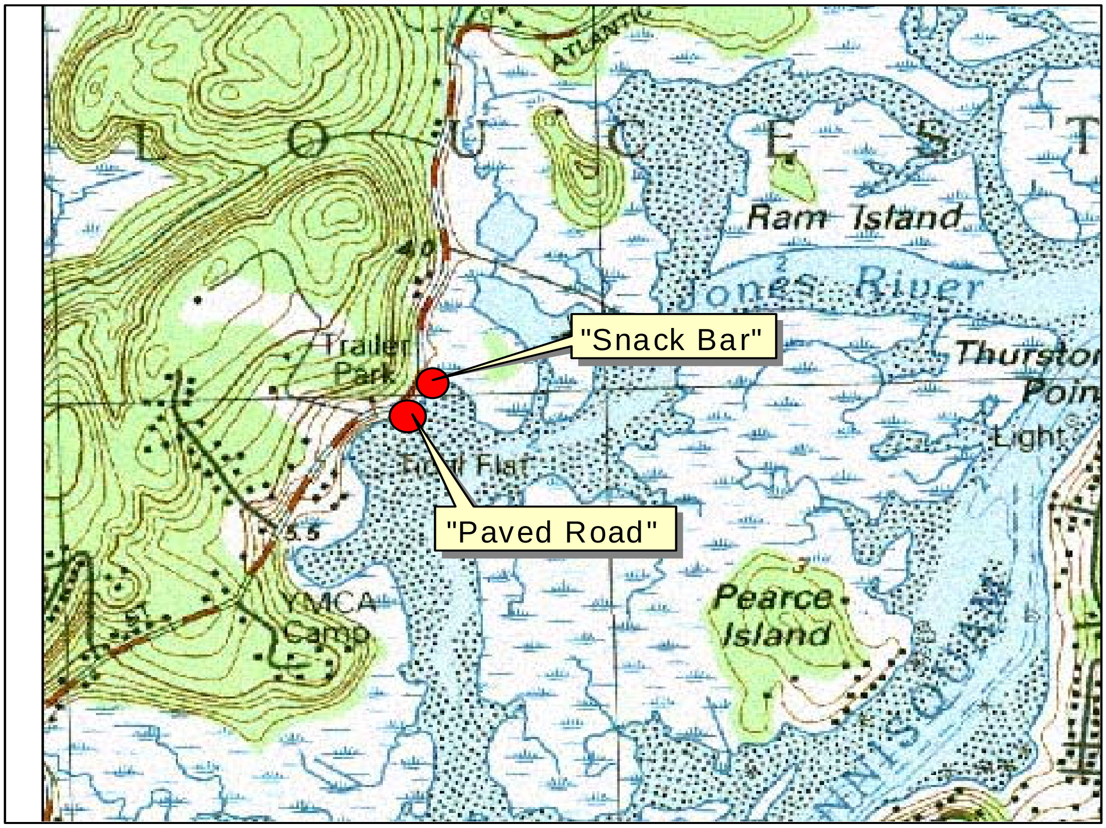

Figure 6. Locations of the Snack Bar and Paved Road subsites along the Jones River in Gloucester.

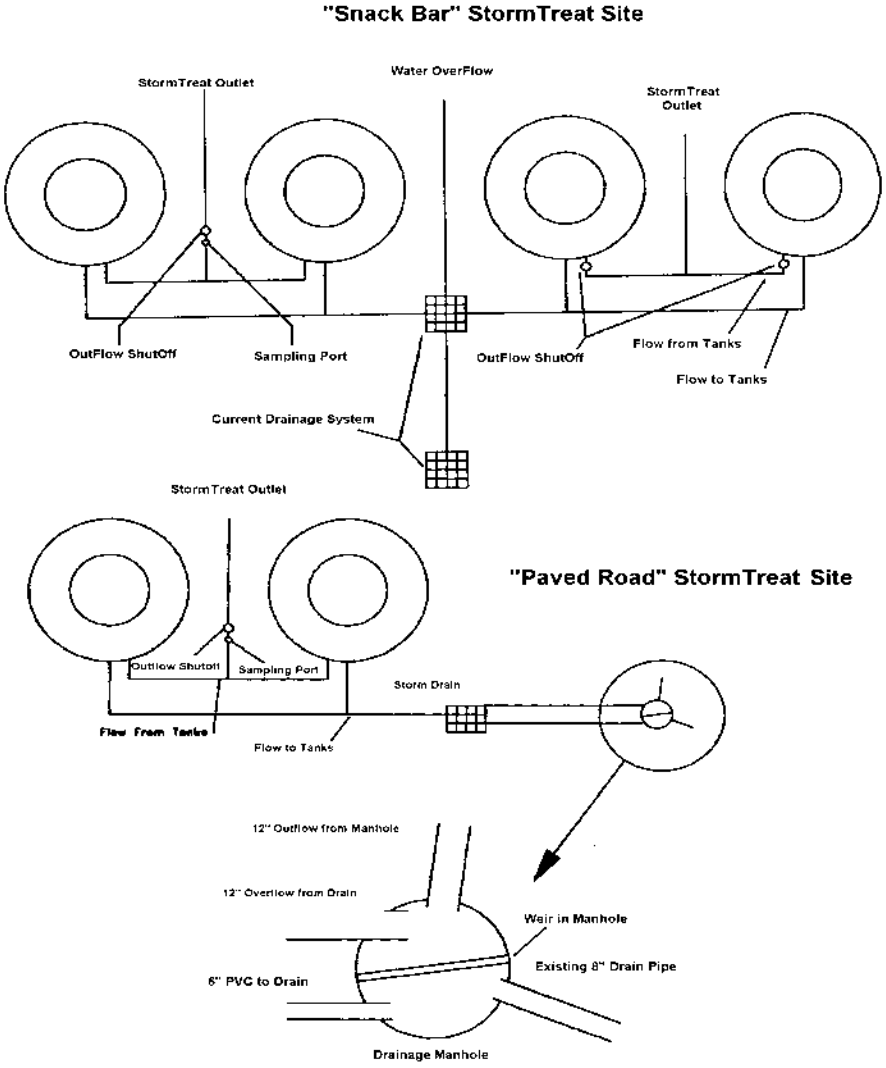

Figure 7. StormTreat System diagram and sampling locations, “Snack Bar” and “Paved Road Subsites, Gloucester.

2.0 TEHNICAL APPROACH

Details of the monitoring approach can be found in the project Quality Assurance Project Plan (QAPP). The QAPP was developed by CZM and submitted to DEP and EPA in July 1998. CZM received approval of the QAPP from EPA in November 1998.

The QAPP outlines the monitoring strategy for evaluating the effectiveness of STS in removing contaminants associated with runoff from the two locations in Harwich and Gloucester. The minimum target precipitation event criteria used for all field studies required at least on half (0.5) inches of rainfall in order to have a representative measure of FF of surface runoff to, and through, the STS. An additional requirement of at least three days of dry weather (no precipitation) preceded each tested rain event. The monitoring study was to be conducted in two phases:

- Phase I: describe "first-flush" flow-through characteristics of stormwater at the Gloucester and Harwich STS installations using tracer studies – for the purpose of optimizing sampling strategies for phase II, and
- Phase II: evaluate pollution remediation of STS installations in Harwich and Gloucester by comparing influent "first-flush" stormwater samples with appropriate effluent (treated) samples (as identified in Phase I).

The data generated by this study is intended to allow for comparison of the stormwater-remediation effectiveness of these STS installations for pollutant parameters commonly found in stormwater runoff with other STS installations (for example, in Kingston, MA). This project will also provide added insights in how to conduct meaningful studies that are designed to assess the effectiveness of stormwater treatment using similar innovative technologies. Further, the project results will provide insight in factors contributing to the effectiveness of the overall technology in stormwater-related pollution.

2.1.a. Phase I, Dye Study

The Phase I dye study was conducted in October 1998 and May 1999 at the Harwich and Gloucester STS installations respectively. The purpose of these Phase I studies was to examine the characteristics of water flow through the StormTreat® systems to properly characterize the timing of discharge of the FF component of a rain event. Using a conservative tracer (Rhodomine WT red dye), the discharge characteristics, as well as the residence time of water in the STS units were determined. Rhodomine WT is an ideal tracer in that it is nontoxic, usable in small quantities, and stable during the course of this study *(10-12)*. Rhodomine WT is approved for use as a conservative tracer by the US EPA *(13)*. From fluorescent tracer studies (the appearance and intensity of dye in the effluent), a water quality sampling program was to be designed that most accurately compares inflow (catch basin) and effluent samples for the assessment of pollutant removal (Phase II) of the FF. Specifically, this dye study was designed to answer two questions:

- ☐ When does the FF portion of a rain event appear at the STS effluent (i.e., what is the residence time of FF in the STS) and what is its duration?
- ☐ How does FF residence time vary among sites?

Evaluation of STS performance requires characterization of flow-through characteristics in order to adequately capture “treated” FF samples in the effluent. If samples are collected after the FF has already passed through the STS and beyond the effluent sampling ports, the removal efficiencies of contaminants to be investigated in Phase II may be over-estimated since post-FF effluent corresponds, in reality, to a relatively cleaner portion of the rain event.

2.1.b. Tracer Methods

Dye (Rhodamine WT red) is introduced in the inlet catch basins of the STS. Rhodomine dye (approximately 0.5L of 10-15% w/v) was added to each catch basin to ensure measurable concentrations after stormwater dilution in effluent samples. Samples were collected manually every 3 to 6 hours after the addition of dye and continued for at least 24 hours after the visible disappearance of dye in the effluent samples. Grab samples were collected by submerging test tubes into the sampling ports or collected from the effluent stream and stored in the dark for later fluorometric analysis. All samples were analyzed within 60 days of collection.

Samples were analyzed for Rhodamine WT content using fluorometry. Instrumentation and setup were as follows: Turner Designs Model 10 Fluorometer equipped with a 13 mm x 100 mm cuvette holder; a 546 nm, excitation filter, a >570 nm emission Filter, >535 nm reference filter, and a clear quartz lamp. An aliquot of stormwater effluent samples (approximately 10 mL) was dispensed from storage containers into 13 mm x 100 mm culture tubes (Fisher*brand*, cat. no. 14-961-27) and analyzed for fluorescence emission. Instrument door factors and subsequent readings were recorded for determining relative fluorescence. Samples falling outside the least sensitive range were diluted 1/10 with deionized water and re-analyzed. High fluorescence samples (0.1-0.5 ppm of Rhodamine WT) that were within instrument range were diluted 1/10 and re-analyzed as a measure of control on potential dilution artifacts. The quality control dilution samples generally agreed to within 2% of measured undiluted samples. The instrument was blank-adjusted using deionized water. Replicate analysis of the same sample collected in the field gave comparative errors to the dilution control measures (~2%).

2.2 Phase II, Stormwater Water Quality Assessment

Results from the Phase I dye studies were used to guide surface runoff water quality sampling strategies. Table 2.2 list the water quality parameters required by the Program's QAPP for both influent and effluent samples (Phase II). Stormwater sampling during four (4) storm events having the minimum target precipitation event criteria described above were proposed in order to capture potential seasonal variability in contaminant removal efficiencies by the STS.

Table 2.2. Parameters for stormwater runoff water quality assessment (Phase II), Harwich and Gloucester STS installations.

Parameter	STS Influent	STS Effluent
Fecal Coliform	1,2,3,4	1,2,3,4
Total Suspended Solids	1,2,3,4	1,2,3,4
Total Phosphorous	1,2,3,4	1,2,3,4
Ortho-Phosphate	1,2,3,4	1,2,3,4
N-Nitrate+Nitrite	1,2,3,4	1,2,3,4
N-Ammonia	1,2,3,4	1,2,3,4
N-Total Kjeldahl Nitrogen	1,2,3,4	1,2,3,4
Trace Metals (Zn, Cd, Cu, Pb)	1,4	1,4

Because of the results obtained during the tracer dye experiments conducted during Phase I of this project, Phase II was not undertaken. These Phase I results are presented below.

3.0 RESULTS (PHASE I)

Tracer studies were conducted during Fall1998 and Spring 1999 in Harwich and Gloucester, respectively. Results from both installations, and within the subsites of Gloucester, yielded highly variable results.

3.1 Wychmere Harbor, Harwich Results

As part of this project, STS installations in Harwich were to be evaluated in their performance for removing contaminants associated with stormwater runoff. The system was designed to treat approximately 0.5 acres of impervious surface from Harbor road and the adjacent town parking area. The stormwater from this area is collected via catch basins, routed through the STS and then discharged into the adjacent Wychmere Harbor. The system has never functioned as designed, and its failure is primary due to improper siting and subsequent installation of the STS.

A system consisting of four tanks was installed in a very low location in an attempt to intercept collected stormwater prior to discharge into the harbor (Figure 8). The site has an elevation of 2 feet above mean high tide and a sub tidal discharge outlet. The parking area within which the system is installed routinely floods during minor storm events and extreme high tides. Moreover, the site is subjected to frequent over wash (Figure 9) and salt spray. This frequent inundation of salt water has, in part, destroyed the wetland component of the STS. After several unsuccessful attempts by the Town of Harwich, the efforts to re-establish wetland plants in the STS were abandoned.

Figure 8. StormTreat™ Installation Site adjacent to the Wychmere Harbor Town Pier parking lot in Harwich.

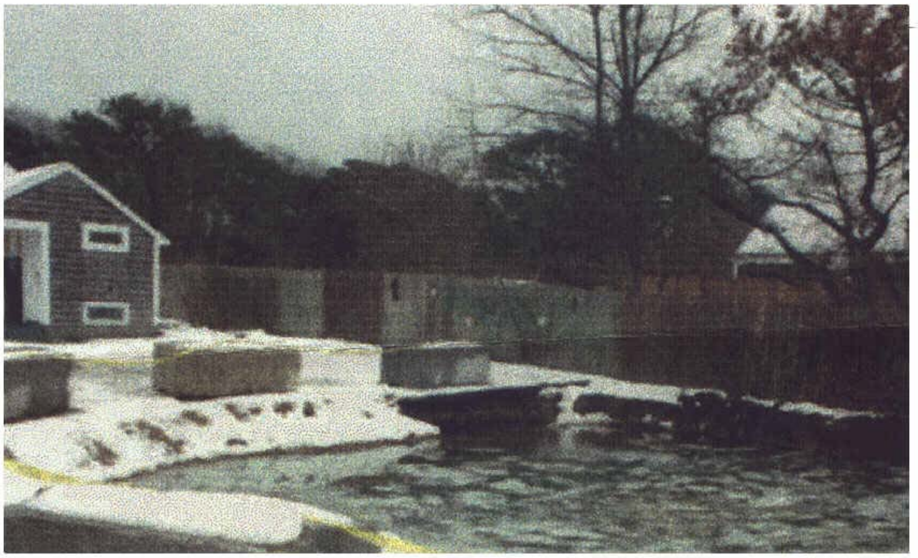

Figure 9. **Saltwater overwash in the STS containment basin during installation in March, 1994.**

The installation at this low elevation was difficult and was never successfully completed. The low elevation required a subtidal discharge at an elevation of 1.5 feet below the mean high tide and necessited the use of a flapper valve (Figure 10) designed to close as the tide rose above the discharge pipe, thereby preventing saltwater intrusion into the system. This flapper valve has been problematic since the initial installation. Many attempts to reseal and repair this valve have proven unsuccessful. In addition to saltwater intrusion from the faulty flapper valve, ground water infiltrates the tanks through the poorly sealed fittings connecting the tanks. Groundwater infiltration is substantial since the system sits within the groundwater table. At a minimum, the system functions as a settling system, and sediment in the tanks are cleaned annually.

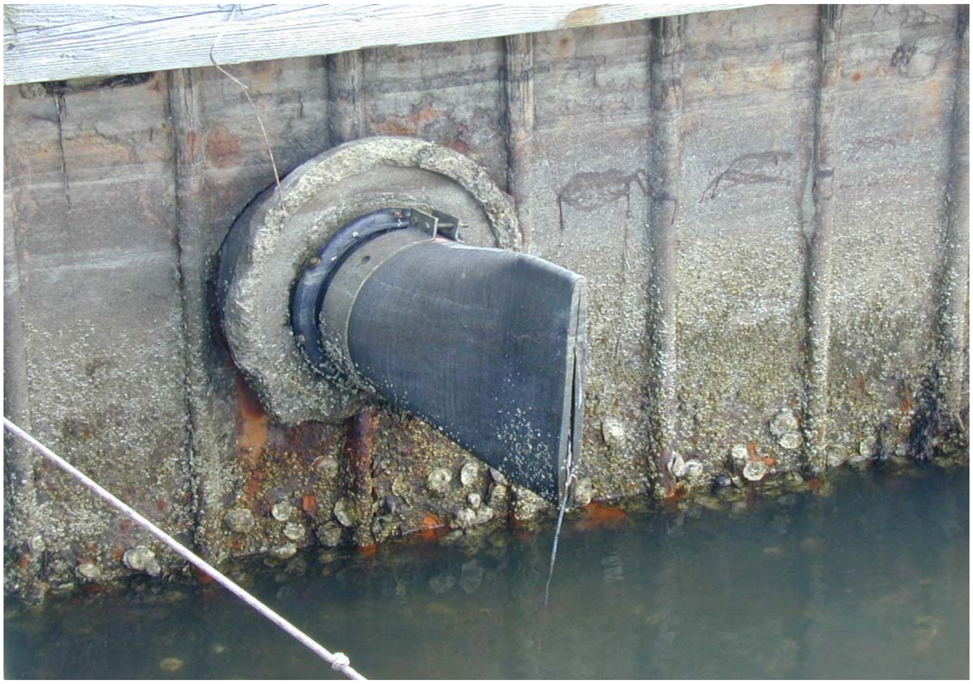

Figure 10. Flapper valve located at the end of discharge of the STS units at the Wychmere Harbor site.

Dye tests at this site were conducted during the fall of 1998. Figure 11 show the results of fluorometric analysis of samples collected from an October 1998 rain event. Trace dye and sampling began at 5AM on 10 October and continued at selected intervals for the next six days. Salinity and tidal stage are also shown in Figure 11. These results show dye present in the effluent shortly after being introduced into the catch basin, suggesting rapid flow through of dye-labeled stormwater runoff. In addition, salinity values of collected dye samples ranged from a low of $12^{o}/_{oo}$ (measured by a hand-held refractometer) to a high of $32\,^{o}/_{oo}$, verifying intrusion of harbor water into the effluent collection area of the STS units.

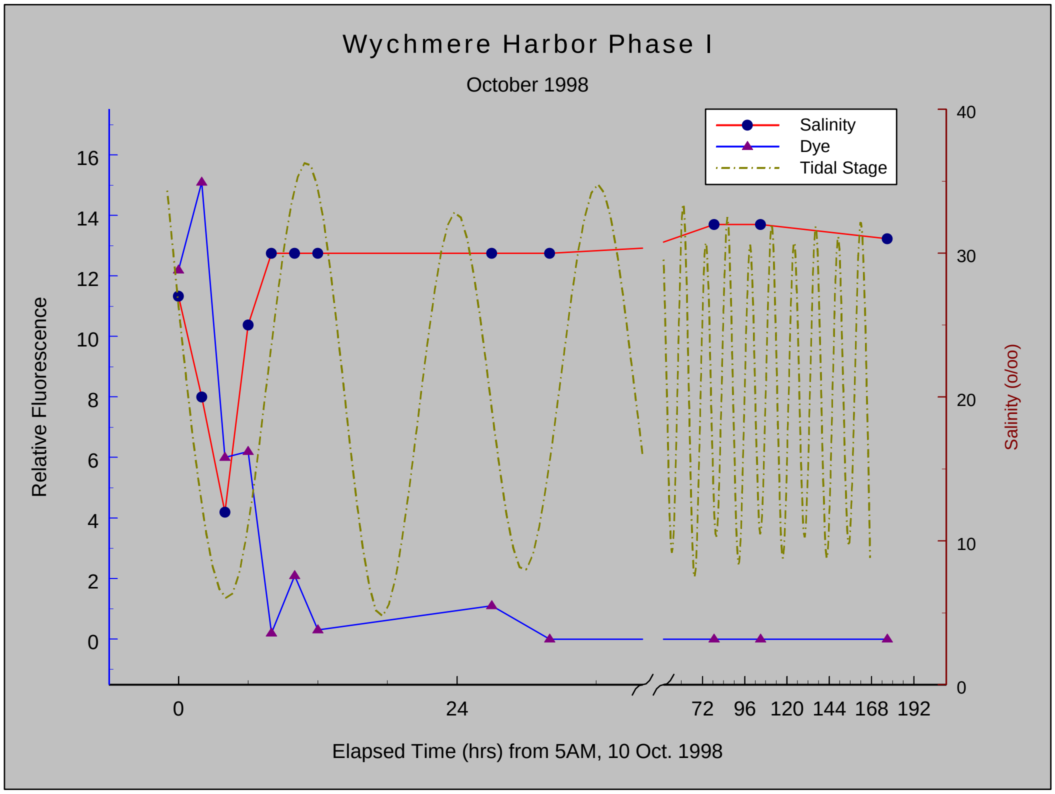

Figure 11. Salinity and dye fluorescence from effluent samples collected during the Phase I dye experiments at the STS installations adjacent to Wychmere Harbor in Harwich.

3.2 Jones River, Gloucester Results

The characteristics of FF throughput of the two STS installations at the Jones River site differed greatly in both timing of peak fluorescence and residence time calculations. These initial dye studies were further complicated by the onset of a second rain event before the FF of the initial storm had been completely evacuated from the STS at the SB subsite. Local daily-integrated rainfall totals obtained from rainfall monitoring gauges at the Gloucester Waste Water Treatment (WWT) Facility were used to interpret the data. The rainfall data (recorded in 15 minute intervals) from the WWT facility shows the onset of this storm to occur on 11:45 AM on 20 May 1999, the field sampling team observed intermittent showers beginning around 9 AM. Dye was introduced at 6 PM on 20 May 1999.

Figure 12 shows dye breakthrough curves from both STS sub-sites. Flow through characteristics of FF behaved as one might expect as observed from samples taken at the SB site except that significant relative fluorescence persisted in the effluent for almost seven days after the dye was introduced. Initial samples were observed to have low relative fluorescence prior to the discharge of dye-labeled FF. Peak relative fluorescence at the SB site was observed 42 hours after the first sample was collected and approximately 72 hours (or ~3 days) after the dye was introduced to the catch basin. Alternatively, the rhodomine breakthrough curves at the PR site (approximately 20 m SW of the SB site) showed rapid movement of dye-labeled FF through the STS units. Here, the highest relative fluorescence was observed in the first sample collected in the outflow.

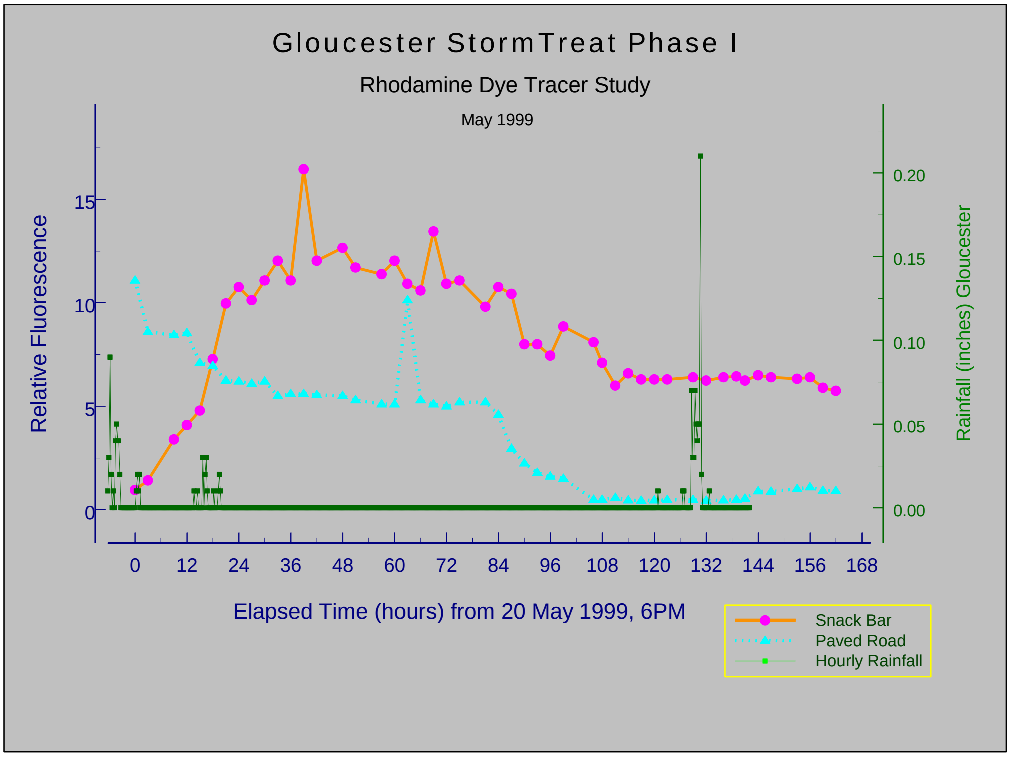

Figure 12. Local daily rainfall and tracer breakthrough curves from the Phase I dye experiments at the STS installations along the Jones River in Gloucester.

4.0 DISCUSSION:

The results of the Phase I studies were designed to provide insight on meaningful sampling strategies. The goal was to develop a procedure for compositing effluent samples (see Appendix 1) for the analysis of selected contaminants (see Table 2.2, above) and comparing them with samples collected from the STS catch basins at the onset of appropriate rainstorm events. The comparison of treated (effluent) samples with untreated (catch basin) samples would provide a measure of removal efficiency for these contaminants by the STS at each of the sites. The results from Phase I revealed that all of the installations were not performing as designed for a myriad of reasons, most of which were related to improper siting and/or installation practices. These systems are failing in their performance from excessively long and short stormwater residence times, saltwater intrusion, and the lack of proper maintenance.

Further efforts in evaluating contaminant removal efficiencies of STS installed at the sites in Harwich and Gloucester as they currently exist would be meaningless. Therefore, Phase 2 (Stormwater Water Quality Assessment) was not conducted. The specifics of each installation are discussed below.

Further efforts in evaluating contaminant removal of the Wychmere Harbor, Harwich STS are not warranted because of suspected groundwater infiltration, overwash potential, and saltwater intrusion. The residence time of dye-labled stormwater in the STS at this installation is apparently controlled, to a large extent, by the Wychmere Harbor tidal stages, as evidenced by the presence of saltwater in the effluent samples. This installation is improper for at least two reasons: (1) the relative low elevation of each STS unit to mean high water of the harbor, and (2) the improperly designed discharge outlet into the bay. The dye results may be explained, in large part, by the STS being saturated with occasional overwash, groundwater, and/or saltwater infiltration.

At the Atlantic Street site in Gloucester, the very rapid flow-through that occurred at the PR sub site is suspected to be due to improper positioning of the outflow valve of the STS units of this site. Closing or opening these valves can be used to adjust for optimal residence times. The effluent valve at the PR site was set to maximum and thereby minimizing the residence time of FF in the system. However, because of the subterranean discharge of these STS, effluent discharge rates could not be measured. While the STS units at the SB site behaved closer to prediction, (peak in fluorescence occurring sometime after rain onset and then gradual tailing off in intensity), peak fluorescence occurs 3 days after the introduction of dye. Fluorescence levels at the SB site did not reach background levels during the time period of monitoring (>7 days after onset of rain event). Based on predictions from the dye experiment, only about 74% of the FF was sampled. (See Figure A1-2 in the Appendix.) The dye breakthrough curve observed for the SB site is typical for systems experiencing plugged flow. The effluent pipe for both the SB and PR sub sites terminate in a subsurface field made of crushed blue stone. The PR effluent pipe is sufficiently higher than the SB site and drains the STS units adequately. While both the PR and SB effluent pipe terminates under the adjacent marsh, the SB effluent appears to be restricted, either because of tidal influences or improperly designed drainage.

As evidenced by the Phase I results, FF flow-through characteristics were unique to each of the three STS installations investigated. Simple comparison of 4 or 5-day effluent samples with initial untreated FF stormwater (as suggested by the manufacturer) would be inappropriate for evaluating the performance of these STS installations. For instance, dye-labeled FF in the effluent did not reach background levels after 156 hours of sampling. Curve fitting of the relative fluorescence data from the Gloucester Snack Bar subsite predicts background levels would be reached after 400 hours (see Appendix 1). Interpretation of the Gloucester data is further complicated by the onset of a second storm, approximately 30 hours after sampling commenced.

5.0 CONCLUSIONS

This report summarizes the results for characterization of stormwater runoff flow through in STS installations at two sites in Gloucester and one in Harwich, Massachusetts. The principal finding of this effort is that consistent and proper criteria in both siting and installing stormwater treatment technologies are needed. The primary objective of this study was to evaluate the effective treatment of contaminants in the FF portion of stormwater runoff by the STS units at these sites. In order to reach this objective a secondary objective was identified and carried out in the first phase of this project. This secondary objective was designed to characterizing the flow of FF runoff through each STS installation in order to optimize sampling strategies for evaluating contaminant removal efficiencies. Labeling the FF of significant storm events with a conservative dye tracer and analyzing dye breakthrough curves were used to describe the flow-through behavior of stormwater FF at each STS installation. Once flow-through characteristics were understood and optimized, appropriate effluent samples were to be collected and compared with untreated FF samples to quantify contaminant removal efficiencies of these systems. However, this later objective was not achieved because of inappropriate location and/or installation designs.

Knowledge of the timing and duration of the portion of FF stormwater in the effluent is critical for an adequate evaluation of contamination removal by innovative stormwater treatment technologies. Inappropriate installation is probably the most significant factor controlling the performance of the systems studied by this project. The STS at the Wychmere Harbor location in Harwich were installed at too low an elevation relative to the tidal ranges in the harbor. The effluent discharge is submerged during high tide and measures taken to minimize saltwater intrusion up the discharge pipe into the STS tanks have proved unsuccessful. In addition, the location of the STS tanks is subjected to frequent overwash and saltwater spray during high spring tides and heavy storms. At the Atlantic Street sites in Gloucester, the effluent discharge for each of the sub sites is located below the marsh and does not allow for adequate drainage for at least one of these subsites. In two of the three installations studied, groundwater intrusion appears to be a significant component in the failure of these systems to perform as designed. Periodic visual inspections during dry periods revealed the presence of water within the tanks at the SB subsite in Gloucester and in Harwich. This is indicative of significant ground water intrusion. If the STS are saturated with groundwater from infiltration, the STS units will not have the capacity to accommodate FF stormwater runoff. Initial results of the Phase I efforts illustrates the importance of FF characterization to ensure meaningful sampling strategies for evaluating the performance of innovative stormwater technologies.

5.1 *Lessons Learned*

1. **Develop siting and installation criteria.** Site evaluation criteria should include consideration of local topographic features relative to receiving water height dynamics. For coastal applications, an analysis of monthly spring tides should be considered in defining minimum installation elevations from a benchmark of sea level (such as mean high tide). CZM recommends that minimum installation depth adhere to +1 SD above annual mean of spring tides. Site-specific criteria, such as frequency of overwash, mean wind speeds, and predominant wind direction, should also be incorporated into developing siting criteria and factored into installation plans. If installations occur in areas where groundwater levels are near or above the levels of STS (or other innovative stormwater treatment technologies), these systems must be demonstrated to be isolated from groundwater infiltration, since the theory of STS performance relies on occasional purging between runoff events in order to be effective in capturing stormwater FF for effective contaminant removal.

2. **Characterize flow-through as part of the innovative stormwater treatment technologies installation process.** In order to insure proper installation of StormTreat® systems and other innovative stormwater treatment technologies, the characterization of stormwater flow through should be conducted as part of the installation process. This would insure that issues associated with groundwater infiltration, saltwater intrusion, installation location, drainage area, and draining mechanics are adequately addressed. An added benefit would be *a prior* knowledge of the systems flow through characteristics if contaminant efficiencies were to be evaluated. Groundwater infiltration and/or saltwater intrusion should be corrected prior to conducting flow through characterization studies. This study utilized rhodomine dye to monitor the flow of FF stormwater through the STS units. However, because ease of monitoring, simpler analyses, and the potential to reduce analytical artifacts, better tracers are recommended. The lengthy rhodomine breakthrough curves may in part indicate the importance of adsorption/desorption of the dye by the organic matrix of the STS. Studies have indicated that adsorption onto organic particles by rhodomine red may be significant, thereby lengthening the breakthrough curves and misrepresenting the timing of FF discharge. Levy and Chamber *(14)* have tested the use of bromine as a conservative tracer for soil-water hydrological investigations. This technique is ideal because the relative inert nature of bromine, the ease of detection, and inexpensive analytical methodologies. Bromide can be detected by ion selective electrodes (ISE). Coupled with flow monitoring and data logging technology, ISE's may provide continuous monitoring of STS effluent and would eliminate separate tracer sample collections.

3. **Wetland component of STS.** The wetland component of the STS is designed to remove dissolved nutrients, such as phosphorous and nitrogen, that are associated with FF stormwater runoff. Several attempts were made to establish the constructed wetland component of the STS in both towns. However, these attempts were unsuccessful. StormTreat™ Sytems, Inc. recommended to the towns additonal plants for testing as more viable for the constructed wetland component of the STS (Table 5.1). Tests to see which of those recommended below were beyond the scope of this project. Because of the larger problems associated with siting and installation, further evaluation of the wetland component will be reserved for other installations that have been demonstrated as properly installed. The Coastal Pollution Remediation (CPR) Program at CZM has become aware of the issues highlighted in this report and has initiated programs to study StormTreat™ Systems and other innovative stormwater treatment technologies installations, with specific attention given to proper installation. Details of these efforts may be obtained by contacting:

Jason Burtner
CPR Program Coordinator
CZM
251 Causeway St.
Boston, MA 02114-2136.

Table 5.1. Recommended vegetation to test for constructed wetland component at STS installations.

Scientific Name Common Name	Indicator Status	Exposure	Tolerance to Salt	Plant Type
Scirpus validus Bulrush	OBL			Herbaceous
Agrostis alba Redtop	FAC	shade	high	Herbaceous
Andropogon virginicus Broomsedge	FACW	sun	low	Herbaceous
Panicum vigatum Switch grass	FACU	sun/shade	high	Herbaceous
Deschampsia caespitosa Tufted hairgrass	FACW	sun	high	Herbaceous
Phalaris arundinacea Reed canary grass	FACW			Herbaceous

OBL – Obligate Wetland, occur almost always (>99%) under natural conditions in wetlands.
FACW – Facultative Wetland, usually occur in wetlands (67%-99%), but occasionally found in non-wetlands.
FAC – Facultative, equally likely to occur in wetlands or non-wetlands (34%-66%)
FACU - Facultative Upland, usually occur in non-wetlands (67%-99%)

4. **Proper maintenance and monitoring.** StormTreat ™ Systems Inc. recommends a semi-annual maintenance plan for the STS. This is included in Appendix 2. Little to no maintenance of the STS was observed at the study sites during this investigation. A clear contact from each town should be identified to better insure proper maintenance of these systems. One of the recommendations listed in Appendix 2 is for an occasional monitoring of effluent flow rates and adjusting the discharge to 0.25 gallons per minute. The effluent outlets for the Gloucester installations are subterranean, and therefore impossible to monitor for exiting flows as presently designed. Again, future installations should be conducted such that adequate monitoring may be performed, at least at the capacity suggested by the semi-annual maintenance plan. For properly installed systems, further evaluation of viable plant assemblages should be conducted (see recommendation #3). One of the purposes of those studies should be the development of a maintenance plan for the constructed wetland component of the STS. Part of the failure of the constructed wetlands may be attributed to the lack of water available to the plants during extended dry periods. Closer monitoring of soil moisture should be conducted and noted. As better knowledge of the conditions for favorable plant growth presents itself, this information should then be incorporated into the overall maintenance plan.

5. **Conduct additional tracer and contaminant removal studies at properly installed installations.** Additional tracer studies should be conducted at a site in Rowley, where STS were properly installed (personal communication with Jason Burtner, coordinator of the CPR Program) to better evaluate the range of FF residence times under different wet weather conditions (high, medium or low rain events). Given the investment in this phase of the project, possible evaluation of StormTreat® Technologies for FF pollutant removal will be deferred to on-going §319-funded efforts of the CPR Program at CZM. The Phase I results of this project will have great utility in the approaches undertaken to evaluate innovative technologies on stormwater pollution remediation.

6. **Explore the use of automated samplers.** Volunteer effort was utilized in collecting samples from the subsites in this project in May 1999. However, because of the intensive nature of these types of sampling, CZM recommends moving towards automated samplers for further work in evaluating this and other innovative stormwater treatment technologies. CZM's Marine Monitoring and Research Program purchased an ©American Sigma Autosampler (Model 900 Max) to perform additional Phase I studies. In addition, the CPR program has obtained a number of these samplers to conduct evaluations of innovative stormwater treatment technologies. These samplers have the capacity to collect 24 samples. This translates to three days of unattended sampling if a 3-hour sampling frequency is employed. However, unattended sampling for contaminants

would be restricted to analytical protocols governing the most sensitive analytes with respect to proper sample preservation and storage protocol.

5.2 *Site-specific Recommendations*

5.2.a. Gloucester.

Each site at the Atlantic street installation require modifications prior to evaluating the performance of the STS in removing selected contaminants from the FF portion stormwater runoff. The effluent control valve of the Paved Road installation should be adjusted to increase the FF residence time to the recommended 3-4 days. The Snack Bar installation would most likely require repositioning the effluent pipe to discharge above the marsh in order to improve discharge and shorten residence time from the STS tanks. Both installations, especially at the SB site, are suspected of having substantial groundwater infiltration. Both installations would once again require verification of flow through. Periodic maintenance is greatly lacking at these sites. After issues of groundwater infiltration and drainage have been remedied, periodic maintenance as prescribe by the manufacture should be implemented.

5.2.b. Harwich.

The installation at Wychmere Harbor is in an area too close in elevation to the daily high tide reach of the Harbor. As is the case for this installation, some areas are not appropriate for stormwater remediation technologies that rely on gravity for flow through. Problems associated with overwash and saltwater intrusion alone dictate that this site is inappropriate for the installation of STS. No apparent location exists for the appropriate installation of STS along the parking lot serving Wychmere Harbor and adjacent Harbor Road.

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Appendix 1

Proposed Method for Flow-Weighted Sampling from Innovative Stormwater Treatment Technologies based on Effluent Tracer Concentrations

Proper sampling of stormwater first flush (FF) effluent would require a weighted composite (in this case, based on relative fluorescence from tracer dye added to the influent) in order to adequately characterize the remediation performance of the StormTreat™ System units. Using the results shown in Figure 12 from the above report (page 18) for the samples taken at the Snack Bar site in Gloucester, one approach to sample compositing would be to plot the data as a histogram (Figure A1-1), and weighting the sample volume as a function of relative fluorescence and the time interval between consecutive sample collections.

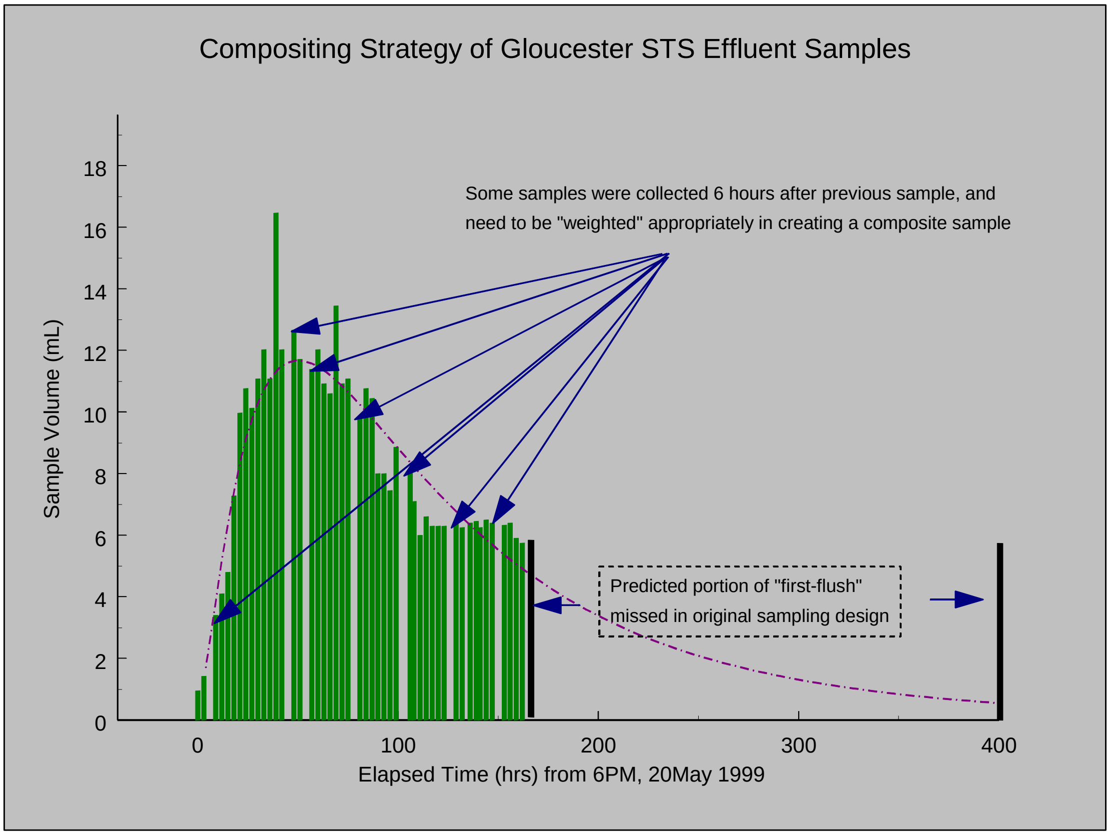

Figure A1-1. Histogram and curve-fit of the Gloucester effluent fluorescence data.

After determining the total volume of sample needed for analytes (in this case, we determined that a minimum of two liters for total suspended solids, nutrients, and metals would be needed), the composite sample's final volume was computed as follows:

$$Composite_{(Vol)} = \sum \; RF * V_{CF} * I_{Sample}$$

where:

Composite$_{(Vol)}$ is in mL
RF = relative fluorescence
V$_{CF}$ = Volume conversion factor (1.5 in this study)
I$_{Sample}$ = time interval since last sample collected

Table A1-1 contains the computed subsample volumes used to create the final volume of the composite sample (~2L).

In order to compute the amount of FF captured, the relative fluorescence data from the Snack Bar site (Figure 12) was fitted to the third-order polynomial:

$$y = 0.717 * x^{(0.087+0.5*\ln x-0.09*\ln x^2)}$$

The curve fitted data predicts that reasonable background fluorescence would be achieved 400 hrs after the first effluent sample was obtained (representing about 16 days). Based on predictions from the dye experiment, only about 74% of the FF was sampled. Figure A1-2 shows an estimation of the FF in the absence of the second rain event. Here, 8.5 days would be required to capture 95% of the FF.

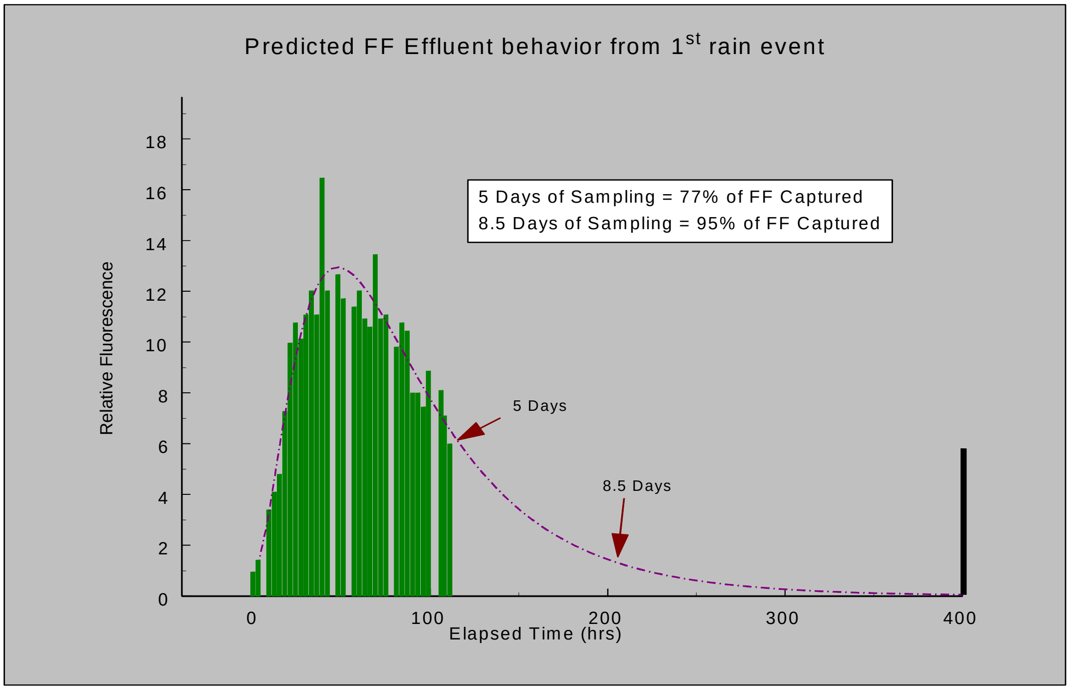

Figure A1-2. The predicted behavior of first flush loading to the "Snack Bar" subsite in the absence of the 2nd rain event which occurred 5 days into the effluent monitoring study.

Table A1-1. Subsample Volumes used to create Snack Bar composite sample

Gloucester 319 Project: StormTreat Dye Experiment 5/20-27/1999

Snack Bar

Sample ID	Time	Relative Fluor (RF)	I_{Sample} (hours)	CF	Sample Vol. (mL)
5-20-1	6PM	0.95	3	1.5	4
5-20-2	9PM	1.42	3	1.5	6
5-21-3	3AM	3.40	6	1.5	31
5-21-4	6AM	4.10	3	1.5	18
5-21-5	9AM	4.80	3	1.5	22
5-21-6	12PM	7.28	3	1.5	33
5-21-7	3PM	9.97	3	1.5	45
5-21-8	6PM	10.76	3	1.5	48
5-21-1	9PM	10.13	3	1.5	46
5-22-2	3AM	11.08	6	1.5	100
5-22-3	6AM	12.03	3	1.5	54
5-22-4	9AM	11.08	3	1.5	50
5-22-5	12PM	16.46	3	1.5	74
5-22-6	3PM	12.03	3	1.5	54
5-22-7	6PM	12.66	3	1.5	57
5-22-8	9PM	11.71	3	1.5	53
5-23-1	3AM	11.39	6	1.5	103
5-23-2	6AM	12.03	3	1.5	54
5-23-3	9AM	10.92	3	1.5	49
5-23-4	12PM	10.60	3	1.5	48
5-23-5	3PM	13.45	3	1.5	61
5-23-6	6PM	10.92	3	1.5	49
5-23-7	9PM	11.08	3	1.5	50
5-24-8	3AM	9.81	6	1.5	88
5-24-1	6AM	10.76	3	1.5	48
5-24-2	9AM	10.44	3	1.5	47
5-24-3	12PM	8.00	3	1.5	36
5-24-4	3PM	8.00	3	1.5	36
5-24-5	6PM	7.45	3	1.5	34
5-24-6	9PM	8.86	3	1.5	40
5-25-7	3AM	8.10	6	1.5	73
5-25-8	6AM	7.10	3	1.5	32
5-25-1	9AM	6.00	3	1.5	27
5-25-2	12PM	6.60	3	1.5	30
5-25-3	3PM	6.30	3	1.5	28
5-25-4	6PM	6.30	3	1.5	28
5-25-5	9PM	6.30	3	1.5	28
5-26-6	3AM	6.40	6	1.5	58
5-26-7	6AM	6.25	3	1.5	28
5-26-8	9AM	6.40	3	1.5	29
5-26-1	12PM	6.45	3	1.5	29
5-26-2	3PM	6.25	3	1.5	28
5-26-3	6PM	6.50	3	1.5	29
5-26-4	9PM	6.40	3	1.5	29
5-27-5	3AM	6.33	6	1.5	57
5-27-6	6AM	6.40	3	1.5	29
5-27-7	9AM	5.90	3	1.5	27
5-27-8	12PM	5.75	3	1.5	26
			Composite	**Vol$_{Final}$**	**2051**

Note: Minimum sample container size must accommodate 103 mL of sample (see sample ID 5-23-1 3AM).

Appendix 2

Semi-Annual Maintenance Plan for the StormTreat™ System

Semi-Annual Maintenance (Spring and Fall) Estimated Time: 5 minutes per catch basin and 15 minutes per STS tank:

1. Inspect and clean catch basins preceding the STS.
2. STS Tanks:
    - Visually inspect influent pipe and clean out debris, if necessary.
    - Remove debris filter sack and attach replacement
    - Visually inspect skimmers to ensure that the flexible hoses are undamaged and tightly connected to the skimmer and the bulkhead. Replace damaged hoses.
    - Measure sediment depth in bottom of tank.
    - Collect debris out of wetland and trim dead growth off wetland plants
    - Rake and tidy area around systems
    - Following a storm event, measure discharge flow rate and adjust to 0.25 gallons per minute per tank. Reset exit valve, if necessary. Close and lock valve cover.