ASSESSMENT OF THE EFFECTIVENESS OF PERMANENT STORMWATER CONTROL MEASURES

A Final Report to

The New Hampshire Office of State Planning, New Hampshire Coastal Program

Submitted by

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OFFICE OF STATE PLANNING
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EXECUTIVE SUMMARY

The effectiveness of designed stormwater control systems for treating contaminants in runoff waters in coastal New Hampshire was studied. The objectives were to assess effectiveness and to determine which systems are most effective. A strong emphasis was placed on assessing systems during cold months because of the frequency of major storm/runoff events that probably contributes significant loading of contaminants to surface waters. Measured water quality parameters were generally present in relatively low concentrations in both influent and effluent waters. Bacterial contaminants were a notable exception, with relatively high concentrations observed throughout the study in some systems. The infiltration chamber was apparently ineffective at treating any contaminant. The wet pond systems were relatively effective in treating many of the contaminants in both summer and winter, while the vegetated swales were inconsistently effective, especially during summer. The swales were not effective in treating nutrients and other dissolved contaminants during summertime when live plants are supposed to remove contaminants. Bacterial contaminants showed a definite trend of increasing concentrations with the onset of warm weather both in influent and effluent waters. This suggests that bacterial indicators are probably growing in the moist, nutrient-rich systems during dry periods between storms and are discharged with new storm events. Overall, the systems were not exposed to high levels of contaminants, and thus were discharging low levels of contaminants except for bacteria during summertime. The results should prove to be a useful basis for rule changes needed for achieving compliance with stormwater control standards. In addition, it will serve as a first step toward determining the public health significance of treated and untreated runoff from storm events.

INTRODUCTION

Runoff from impervious surfaces in urban areas contains significant amounts of hazardous contaminants, including microbial pathogens/indicators, heavy metals, and toxic organic compounds like oils and hydrocarbons. Both the Casco Bay and Massachusetts Bays National Estuaries Programs and associated research highlight stormwater control as a major issue relative to surface water contamination with toxic compounds. In coastal New Hampshire, all shellfish beds (Hampton and Little harbors; Great and Little bays and tributaries) are subject to bacterial contamination following major storm events to the extent that all beds are closed. Based on numerous recent studies, most of the contamination appears to be coming from urbanized areas. A major effort by the state and the region is currently underway to reduce bacterial contamination and reopen more shellfish beds. The threat of these contaminants entering surface waters has been addressed by NHDES which requires the use of a variety of permanent stormwater control measures designed to capture, treat, or reduce the contaminant content of the runoff from large impervious areas (parking lots; roofs).

In 1983, the US EPA reported on its National Urban Runoff Program (NURP), in which field data from 81 sites in 22 different cities were gathered over 1981 and 1982. Although a variety of chemical and microbiological constituents were measured in the runoff water samples, the following constituents were determined to be "...the standard pollutants characterizing urban runoff": total suspended solids, biochemical oxygen demand, chemical oxygen demand, total phosphorus, soluble phosphorus, total nitrogen, nitrate, nitrite, total copper, total lead and total zinc. One conclusion of the study was that dry systems consistently exhibited poor removal efficiencies for nitrate, nitrite and soluble phosphorus. This has lead to the design of many stormwater control facilities to have resident or permanent pools (wet systems).

There is an increasing body of data that indicates that wet stormwater control systems, catch basins and stormwater pipes may be enhancing microorganism and organic contamination (Ellis and Yu, 1995; Butler et al., 1995). In this study, field studies have been conducted to better determine the extent of contamination from stormwater control systems, and to assess the effectiveness of both new and old systems in coastal NH. The approach will emphasized determining the fate of microbial and non-biological contaminants under different environmental conditions and seasons.

METHODS

Ten sites at eight locations in the Great Bay watershed (Table 1) were sampled and analyzed during five rainfall events (Tables 2 and 3) between January and September, 1996. The land use was commercial at all locations and consisted of five shopping center parking lots, two work site lots, and a lot at a marina. The descriptions of the stormwater control systems at each sampling location are presented in Table 1.

Sampling occurred during the initial flush of the storm, essentially during the first 0.5" of rainfall. Most storms approached the area from the west or southwest, and sampling sequences occurred along two north to south transects (see Figure 1). One sampling pair would sample SW1, SW2, DS and SP, in that order. The other sampling pair sampled PC, BJ, CC, PW1&2, and NM, usually in that order. Measurements of temperature, conductivity, water flow velocity and observations of weather and system conditions were recorded at sampling times. At some sites, influent or effluent pipes and surrounding areas were modified to allow for measurement of flow velocity. Detailed field notes recorded sampling site and system conditions, and any problems encountered with sampling at different times of year. Separate containers were used for collection of water samples for microbial, metals, oil and grease, BOD, COD and nutrient analyses. Thus, six separate bottles were required for sampling from each of the two locations at each site. Bottles for microbial analyses were cleaned and autoclave-sterilized. Nutrient bottles were acid-washed and rinsed with deionized water. Metal sampling, COD and oil and grease bottles were cleaned and contained acids for preservation of samples. BOD bottles were also cleaned and rinsed prior to sampling. All samples were immediately refrigerated and transported back to JEL within 3 hours of collection. Samples for analysis by NHDES were transported on ice on the day of sampling or the next day.

At JEL, total phosphates were measured using for a persulfate digestion method. Total nitrogen was analyzed using a Shimadzu ion specific chromatography with an ANTEK Nitrogen detector. Microbial analysis of JEL samples involved standard membrane filtration methods using mTEC agar for detection of fecal coliforms and *Escherichia coli.*, with incubation of plates at 44.5°C for 24 h. Urea substrate was used to differentiate *E. coli* from fecal coliforms. At NHDES, samples were analyzed for aluminum, cadmium, copper, zinc, chloride, turbidity, BOD, COD and oil/grease according to standardized methods.

Means or geometric means were established for all parameters and graphed to determine differences between systems and with season. The variety of storm and seasonal conditions under which the samples were collected at the variety of different types of stormwater control systems for only five events are reasons why rigorous statistical analysis was not conducted on the data. Contaminant concentrations were compared to published criteria for the protection of aquatic life, EPA 6217 guidelines, and classification standards for freshwater and shellfish-growing waters. The effectiveness of individual and types of systems were assessed by comparing contaminant removal efficiencies to published expected values.

RESULTS AND DISCUSSION

Sampling during the five storm events was affected by a variety of factors. As presented in Table 2, some of the systems were not functioning as designed.

-At SP, water from the parking lot adjacent to the treatment swale was transported by sheet flow into the swale over a small vegetated berm during all events, whereas the system was designed to treat water collected from the parking lot via drainage through manhole grates.

-At SW2 and PW2, the level spreader were causing serious erosion of the surrounding receiving area because water flowed out of the spreaders in high-flow streams, and not by sheet flow across the area of the spreader.

-At CC, the v-notch weir was largely disfunctional because water flowed mainly through a crack below the notch when water height behind the weir was relatively shallow, making measurement of water flow difficult.

-At PC, snow plowed from the parking lot was piled and compacted over the treatment swale area. In addition, the water from the relatively small parking lot flowed through breaks in the curbing around the lot into a short swale and out through a small level spreader. Overall, the water quality in the water from the building roof and back shipping area was cleaner than the water from the parking lot discharging from the level spreader.

At PW1, the diked pond seemed to be functioning as designed, except that a medium-sized drain from adjacent U.S. Route 1 emptied into the pond ~15' from the system effluent pipe. This generally caused the discharged effluent waters to be more contaminated than the water further into the diked area.

At NM, the system had plowed snow interfering with sampling in winter and the water seemed to disappear a short distance into the swale from the influent pipe during summer.

Measurements of flow were taken when possible under the conditions at the sites. Many of the systems, especially the ponds, had standing water with little or no apparent flow of water.At sites where flow velocity was measured, it appeared that flow was similar during the January and July storms. However, the September storm never developed into the storm it was predicted to become, and flow was never intense. Temperature of sample water was never variable between sites on a given day.

Table 3 presents meteorological conditions during and prior to the sampled storm events. Hourly rainfall data was available for the first few sampling events at the time of writing this report, and those data were never received in time for inclusion. The first two events were relatively average rainfall events, but were marked by significant snow melt. This was especially true for the first event on January 19, 1996, when snow depth recorded in Durham decreased from 24" to 11" in two days. The April and July storms were significant events, and came during periods following previous storm events. As previously mentioned, the September storm event never materialized into the major storm it was predicted to be, being part of a hurricane system. In addition, the September event was only the second rainfall event in the previous 30 days, when the hot weather and lack of rainfall caused the groundwater level to drop and the soils conducive to holding rainfall. These conditions are some of the reasons for the lack of water flow and significant runoff during this event.

The following sections of the Results are organized according to the initial objectives that were the basis for conducting this project.

<u>Effectiveness of existing stormwater control systems at removing NPS pollutants</u>

The contaminant concentrations at the ten sampling sites for the five storm events are presented in Tables 4 and 5. Average concentrations for the five storms are calculated for the non-biological water quality variables and geometric means for the bacterial contaminants. Many of the non-biological variables were non-detectable for some sites and dates. Averages were calculated assuming those values were equal to the detection limit. The sites with the highest bacterial contaminant levels were SW1-I, CC-E and BJ-E during winter storms, while many sites had elevated bacterial levels during summer storms.

Additional information in Table 5 include ratios of the influent to effluent geometric means for each sampling site. Sites with ratios >1 showed evidence of treatment occurring for that contaminant in the control system. In addition, the ratios of FC to *E. coli* were calculated to determine what portion of the total FC counts were *E. coli*.. Ratios much greater than 1 suggest that those samples had elevated fractions of FC that were probably not of fecal origin, and may reflect regrowth of FC-positive bacteria within the systems. Seven sites had FC:Ec ratios >2, including influent water into the pond systems SW1-I, SW2-I, PW1-I and PW2-I, and effluent water at the pond SW1-E and the swales DS-E,and NM-E. Notably, the sites (SW1-I, CC-E, BJ-E) with the highest bacterial levels during winter when regrowth is less likely to occur, had FC:Ec ratios close to or equal to one, indicating that the bacteria were more likely indicative of a fecal contamination source.

One way of assessing the effectiveness of the test systems is to determine if the effluent water meets water quality criteria. The State of New Hampshire has recently adopted water quality criteria for toxic substances for the protection of both aquatic life in fresh and marine waters and of human health for water and fish ingestion (NHDES, 1996). All of the system effluent waters discharged into natural wetland habitats, so the criteria for protection of aquatic life in fresh water were used to compare to measured toxic substance concentrations at the study sites (Table 6). For the five contaminants, concentration ranges are listed along with the sites with concentrations that fall into ranges above the fresh acute criteria and below the fresh chronic criteria. The acute criteria for aluminum, copper and zinc were commonly exceeded at many sites, especially during the two winter storms.For cadmium and chloride, even the chronic criteria were not exceeded during summer storms, and sites exceeding acute criteria were uncommon during winter storms. The sites at PW, 9i and 9e, were commonly below the chronic criteria for the different toxic substances.

Stormwater is known to contain the target contaminants at elevated levels, and stormwater control systems are designed to treat these contaminants to a limited extent. Thus, the above described instances of exceeding of water quality criteria for protection of aquatic life are not surprising. Another approach for assessing the effectiveness of these systems is to determine if the effluent from the control systems meets stormwater control standards outlined by the U.S. EPA in 6217 guidelines (USEPA, 1993). In these guidelines, estimated mean runoff concentrations of water quality parameters for different land uses are presented, based on the National Urban Runoff Program (NURP) studies. The criteria for commercial land use are presented in Table 6 for copper and zinc. These concentrations are much higher than the acute criteria used previously. For copper, only sites 9i and 6i during the January storms exceeded the NURP concentrations, which are estimated mean concentrations. The copper concentration at site 9i was 109 mg/l and the concentration at 6i was 59 mg/l, both relatively close to the NURP concentration of 50 mg/l. For zinc, the NURP concentration of 418 was exceeded only at site 7i on 9/8/96, where the zinc concentration was 686, again quite close to the NURP concentration. Thus, the stormwater systems are discharging contaminants at levels that are typically on the low end of average runoff from commercial sites.

Table 7 presents results for other non-toxic/non-biological contaminants. NURP concentrations were available for total phosphorus, total nitrogen, BOD and COD. A turbidity concentration of 10 NTU and an oil/grease concentration of 10 mg/l were chosen for comparison. The turbidity concentration of 10 NTU would be the limit for Class B waters if there was no measurable turbidity under naturally occurring conditions for these systems. This conservative criterion was only exceeded at a few sites, with no more than 5 sites exceeding the criterion for any given storm. Some of the samples probably had elevated turbidity as a result of having to sample extremely shallow water on some dates. This was especially true on 9/8/96, when 5 sites were >10 NTU, and little water was flowing in the systems. The extremely low concentration of 10 mg/l oil/grease was only exceeded four times, and the highest concentration was only 20 mg/l. Thus, these systems had little in the way of oil and grease in influent and effluent water.

NURP concentrations were exceeded on only a few occasions for the other parameters.

The NURP concentration of 2.29 mg total P/l was never exceeded, while the concentration of 1.5 mg total N/l was exceeded twice on each January storm and at four sites on 9/8/96. The highest total N concentration was only 3.18 mg/l, barely twice the NURP mean estimate. The results for 9/8/96 again probably reflect the presence of nitrogen in stagnant water left from a previous storm (Butler et al., 1995). The relatively high levels at site 1e during winter may be related to the elevated fecal bacterial concentrations observed at this site during winter storms. BOD and COD NURP concentrations were also exceeded only on rare occasions. The concentration of 14 mg BOD/l was exceeded only once during the first four storms, then at four sites on 9/8/96, and the highest concentration was only 16.7 mg/l. The concentration of 84 mg COD/l was exceeded four times during January storms and twice thereafter, with the highest concentration being 218 mg/l. Thus, none of these other contaminants were present at high concentrations, and generally the systems had low levels of contaminants in both the influent and effluent waters.

Bacterial contaminant concentrations were compared to criteria used for classifying shellfish-growing waters (fecal coliforms) and for freshwater recreational areas (*E. coli*). Surprisingly, the sites that exceeded FC also typically exceeded *E. coli* criteria. During the second, third and fourth storms, the same exact sites that exceeded the FC criteria also exceeded the *E. coli* criteria. In the fifth storm, one extra site exceeded the FC concentration of 88 FC/100 ml, while five more sites exceeded the FC concentration in the first storm. The *E. coli* concentration of 126/100 ml was exceeded less often during winter and the April storms (4-5 sites/storm) and more frequently during summer storms (13-14 sites/storm). Sites with low *E. coli* (<47/100 ml) were more frequent in winter (10-13 sites/storm) than in summer (1-3 sites/storm), thus supporting the observation of increasing bacterial concentrations during warmer months. No NURP concentrations were available for comparison to typical stormwater concentrations, but the high concentrations of bacteria for each storm were relatively high,, ranging from 520 to 528,000 FC/100 ml and 500 to 48,000 *E. coli*/100 ml. Unlike the other contaminants, the elevated levels of bacterial contaminants are frequent enough to cause concern.

Comparisons of the effectiveness of different system types

Another major objective of this study was to determine which type of system, if any, is effective for removing NPS pollutants from runoff water. In particular, the effectiveness of new, "state-of-the-art" systems compared to older systems was of interest. The approach taken to evaluate the effectiveness of the different systems was to look at contaminant removal efficiencies. The removal efficiencies (% of I removed in E) for each study system are presented in Table 9 for COD, turbidity, zinc, total N and total P. The study systems were grouped into wet ponds, vegetated swales and an infiltration chamber. EPA estimates for removal efficiencies for these different control systems and contaminants are published (USEPA, 1993), and are included in Table 9, along with the average efficiencies for the different types of systems for each storm. Table 10 presents the same information for aluminum, cadmium, copper, fecal coliforms, *E. coli*, oil/grease, chloride and BOD, only without the EPA estimated removal efficiencies. In general, the infiltration chamber was ineffective for treating all contaminants, and performed well below the estimated removal values. Wet ponds are relatively effective for treating the contaminants listed in Table 9, but are ineffective for contaminants in Table 10, except for copper and oil/grease. Vegetated swales appeared to be relatively effective in removing copper and oil/grease, but were ineffective for all of the other contaminants. The high negative values for removal of turbidity and total P were greatly influenced by site PC, where the effluent sample was most often collected from the level spreader that also collected large amounts of untreated parking lot runoff. Again, the variability of conditions under which samples were collected probably has a large influence on these results. However, the overall ineffectiveness of the vegetated systems, the swales and ponds, illustrates the known limitations of these systems during much of the year in cold climates (USEPA, 1993).

The largest negative removal numbers were observed for chloride (Table 10), especially in the vegetated systems. Of course, the immense amount of road salt applied to the parking lots has a large effect on this parameter. The other highest negative removal values were for bacterial contaminants (Table 10), especially in the infiltration chamber. The data in Table 5 and Figures 2 and 3 show the worst systems are BJ and CC, with only one high number at PC giving a high negative removal number in Table 10. Both at BJ and CC, bacterial levels were always high in the E locations and relatively low in the I locations. This implies that there may be either sources of bacteria in the systems, or that the system is conducive to regrowth and sustained survival of the target bacteria. It is conceivable at BJ that temperatures in the below-ground system could be warm enough to nurture fecal-borne bacteria and sustain populations in moist, nutrient-enriched conditions between storms, even during winter. Thus, the systems studied appear to be at best inconsistently effective in removing contaminants from runoff, and at worst may be increasing concentrations of some contaminants (bacteria, nitrogen).

Seasonal influences on control system effectiveness

The typical stormwater control system with vegetation is designed so that the live plants will interact with the runoff to remove contaminants. The plants reduce flow velocity and are capable of active uptake of dissolved contaminants, thus tying them up in a form that could be removed with maintenance routines. This study purposefully included three major storm/runoff events during the colder months, because the frequency of major runoff events is high during colder months and stormwater-driven loading to surface waters probably is significantly dominated by colder month events. Two summer storm events were also included to give a balanced assessment of the systems at all times of year. The data in Tables 9 and 10 have presented to differentiate summer from winter removal efficiencies. The wet ponds were relatively effective for removing COD, turbidity, copper, oil/grease and zinc during winter along with total P and BOD during summer. Total N was effectively removed during summer but there was evidence of nitrogen generation or a source during winter in these systems, especially at SW1.

Vegetated swales were inconsistently effective with season. During winter, apparently effective removal of aluminum, copper, *E. coli*, and oil/grease were observed in these systems, but all contaminants showed negative removal rates during summer. The design of vegetated systems is based on the fact that live plants will help to remove dissolved contaminants. Both vegetated swales and wet ponds have better removal efficiencies during summer than in winter, but they do poorly with total P during summer storms.

Storm control systems have been shown to be active as physical, chemical and biological reactors during dry periods between storm events (Butler et al., 1995). Biological processes that would affect the solubility of metals, ammonium generation, and bacterial regrowth would be especially important during warm months, as the colder months are too cold to support biological activity in New Hampshire. Ellis and Yu (1995) reported extended bacterial survival and regrowth in the nutrient-rich sediments of combined sewers, similar to the environments present in stormwater influent pipes, wet ponds and vegetated swales. The highest negative removal rates during summertime were observed for bacterial contaminants in all three types of systems. Except for SW2, all sites had negative removal efficiencies during summer storms. These results suggest that either sources of bacteria exist in these systems during summer, or that regrowth is occurring in the systems. The use of the indicators, fecal coliforms and *E. coli*, are useful because they are supposed to indicate the presence of fecal contamination, and they are used for classifying surface waters for different purposes. However, it is well known that fecal coliforms include environmental bacteria that are not of fecal origin, and *E. coli* is capable of regrowth in the environment. The critical question is, what is the public health significance of these elevated bacterial indicator levels? Few if any studies have focused on the fate of specific bacterial pathogens in stormwater control systems, so it is unknown if these systems are generators of pathogens.

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Table 1. Study sites for stormwater control project

Site name	Location	Acronym	Stormwater control description
1. Wall Mart	Somersworth	SW1	cattail pond
2. Wall Mart	Somersworth	SW2	cattail pond/level spreader
3. Shaw's Plaza expansion	Dover	DS	swale; high flow
4. Sawtelle parking lot	Dover	SP	swale; medium flow
5. BJ Wholesale	Portsmouth	BJ	infiltration chambers
6. Costco/JDC property	Portsmouth	CC	level spreader/wetland
7. CellTech	Portsmouth	PC	swale; medium flow
8. Wall Mart	Portsmouth	PW1	pond/staggered dike
9. Wall Mart	Portsmouth	PW2	swale with level spreader
10. Wentworth by the Sea condominiums	Newcastle	NM	swale w/storage; low flow

Table 2. Sampling conditions at sites.

Date	Site	Sample time	Flow (l/min)	Temp I/E (°C)	Conductivity I/E (μmhos)	Comments
1/19/96	SW1	18:20-18:30		0		
	SW2	18:50-19:15	E: 300	0		
	DS	19:30-19:45		0		
	SP	20:05-20:15	E:75	0		much of flow over top from adjacent parking lot
	BJ	18:10-18:25		0		
	CC	20:15-20:30	E: 130	0		I collected from water entering manhole; good flow through weir
	PC	17:30-17:45		0		I and swale covered under 10-15' snow; E collected at level spreader
	PW1	18:30-18:50		0		E collected near outlet and inflow from road
	PW2	18:55-19:20		0		
	NM	19:30-19:45		0		swale covered with snow; E collected from slush
1/24/96	SW1	14:55-15:00		0		
	SW2	15:20-15:40		0		
	DS	16:00-16:20		0		
	SP	16:45-16:55		0		much of flow over top from adjacent parking lot
	BJ	15:25-15:30		0		
	CC	17:25-17:30		0		I collected from water entering manhole; good flow through weir
	PC	no I-15:05		0		I and swale covered under 10-15' snow; E collected at level spreader
	PW1	15:50_15:55		0		
	PW2	16:05-16:10		0		
	NM	16:45-no E		0		swale covered with snow and E not collected
4/16/96	SW1	10:20-10:30				
	SW2	10:50-11:05				
	DS	11:20-11:30				
	SP	11:50-11:55				much of flow over top from adjacent parking lot
	BJ	10:25-10:35				
	CC	10:45-10:55				I collected from inflow pipe; flow through weir
	PC	11:00-11:10				E collected within swale
	PW1	11:40-11:50				
	PW2	11:25-11:35				
	NM	12:10-12:20				
7/13/96	SW1	11:55-12:05	I: 120	21/22.5		
	SW2	12:10-12:25	E: 240	20.5		
	DS	11:40-11:45		21		
	SP	11:15-11:20	E: 160	21/21.5		much of flow over top from adjacent parking lot
	BJ	12:15-12:25	I: 135	20	130/0	
	CC	11:45-11:55	I: 150	21.5	0/0	water flowing under weir
	PC	11:15-11:25		19.5	0/0	E collected within swale
	PW1	13:15-13:25		21	430/320	E collected near outlet and inflow from road
	PW2	13:30-13:45		20/21	1800/1200	
	NM	no samples				no water into or within swale
9/8/96	SW1	11:40-11:50				
	SW2	12:10-12:25				
	DS	12:40-12:50				
	SP	no samples				not enough water to sample
	BJ	10:55-11:05		20		couldn't open manhole, I collected from adjacent puddle
	CC	11:10-11:20	I: 1.4	19		no flow through weir
	PC	12:25-11:35		18-18.5		little flow, water at I collected; E collected at level spreader
	PW1	12:15-12:20		19		little flow
	PW2	12:25-12:40		20		no water at E
	NM	no samples				no water at I; E collected from outfloe pipe to high marsh

Table 3. Meteorological data for A.) sampled storm events; B.) monthly totals.

A.

Date	Sampling time	Storm event rainfall (in)	Antecedent dry (>0.5") period (d)	Prior event rainfall (in)	Comments
1/19/96	18:10-20:15	0.23+0.08	5	.28/48h	lost 13" snow/48h
1/24/96	14:55-17:30	0.55+0.15	3	.31/48h	
4/16/96	10:20-12:20	2.15+0.8	1	0.56/24h	
7/13/96	11:15-13:30	2.8+1.35	2	1.46/48h	
9/8/96	10:55-12:50	0.28	4	0.76/48h	hurricane

B.

Month	Total rainfall (in)	Total snowfall (in)	#events>0.5"
Jan	2.74	24	2 (1 snow)
Feb	1.59	7	1
Mar	2.49	20.5	4 (3 snow)
Apr	6.64	4	6 (1 snow)
May	3.64	-	3
June	1.86	-	1
July	7.87	-	3
Aug	0.84	-	1
Sept	3.6	-	2

Table 4. Non-biological contaminant concentrations at both influent (I) and effluent (E) locations at the 10 sample sites. Averages assume contaminant concentrations below detection limits equal detection limits. Concentrations are mg/l, except for turbidity, which is NTU.

Turbidity	1I	1E	2I	2E	3I	3E	4I	4E	5I	5E	6I	6E	7I	7E	8I	8E	9I	9E	10I	10E
1/19/96	150	130	76	70	90	58	90	80	22	35	64	78		25	56	100	3.3	6.8	50	21
1/24/96	89	100	54.5	32.5	82	111	20	24	29	35	194	78		19	74	18.7	5.6	3.5	37	
4/16/96	51	27	24	11.6	64	23	75	31	9.1	16.6	21	12.7	1.04	4.8	27	21	18.1	7	51	47
7/13/96	15	9.3	9.3	8.4	13	12	6.8	6.5	10	8.9	4.5	3.2	1.9	2.3	8.3	7.6	3.3	5.5		
9/8/96	11	14	6.6	3.4	16	300			6.8	12	4.1	5.8	1.7	1.6	7.3	6.6	6.3			33
Average	**63**	**56**	**34**	**25**	**53**	**101**	**48**	**35**	**15**	**22**	**58**	**36**	**1.5**	**11**	**35**	**31**	**7.3**	**5.7**	**46**	**34**
Aluminum	1I	1E	2I	2E	3I	3E	4I	4E	5I	5E	6I	6E	7I	7E	8I	8E	9I	9E	10I	10E
1/19/96	4.72	3.04	1.81	2.27	2.54	1.35	2.76	2.18	0.518	0.98	1.95	2.35		1.09	1.49	3.71	0.085	0.452	1.06	0.698
1/24/96	2.06	2.1	1.23	0.765	1.76	2.01	0.496	0.422	0.56	1.07	10.5	2.26		1.05	2.01	0.401	0.093	0.209	1.42	
4/16/96	3.67	0.401	0.669	0.21	2.03	0.58	3.65	1.17	0.339	0.604	1.03	0.434	0.065	0.37	1.24	0.994	0.844	0.234	1.31	1.04
7/13/96	0.35	0.055	<0.025	0.036	0.34	0.141	0.182	0.142	0.262	0.341	0.158	0.073	<0.05	0.123	0.253	0.201	0.14	0.49		
9/8/96	0.238	0.1	0.163	0.062	0.219	3.32			0.472	0.457	0.161	0.199	<0.05	0.136	0.17	0.166	0.215			0.19
Average	**2.21**	**1.14**	**0.78**	**0.67**	**1.38**	**1.48**	**1.77**	**0.98**	**0.43**	**0.69**	**2.76**	**1.06**	**0.06**	**0.55**	**1.03**	**1.09**	**0.28**	**0.35**	**1.26**	**0.64**
Copper	1I	1E	2I	2E	3I	3E	4I	4E	5I	5E	6I	6E	7I	7E	8I	8E	9I	9E	10I	10E
1/19/96	0.036		0.023	0.021	0.026	<0.0025	0.02	0.0065	0.024	0.013	0.021	0.022		<0.0025	0.015	0.026	0.109	<0.0025	0.026	0.007
1/24/96	0.018	0.02	0.0145	0.0105	0.026	0.017	0.011	0.008	0.011	0.015	0.059	0.024		0.008	0.02	0.01	0.006	0.008	0.012	
4/16/96	0.023	0.0054	0.008	0.005	0.014	0.0028	0.017	0.0042	0.0034	0.006	0.006	0.0032	<0.0025	0.0027	0.008	0.007	0.006	0.0028	0.01	0.01
7/13/96	0.0059	<0.0025	<0.0025	0.0029	0.0055	0.0046	0.0036	0.0096	0.0026	0.0034	<0.0025	<0.0025	0.0073	0.0096	0.0052	0.0048	<0.0025	<0.0025		
9/8/96	0.02	<0.0025	0.011	0.007	0.014	0.022			0.009	0.011	0.009	0.011	0.019	0.0042	0.01	0.011	0.009			<0.0025
Average	**0.021**	**0.011**	**0.012**	**0.009**	**0.017**	**0.010**	**0.013**	**0.007**	**0.010**	**0.010**	**0.020**	**0.013**	**0.010**	**0.005**	**0.012**	**0.012**	**0.027**	**0.004**	**0.016**	**0.007**
Zinc	1I	1E	2I	2E	3I	3E	4I	4E	5I	5E	6I	6E	7I	7E	8I	8E	9I	9E	10I	10E
1/19/96	0.217	0.186	0.122	0.147	0.222	0.137	0.077	0.11	0.036	0.089	0.058	0.105		0.103	0.097	0.169	0.041	<0.025	<0.025	0.038
1/24/96	0.108	0.17	0.109	0.0865	0.224	0.163	0.06	0.093	<0.025	0.193	0.169	0.09		0.082	0.114	0.083	0.031	<0.025	0.034	
4/16/96	0.154	0.0595	0.134	0.114	0.126	0.072	0.094	0.036	0.038	0.05	0.043	0.034	0.054	0.07	0.08	0.051	0.066	0.058	0.035	0.088
7/13/96	0.052	0.034	<0.025	0.027	0.104	0.085	<0.025	0.117	<0.025	0.073	<0.025	<0.025	0.179	0.154	0.04	0.03	0.025	0.025		
9/8/96	0.284	<0.025	0.132	0.115	0.32	0.43			0.11	0.223	0.038	0.09	0.686	0.112	0.14	0.149	0.128			<0.025
Average	**0.163**	**0.095**	**0.104**	**0.098**	**0.199**	**0.177**	**0.064**	**0.089**	**0.047**	**0.126**	**0.067**	**0.069**	**0.306**	**0.104**	**0.094**	**0.096**	**0.058**	**0.033**	**0.031**	**0.050**
Oil &Grease	1I	1E	2I	2E	3I	3E	4I	4E	5I	5E	6I	6E	7I	7E	8I	8E	9I	9E	10I	10E
1/19/96	19.2	11.61	5.84	5.69	6.41	2.44	7.61	4.67	1.25	2.18	5.05	5.36		1.17	4.11	8.35	1.28	<1	1.24	1.25
1/24/96	5.41	5.84	3.36	2.74		5.06	1.16	1.74	1.37	2.17	20	7.4		3.04	10.22	2.16	1.33	2.22	2.84	
4/16/96	8.25	1.98	10.89	1.22	2.64	<1	8.89	1.41	<1	<1	1.1	<1	<1	<1	3.77	1.35	5.42	1.15	1.68	2.4
7/13/96	<1	<1	<1	<1	<1	1.61	<1	<1	<1	1.46	1.49	2.5	3.24	1.81	<1	1.94	3.09	4.4		
9/8/96	4.17	1.79	9.24	2.53	3.51	3.88			2.11	9.48	2.92	1.68	1.26	4.21	2.9	3.96	1.56			1.29
Average	**7.61**	**4.44**	**6.07**	**2.64**	**3.39**	**2.80**	**4.67**	**2.21**	**1.35**	**3.26**	**6.11**	**3.59**	**1.83**	**2.25**	**4.40**	**3.55**	**2.54**	**2.19**	**1.92**	**1.65**

		1I	1E	2I	2E	3I	3E	4I	4E	5I	5E	6I	6E	7I	7E	8I	8E	9I	9E	10I	10E
Total P		1I	1E	2I	2E	3I	3E	4I	4E	5I	5E	6I	6E	7I	7E	8I	8E	9I	9E	10I	10E
	1/19/96	0.667	0.601	0.361	0.406	0.379	0.270	0.346	0.405	0.074	0.203	0.299	0.361		0.167	0.314	0.705	0.043	0.093	0.462	0.475
	1/24/96	0.513	0.812	0.665	0.439	0.889	1.616	0.624	0.366	0.324	0.475	2.068	1.094		0.678	0.986	0.319	0.065	0.109	1.038	
	4/16/96	0.100	0.176	0.237	0.214	0.069	0.059	0.401	0.108	0.028	0.056	0.045	0.029	0.010	0.023	0.047	0.072	0.039	0.022	0.184	0.262
	7/13/96	0.139	0.107	0.132	0.143	0.072	0.061	0.044	0.057	0.057	0.046	0.039	0.031	0.022	0.005	0.063	0.085	0.017	0.053		
	9/8/96	0.411	0.090	0.165	0.091	0.202	0.549			0.092	0.222	0.051	0.122	0.016	0.077	0.103	0.294	0.113			0.229
Average		**0.366**	**0.358**	**0.312**	**0.259**	**0.322**	**0.511**	**0.354**	**0.234**	**0.115**	**0.200**	**0.500**	**0.327**	**0.016**	**0.190**	**0.303**	**0.295**	**0.055**	**0.069**	**0.562**	**0.322**
Chloride		1I	1E	2I	2E	3I	3E	4I	4E	5I	5E	6I	6E	7I	7E	8I	8E	9I	9E	10I	10E
	1/19/96	265	1565	832	1156	250	224	102	223	303	342	107	658		213	414	1037	29	9	108	104
	1/24/96	71	1010	560	545	128	285	79	140	171	255	12	275		335	192	385	6	39	120	
	4/16/96	6	923	432	391	6	12	<2	<2	<2	3	4	8	3	3	5	6	13	33	5	5
	7/13/96	<2	83	62	36	2	11	<2	<2	<2	<2	<2	<2	<2	<2	<2	2	<2	2		
	9/8/96	4	39	4	22	25	70			2	2	2	2	<2	<2	3	22	4			1506
Average		**70**	**724**	**378**	**430**	**82**	**120**	**46**	**92**	**96**	**121**	**25**	**189**	**2**	**111**	**123**	**290**	**11**	**21**	**78**	**538**
TN		1I	1E	2I	2E	3I	3E	4I	4E	5I	5E	6I	6E	7I	7E	8I	8E	9I	9E	10I	10E
	1/19/96	0.83	2.67	1.38	1.95	0.73	0.61	0.31	0.42	0.33	0.66	0.34	0.46		0.41	0.32	0.50	0.30	0.25	1.18	1.15
	1/24/96	0.65	3.18	2.25	1.50	0.74	0.81	0.69	0.61	0.46	0.87	0.34	0.32		0.59	0.89	1.32	0.30	0.25	0.85	
	4/16/96	0.23	0.59	0.52	0.70	0.30	0.45	0.29	0.18	0.18	0.35	0.16	0.30	0.13	0.16	0.21	0.20	0.17	0.30	0.54	0.92
	7/13/96	0.50	0.25	0.52	0.44	0.35	0.44	0.21	0.29	0.48	0.49	0.28	0.28	0.37	0.45	0.39	0.46	0.25	0.34		
	9/8/96	1.26	0.53	1.57	0.98	2.72	1.66			0.63	1.96	0.57	0.27	0.64	0.48	0.96	0.83	0.85			1.30
Average		**0.69**	**1.44**	**1.25**	**1.11**	**0.97**	**0.79**	**0.38**	**0.37**	**0.42**	**0.87**	**0.34**	**0.33**	**0.38**	**0.42**	**0.55**	**0.66**	**0.37**	**0.28**	**0.85**	**1.12**
COD		1I	1E	2I	2E	3I	3E	4I	4E	5I	5E	6I	6E	7I	7E	8I	8E	9I	9E	10I	10E
	1/19/96	124	97	64	67	57	38	65	56	<20	31	58	64		<20	42	100	<20	<20	<20	<20
	1/24/96	43	73	43	29	38	58	<20	<20	<20	29	218	64		30	82	35	<20	<20	<20	
	4/16/96	59.5	52.5	43	<20	31	<20	106	21	<20	<20	<20	<20	<20	<20	33	23	30	<20	<20	<20
	7/13/96	<20	32	21	22	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20		
	9/8/96	62	30	48	46	43	119			37	32	<20	21	<20	<20	36	53	43			38
Average		**62**	**57**	**44**	**37**	**38**	**51**	**53**	**29**	**23**	**26**	**67**	**38**	**20**	**22**	**43**	**46**	**27**	**20**	**20**	**26**
BOD		1I	1E	2I	2E	3I	3E	4I	4E	5I	5E	6I	6E	7I	7E	8I	8E	9I	9E	10I	10E
	1/19/96	12	11	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10		<10	<10	<10	<10	<10	<10	<10
	1/24/96	4.3	16.7	9.35	5.45	4.1	5	4.4	<3	<3	<3	4.1	4.4		3.8	8.6	5.9	<3	<3	<3	
	4/16/96	<3	9.5	5.3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3	<3
	7/13/96	2.7	5.7	4.2	3	3	3	2.1	2.1	1.5	2.4	1.2	<1	<1	1.5	1.2	1.8	<1	2.7		
	9/8/96	14.1	2.7	13.8	5.4	9.3	16.2			3.3	14.7	4.5	4.2	2.4	2.7	9	14.4	8.7			4.2
Average		**7.22**	**9.12**	**8.53**	**5.37**	**5.88**	**7.44**	**4.88**	**4.53**	**4.16**	**6.62**	**4.56**	**4.52**	**2.13**	**4.20**	**6.36**	**7.02**	**5.14**	**4.68**	**5.33**	**5.73**
Cadmium		1I	1E	2I	2E	3I	3E	4I	4E	5I	5E	6I	6E	7I	7E	8I	8E	9I	9E	10I	10E
	1/19/96	0.0012	0.0011	0.0006	0.0011	0.001	0.0005	0.0004	0.0007	0.0004	0.0006	0.0004	0.0009		0.0006	0.001	0.0019	0.0012	<.00025	<.00025	<.00025
	1/24/96	0.00100	0.00120	0.0009	0.00060	0.00080	0.00040	<.00025	<.00025	<.00025	0.00035	0.00055	0.00035		0.00040	0.00055	0.00065	0.0005	<.00025	<.00025	
	4/16/96	<.0005	0.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005
	7/13/96	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005		
	9/8/96	0.0005	<.0005	0.0007	<.0005	<.0005	<.0005			<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005	0.0007			<.0005
Average		0.0007	0.0008	0.0006	0.0007	0.0007	0.0005	0.0005	0.0006	0.0005	0.0005	0.0005	0.0006	0.0005	0.0005	0.0006	0.0009	0.0007	0.0005	0.0005	0.0005

Table 5. Fecal coliform and E. coli levels (per 100 ml) at ten stormwater control sites in Coastal New Hampshire (I=INFLUENT; E=EFFLUENT).

FECAL COLIFORMS

Date	SW1 1I	SW1 1E	SW2 2I	SW2 2E	DS 3I	DS 3E	SP 4I	SP 4E	BJ 5I	BJ 5E	CC 6I	CC 6E	PC 7I	PC 7E	PW1 8I	PW1 8E	PW2 9I	PW2 9E	NM 10I	NM 10E
1/19/96	1320	4	6	20	105	16	50	120	28	1600	90	940		26	140	125	800	13	5	12
1/24/96	860	14	73	21	4	10	80	165	1.5	220	6.5	260		10.5	35	3	22	6	56	
4/16/96	340	35.5	27	142.5	520	140	14	25	2.5	460	0.5	0.5	0.5	0.5	9.5	16.5	15	16.5	0.5	0.5
7/14/96	1400	18200	10800	3200	940	1080	1800	2000	2	1370	21	400	0.5	4	28600	1000	280	800		
9/8/96	528000	46000	60000	50000	2000	66000			38	5600	260	5000	20	1200	5000	16000	16000			40
Geo. mean	**3098**	**278**	**377**	**395**	**210**	**276**	**100**	**177**	**6**	**1044**	**17**	**190**	**2**	**15**	**367**	**158**	**260**	**32**	**5**	**6**
I:E	11.1		1.0		0.8		0.6		0.01		0.1		0.1		2.3		2.9		0.6	

E. coli

Date	SW1 1I	SW1 1E	SW2 2I	SW2 2E	DS 3I	DS 3E	SP 4I	SP 4E	BJ 5I	BJ 5E	CC 6I	CC 6E	PC 7I	PC 7E	PW1 8I	PW1 8E	PW2 9I	PW2 9E	NM 10I	NM 10E
1/19/96	1260	2	2	8	95	7	46	60	24	1600	80	920		25	130	75	60	4	7	2
1/24/96	760	3	9	14	1	10	80	165	0.4	220	3.5	260		10.5	35	3	9.5	5	51	
4/16/96	300	24.5	6	112.5	500	140	8	15	2.5	390	0.5	0.5	0.5	0.5	8.5	13	7.5	11	0.5	0.5
7/14/96	1400	17200	9400	2400	900	520	1800	2000	2	1370	20	400	0.5	4	1600	1000	265	600		
9/8/96	6000	12000	48000	20000	2000	6000			32	4000	260	2000	5	1200	3600	8000	1000			15
Geo. mean	**1193**	**125**	**137**	**227**	**154**	**125**	**85**	**131**	**4**	**945**	**15**	**157**	**1**	**14**	**186**	**119**	**65**	**19**	**6**	**2**
I:E	9.6		0.6		1.2		0.6		0.00		0.1		0.1		1.6		1.7		1.9	

FC/Ec

Date	SW1 1I	SW1 1E	SW2 2I	SW2 2E	DS 3I	DS 3E	SP 4I	SP 4E	BJ 5I	BJ 5E	CC 6I	CC 6E	PC 7I	PC 7E	PW1 8I	PW1 8E	PW2 9I	PW2 9E	NM 10I	NM 10E
1/19/96	1.0	2.0	3.0	2.5	1.1	2.3	1.1	2.0	1.2	1.0	1.1	1.0		1.0	1.1	1.7	13.3	3.3	0.7	6.0
1/24/96	1.1	4.7	8.1	1.5	4.0	1.0	1.0	1.0	3.8	1.0	1.9	1.0		1.0	1.0	1.0	2.3	1.2	1.1	
4/16/96	1.1	1.4	4.5	1.3	1.0	1.0	1.8	1.7	1.0	1.2	1.0	1.0	1.0	1.0	1.1	1.3	2.0	1.5	1.0	1.0
7/14/96	1.0	1.1	1.1	1.3	1.0	2.1	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.0	17.9	1.0	1.1	1.3		
9/8/96	88.0	3.8	1.3	2.5	1.0	11.0			1.2	1.4	1.0	2.5	4.0	1.0	1.4	2.0	16.0			2.7
Average	**18.5**	**2.6**	**3.6**	**1.8**	**1.6**	**3.5**	**1.2**	**1.4**	**1.6**	**1.1**	**1.2**	**1.3**	**2.0**	**1.0**	**4.5**	**1.4**	**6.9**	**1.8**	**0.9**	**3.2**

Table 6. Sample concentrations relative to water quality criteria for toxic substances*

Date	Concentration range (µg/l)	Sites >acute concentration	Sites acute>sample conc>chronic	Sites <chronic concentration	Sites >NURP conc.
Aluminum		**>750**	**750>sample conc>87**	**<87**	**NA**
1/19/96	85-4720	1-4,6,8i&e; 5e,7e,10i	5i,9e	9i	
1/24/96	93-10500	1-3,6i&e; 5e,7e,8i,10i	4,9i&e; 5i,8e	none	
4/16/96	65-3670	4,8,10i&e; 1i,3i,6i,9i	2,5i&e; 1e,3e,6e,7e,9e	7i	
7/13/96	50-490	none	2-5,8,9i&e;1i,6i,7e	1e,6e,7i	
9/8/96	50-3320	3e	1,5,6,8i&e; 2i,3i,7e,9i,10e	2e,7i	
Cadmium		**>0.82**	**0.82>sample conc>0.38**	**<0.38**	**NA**
1/19/96	<.25-1.9	1,8i&e; 2e,3i,6e,9i	5i&e; 2i,3e,4e,7e	10i&e; 4i,6i,9e	
1/24/96	<.25-1.2	1i&e	2,3,8i&e; 6i,7e,9i	4,5i&e; 6e,9e,10i	
4/16/96	<0.5	none	none	all samples	
7/13/96	<0.5	none	none	all samples	
9/8/96	<0.5-0.7	none	none	all samples	
Copper		**>4.6**	**4.6>sample conc>3.5**	**<3.5**	**>50**
1/19/96	2.5-109	1,2,4-6,8,10i&e; 3i,4i,9i	none	3e,7e,9e	9i
1/24/96	6.0-59	all samples			6i
4/16/96	2.8-23	1,2,8,10i&e; 3i,4i,5e,6i,9i	4e	7i&e; 3e,5i,6e,9e	none
7/13/96	2.5-10	7,8i&e; 1i,3i,4e,	3e,4i	2,5,6,9i&e; 1e	none
9/8/96	2.5-22	2,3,5,6,8i&e; 1i,7i,9i	7e	1e,10e	none
Zinc		**>35**	**35>sample conc>32**	**<32**	**>418**
1/19/96	25-222	1-8i&e; 9i,10e		9e,10i	none
1/24/96	25-224	1-4,6,8i&e; 5e,7e	10i	9i&e; 5i	none
4/16/96	34-154	1-5,7-9i&e; 6i,10e	6e,10i	none	none
7/13/96	25-179	3,7i&e; 1i,4e,5e,8i	1e	2,6,9i&e; 4i,5i,8e	none
9/8/96	25-686	all but 1e&10e	none	1e, 10e	7i
Chloride		**>860,000**	**860,000>SC>230,000**	**<230,000**	**NA**
1/19/96	9,000-1,565,000	1e,2e,8e	5i&e; 1e,2i,3i,6e,8i	4,9,10i&e; 3e,6i,7e	
1/24/96	6,000-1,010,000	1e	2i&e; 3i,5e,6e,7e,8e	4,9i&e; 1i,3i,5i,6i,8i,10i	
4/16/96	2,000-923,000	1e	2i&e	1i; 3-10i&e	
7/13/96	2,000-83,000	none	none	all < 84,000	
9/8/96	2,000-70,000	none	none	all < 84,000	

*Acute and chronic concentrations for State of New Hampshire criteria for protection of aquatic life; in µg/l (NHDES, October, 1996).
NURP concentrations for mean runoff concentrations for commercial land use.

Table 7. Contaminant concentrations relative to NURP estimates for runoff from commercial land use.

Date	Concentration range	Sites with >NURP concentrations
Total phosphorus	(mg/l)	**>2.29**
1/19/96	0.043-0.667	none
1/24/96	0.065-2.07	none
4/16/96	0.010-0.262	none
7/13/96	0.017-0.143	none
9/8/96	0.016-0.549	none
Total nitrogen	(mg/l)	**>1.5**
1/19/96	0.249-2.66	1e, 2e
1/24/96	0.250-3.18	1e, 2i
4/16/96	0.130-0.697	none
7/13/96	0.211-0.522	none
9/8/96	0.271-2.72	2i, 3i, 3e, 5e
BOD	(mg/l)	**>14**
1/19/96	<10-12	none
1/24/96	<3-16.7	1e
4/16/96	<3-9.5	none
7/13/96	<1-5.7	none
9/8/96	2.4-16.2	1i, 3e, 5e, 8e
COD	(mg/l)	**>84**
1/19/96	<20-124	1i, 1e, 8e
1/24/96	<20-218	6i
4/16/96	<20-106	4i
7/13/96	<20-32	none
9/8/96	<20-119	3e
Turbidity	NTU	**<10NTU***
1/19/96	3.3-150	9i
1/24/96	3.5-194	9i&e
4/16/96	1.04-75	5i,7i&e,9e
7/13/96	2.3-15	all samples except 1i,3i&e
9/8/96	1.6-300	all samples except 1,3i&e; 5e,10e
Oil and grease	(mg/l)	**<10****
1/19/96	<1-19.2	all samples except 1i&e
1/24/96	1.16-20.0	all samples except 6i
4/16/96	<1-10.89	all samples except 2i
7/13/96	<1-4.40	all samples
9/8/96	1.26-9.48	all samples

*Assuming no measureable turbidity under naturally occurring conditions, a value of 10 NTU would be required to meet Class B water criteria.

**A concentration of 10 mg/l was arbitrarily chosen for comparitive purposes.

Table 8. Bacterial concentration ranges relative to classification criteria.

Date	Concentration range	Sites with high* concentrations	Sites with low** concentrations
Fecal coliforms	cfu/100 ml	**>88**	**<14**
1/19/96	4-1600	6,8i&e; 1i,3i,4e,5e,9i	10i&e, 1e,2i,9e
1/24/96	1.5-860	1i,4e,5e,6e	3i&e, 5i,6i,7e,8e,9e
4/16/96	0.5-520	3i&e, 1i,2e,5e	6,7,10i&e; 5i,8i
7/13/96	0.5-28600	1-4,8,9i&e; 5e,6e	5i,7i&e
9/8/96	20-528000	1-3,8i&e; 5e,6e,7e,9i	none
E. coli	cfu/100 ml	**>126**	**<47**
1/19/96	2-1600	1i,5e,6e,8i	2,10i&e; 1e,3e,4i,5i,7e,9e
1/24/96	0.4-760	1i,4e,5e,6e	3,9i&e; 1e,2i,5i,6i,7e,8e
4/16/96	0.5-500	1i,2e,5e,3i&e	6-10i&e; 2i,4i,5i
7/13/96	0.5-17200	1-4,8,9i&e; 5e,6e	5i, 7i&e
9/8/96	5-48000	1-3,6,8i&e; 5e,7e,9i	7i

*The high fecal coliform level is the concentration at which shellfish growing areas are classified as prohibited. The high E. coli level is the concentration at which Class B water classification criteria are violated.
**The low fecal coliform level is the concentration at which shellfish growing areas are classified as approved. The low E. coli level is the concentration at which Class A water classification criteria are met.

Table 9. Measured and estimated* removal efficiencies of contaminants in stormwater control systems.

Overall	Wet ponds						Vegetated swales							Infiltration chamber	
					Estimated	Average						Estimated	Average		Estimated
Site:	SW1	SW2	PW1	CC	% removal	% removal	PW2	PC	DS	SP	NM	% removal	% removal	BJ	% removal
COD	8	16	-8	44	**40**	15	25	-10	-35	45	-30	**40**	-1	-13	**65**
turbidity	11	26	11	38	**60**	22	22	-581	-90	26	27	**65**	-119	-40	**75**
zinc	42	6	-2	-3	**60**	11	43	66	11	-39	-61	**60**	4	-168	**65**
total P	2	17	3	35	**45**	14	-25	-1073	-59	34	43	**40**	-216	-74	**65**
total N	-108	11	-19	4	**35**	-28	24	-10	18	0	-31	**40**	0	-108	**60**

Winter	Wet ponds						Vegetated swales							Infiltration chamber	
					Estimated	Average						Estimated	Average		Estimated
Site:	SW1	SW2	PW1	CC	% removal	% removal	PW2	PC	DS	SP	NM	% removal	% removal	BJ	% removal
COD	-2	10	-9	54	**40**	13	0	NA	-1	11	0	**40**	2	-50	**65**
Turbidity	9	44	61	58	**60**	43	56	-1044	8	42	-7	**65**	-189	-35	**75**
Zinc	12	17	31	42	**60**	26	14	-41	33	16	-155	**60**	-26	-286	**65**
Total P	-61	28	62	47	**45**	19	-26	-3268	-75	54	57	**40**	-651	-51	**65**
Total N	-330	20	-39	-23	**35**	-93	-16	-191	-22	20	-33	**40**	-48	-90	**60**

Summer	Wet ponds						Vegetated swales							Infiltration chamber	
					Estimated	Average						Estimated	Average		Estimated
Site:	SW1	SW2	PW1	CC	% removal	% removal	PW2	PC	DS	SP	NM	% removal	% removal	BJ	% removal
COD	24	1	-30	-2	**40**	-2	37	0	-121	0	NA	**40**	-21	9	**65**
Turbidity	6	30	11	33	**60**	20	16	-274	-481	26	28	**65**	-137	-51	**75**
Zinc	73	10	-5	-52	**60**	7	64	78	-17	-39	-20	**60**	13	-122	**65**
Total P	42	27	-45	18	**45**	11	17	-719	-102	34	51	**40**	-144	-104	**65**
Total N	-1	26	2	34	**35**	15	53	12	33	0	-42	**40**	12	-169	**60**

*EPA estimates based on published studies (6217 guidelines, 1993).

Table 9. Measured and estimated* removal efficiencies of contaminants in stormwater control systems.

Overall	Wet ponds						Vegetated swales							Infiltration chamber	
Site:	SW1	SW2	PW2	CC	Estimated % removal	Average % removal	PW1	PC	DS	SP	NM	Estimated % removal	Average % removal	BJ	Estimated % removal
COD	8	16	25	44	**40**	23	-8	-10	-35	45	-30	**40**	-8	-13	**65**
turbidity	11	26	22	38	**60**	24	11	-581	-90	26	27	**65**	-122	-40	**75**
zinc	42	6	43	-3	**60**	22	-2	66	11	-39	-61	**60**	-5	-168	**65**
total P	2	17	-25	35	**45**	7	3	-1073	-59	34	43	**40**	-211	-74	**65**
total N	-108	11	24	4	**35**	-17	-19	-10	18	0	-31	**40**	-9	-108	**60**

Winter	Wet ponds						Vegetated swales							Infiltration chamber	
Site:	SW1	SW2	PW2	CC	Estimated % removal	Average % removal	PW1	PC	DS	SP	NM	Estimated % removal	Average % removal	BJ	Estimated % removal
COD	-2	10	0	54	**40**	16	-9	NA	-1	11	0	**40**	0	-50	**65**
Turbidity	9	44	56	58	**60**	42	61	-1044	8	42	-7	**65**	-188	-35	**75**
Zinc	12	17	14	42	**60**	21	31	-41	33	16	-155	**60**	-23	-286	**65**
Total P	-61	28	-26	47	**45**	-3	62	-3268	-75	54	57	**40**	-634	-51	**65**
Total N	-330	20	-16	-23	**35**	-87	-39	-191	-22	20	-33	**40**	-53	-90	**60**

Summer	Wet ponds						Vegetated swales							Infiltration chamber	
Site:	SW1	SW2	PW2	CC	Estimated % removal	Average % removal	PW1	PC	DS	SP	NM	Estimated % removal	Average % removal	BJ	Estimated % removal
COD	24	1	37	-2	**40**	15	-30	0	-121	0	NA	**40**	-38	9	**65**
Turbidity	6	30	16	33	**60**	21	11	-274	-481	26	28	**65**	-138	-51	**75**
Zinc	73	10	64	-52	**60**	24	-5	78	-17	-39	-20	**60**	-1	-122	**65**
Total P	42	27	17	18	**45**	26	-45	-719	-102	34	51	**40**	-156	-104	**65**
Total N	-1	26	53	34	**35**	28	2	12	33	0	-42	**40**	1	-169	**60**

*EPA estimates based on published studies (6217 guidelines, 1993).

Table 10. Removal efficiencies (% removal) for contaminants in different stormwater control systems.

Overall	Wet ponds					Vegetated swales						Infiltration chamber
Site:	SW1	SW2	PW2	CC	Average	PW1	PC	DS	SP	NM	Average	BJ
Aluminum	48	14	-26	61	**25**	-6	-907	-7	45	49	**-165**	-60
Cadmium	-3	-5	24	-18	**-1**	-39	0	32	-22	0	**-6**	-2
Copper	46	21	85	36	**47**	-1	44	43	45	59	**38**	3
Fecal coliform	91	-5	88	-989	**-204**	57	-752	-31	-77	-20	**-165**	-17216
E. coli	*90*	*-65*	*71*	*-956*	***-215***	*36*	*-1241*	*19*	-54	*56*	**-237**	-21677
Oil and grease	42	57	14	41	**38**	19	-23	17	53	14	**16**	-142
Chloride	-940	-14	-92	-644	**-423**	-136	-4657	-46	-98	-593	**-1106**	-26
BOD	-26	37	9	1	**5**	-10	-97	-27	7	-8	**-27**	-59

Winter	Wet ponds					Vegetated swales						Infiltration chamber
Site:	SW1	SW2	PW2	CC	Average	PW1	PC	DS	SP	NM	Average	BJ
Aluminum	24	0	-271	63	**-46**	-17	NA	22	20	44	**17**	-90
Cadmium	-5	-14		-39	**-19**	-65		50	-86		**-33**	-13
Copper	17	16	91	43	**42**	-3	NA	63	53	63	**44**	20
Fecal coliform	99	2	93	-1944	**-437**	72	NA	38	-122	28	**4**	-9055
E. coli	100	-149	81	-2823	**-698**	78	NA	14	-64	89	**29**	-19049
Oil and grease	29	8	-23	49	**16**	27	NA	41	27	39	**33**	-66
Chloride	-666	-22	-37	-684	**-352**	-135	NA	-35	-101	9	**-65**	-26
BOD	-70	20	0	-2	**-13**	15	NA	-6	10	-54	**-9**	0

Summer	Wet ponds					Vegetated swales						Infiltration chamber
Site:	SW1	SW2	PW2	CC	Average	PW1	PC	DS	SP	NM	Average	BJ
Aluminum	74	48	-176	15	**-10**	13	-159	-519	22	NA	**-161**	-9
Cadmium	all below detection limits							all below detection limits				all below detection limits
Copper	81	27	57	-17	**37**	-4	48	-36	-167	NA	**-40**	-24
Fecal coliform	-6	50	-186	-1814	**-489**	67	-2091	-516	-11	NA	**-638**	-31672
E. coli	-396	67	-126	-1140	**-399**	-18	-4282	-32	-11	NA	**-1086**	-29162
Oil and grease	46	66	-89	5	**7**	-51	-34	-22	0	NA	**-27**	-252
Chloride	-1933	12	33	0	**-472**	-380	0	-200	0	NA	**-145**	0
BOD	50	53	44	9	**39**	-59	-24	-56	0	NA	**-35**	-256

Table 10. Removal efficiencies (% removal) for contaminants in different stormwater control systems.

Overall	Wet ponds					Vegetated swales						Infiltration chamber
Site:	SW1	SW2	PW1	CC	Average	PW2	PC	DS	SP	NM	Average	BJ
Aluminum	48	14	-6	61	**30**	-26	-907	-7	45	49	**-169**	-60
Cadmium	-3	-5	-39	-18	**-16**	24	0	32	-22	0	**7**	-2
Copper	46	21	-1	36	**26**	85	44	43	45	59	**55**	3
Fecal coliform	91	-5	57	-989	**-211**	88	-752	-31	-77	-20	**-158**	-17216
E. coli	90	-65	36	-956	**-224**	71	-1241	19	-54	56	**-230**	-21677
Oil and grease	42	57	19	41	**40**	14	-23	17	53	14	**15**	-142
Chloride	-940	-14	-136	-644	**-433**	-92	-4657	-46	-98	-593	**-1097**	-26
BOD	-26	37	-10	1	**0**	9	-97	-27	7	-8	**-23**	-59

Winter	Wet ponds					Vegetated swales						Infiltration chamber
Site:	SW1	SW2	PW1	CC	Average	PW2	PC	DS	SP	NM	Average	BJ
Aluminum	24	0	-17	63	**17**	-271	NA	22	20	44	**-46**	-90
Cadmium	-5	-14	-65	-39	**-30**			50	-86		**-18**	-13
Copper	17	16	-3	43	**18**	91	NA	63	53	63	**67**	20
Fecal coliform	99	2	72	-1944	**-443**	93	NA	38	-122	28	**9**	-9055
E. coli	100	-149	78	-2823	**-699**	81	NA	14	-64	89	**30**	-19049
Oil and grease	29	8	27	49	**28**	-23	NA	41	27	39	**21**	-66
Chloride	-666	-22	-135	-684	**-377**	-37	NA	-35	-101	9	**-41**	-26
BOD	-70	20	15	-2	**-9**	0	NA	-6	10	-54	**-13**	0

Summer	Wet ponds					Vegetated swales						Infiltration chamber
Site:	SW1	SW2	PW1	CC	Average	PW2	PC	DS	SP	NM	Average	BJ
Aluminum	74	48	13	15	**37**	-176	-159	-519	22	NA	**-208**	-9
Cadmium	all below detection limits							all below detection limits				*all below detection limits*
Copper	81	27	-4	-17	**22**	57	48	-36	-167	NA	**-25**	-24
Fecal coliform	-6	50	67	-1814	**-426**	-186	-2091	-516	-11	NA	**-701**	-31672
E. coli	-396	67	-18	-1140	**-372**	-126	-4282	-32	-11	NA	**-1113**	-29162
Oil and grease	46	66	-51	5	**16**	-89	-34	-22	0	NA	**-36**	-252
Chloride	-1933	12	-380	0	**-575**	33	0	-200	0	NA	**-42**	0
BOD	50	53	-59	9	**13**	44	-24	-56	0	NA	**-9**	-256

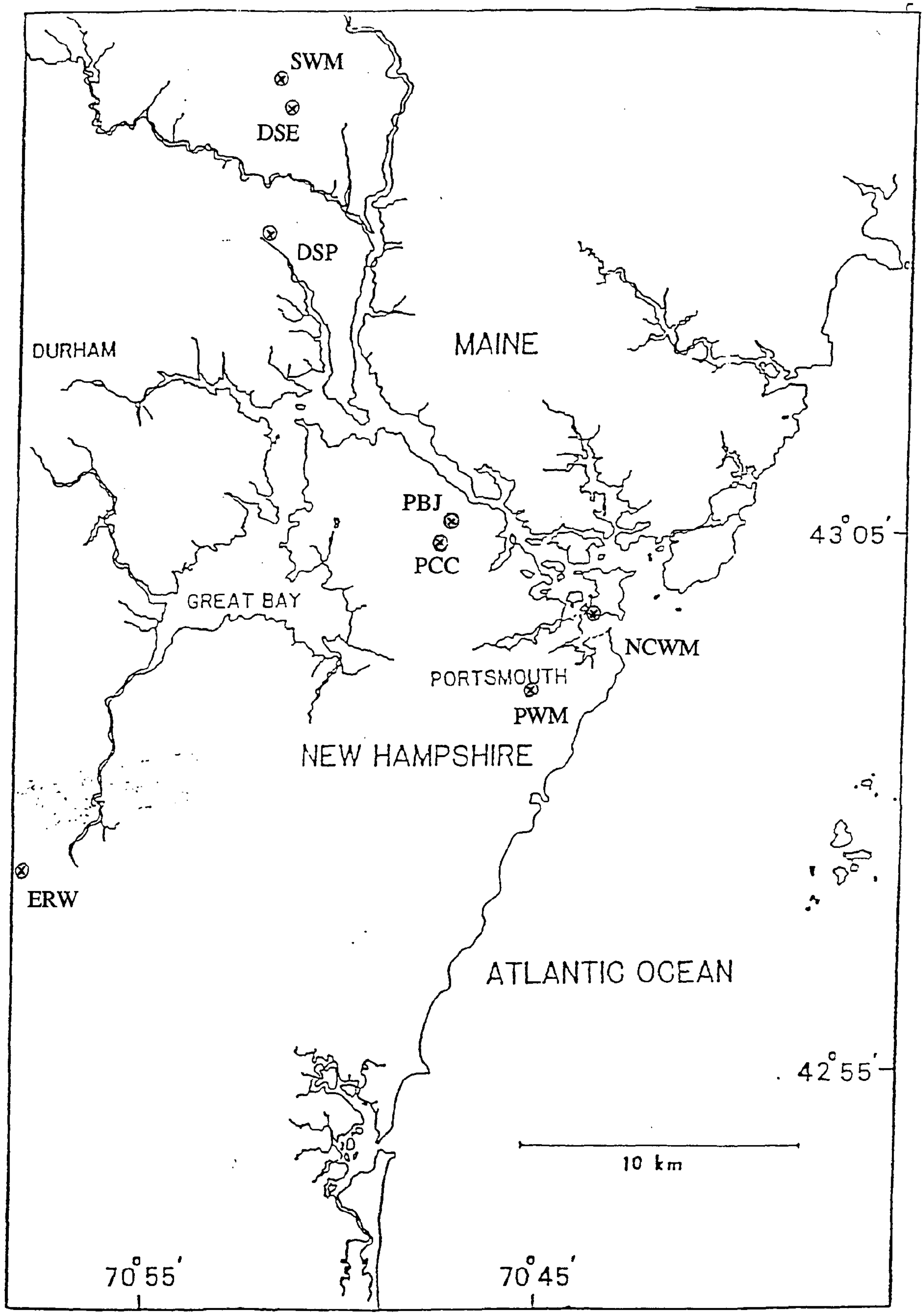

Figure 1. Study sites for the stormwater control project: 1995-96.

Figure 2. Geometric mean fecal coliform concentrations in influent and effluent water.

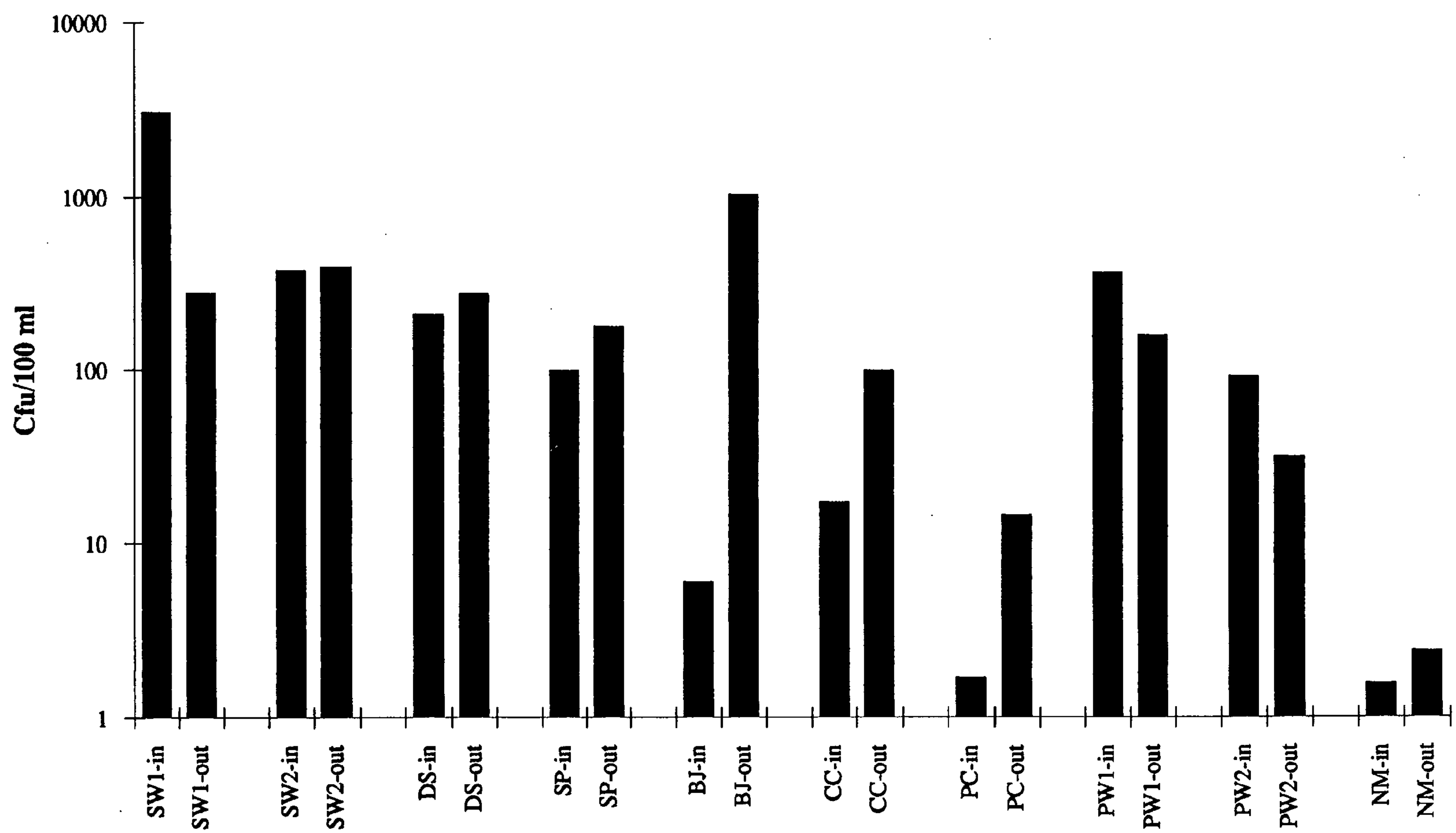

Figure 3. Geometric mean E. coli concentrations in influent and effluent water.