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MITIGATION OF AGRICULTURAL CONTAMINANTS OF ESTUARINE WATER USING CONSTRUCTED WETLANDS

A final report submitted to the New Hampshire Coastal Program
NH Office of State Planning

by

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This report was funded in part by a grant from the Office of State Planning, New Hampshire Coastal Program, under the auspices of the National Oceanic and Atmospheric Administration (NOAA), Award Number NA370Z0277-01.

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INTRODUCTION

The Squamscott River has historically been a significant source of bacterial contaminants and nutrients to Great Bay, due in large part to two POTW's that discharge directly into the tidal portion of the river. Recent improvements in wastewater treatment processes have decreased contamination from these sources, resulting in some improvement in water quality in the river. However, the river still has elevated levels of fecal-borne microbial contaminants and dissolved nitrogen and phosphorus. Much of this contamination comes from nonpoint sources, including agricultural areas like the Stuart Farm in Stratham. This site is of particular interest because the farm's animal waste storage area is located at the head of a ditch that drains into the Squamscott River. Assessment of the fate of nutrients and microbial contaminants from the animal waste storage area was initiated by NH DES in 1992 and continued by UNH/JEL in 1992-1993. In the fall of 1993, the drainage ditch was altered by creating two impoundments to promote longer detention times for water-borne contaminants and to allow for growth of wetlands plants that should serve as sinks for nutrients. The purpose of this project was to evaluate the effectiveness of these management practices in reducing the impact of agricultural contamination of tidal waters.

MATERIALS AND METHODS

Five sites were chosen on a transect extending from the manure storage area through the drainage ditch and impoundments and ending in the Squamscott River (Figure 1). The locations of the sites were as follows:

Site 1. The ditch just below the manure pile/picket dam;
Site 2. The effluent from the first new impoundment pond/solids settling basin;
Site 3. The effluent from the second, larger pond;
Site 4. The small pond at the end of the ditch just upstream of the tidal dam;
Site 5. The mouth of the tidal portion of the ditch/stream where it meets the Squamscott River.

Samples were collected on six dates, which included dry periods as well as rainfall/snowmelt runoff events. The six sample dates were November 30, 1993 (wet), March 30, 1994 (wet), May 13, 1994 (dry), June 2, 1994 (relatively dry), June 15, 1994 (wet), and June 27, 1994 (dry). Sample analysis included the microbial indicators fecal coliforms, *Escherichia coli*, *Clostridium perfringens* and enterococci; the inorganic nutrients ammonium, nitrate/nitrite and orthophosphate. Measurements were made of temperature, salinity, conductivity and pH at the time of sampling. Analytical methods used were standard multiple tube fermentation MPN analyses or EPA-recommended and other standard membrane filtration methods for microorganisms, the appropriate LACHAT "Quik-Chem" methods for nutrients, and standard procedures for all other parameters. Data from this study was compared to the assessment data collected before the alteration of the drainage ditch and creation of impoundments.

RESULTS AND DISCUSSION

Bacteria

The spatial trend for concentrations of bacterial indicators was relatively clear throughout the year. Concentrations of bacterial contaminants were always higher at the manure pile source (Site 1) than downstream at Site 5 in the Squamscott River (Figures 2-4). The greatest drop in levels was between the second pond (Site 3) and the tidal dam pond (Site 4) for all three indicators, especially for *C. perfringens* (Figure 4). *C. perfringens* tends to be strongly associated with surfaces and suspended solids, and the cleansing of particulate matter that occurs from the second pond to the tidal dam pond probably takes the *C. perfringens* with it. The levels of bacteria were similar in the first three sites except for fecal coliforms (Figure 2) and enterococci (Figure 3) during the spring and summer of 1994. During this time, there was an apparent die off of these indicators from the first pond effluent to the second pond effluent. This may be attributed to the higher temperatures during this time compared to the two previous sample dates (Table 1). In fact, the levels of enterococci and fecal coliforms were also relatively high at Sites 4 and 5 on the colder, first two sample dates. The same was not observed for *C. perfringens*, which survives in spore form and is better able to survive over wide temperature ranges. Both fecal coliforms and enterococci were present at very low levels on November 30 at Site 1. The pH was relatively alkaline (>10x [H^+] at downstream sites) and may reflect the presence of inhibitory substances (i.e. bleach, disinfectant, etc.) from the milk house effluent that mixes into the manure pile runoff just above Site 1.

Samples were collected during dry and after rainy periods. No consistent trends were observed that reflected any influence of rainfall-associated runoff on bacterial indicators. This is not surprising because of the infrequency of sampling and because comparisons are made for different seasons. The only potential trend was for fecal coliforms at Sites 1, 2, 4 and 5 during June, 1994. During this time, fecal coliform levels were higher for samples collected after dry periods than for the rainy sample at these sites, potentially reflecting some dilution effect from rainfall runoff. However, this was not observed consistently for the other bacteria. As previously mentioned, temperature seems to influence levels of the non-spore forming bacteria, so season does have an influence on bacteria.

Nutrients

Though the general trend for nutrient concentration was that the levels decreased along the transect, there was a great deal of variation in concentration between sample dates, as well as variation in the location (site) of reduction for a particular nutrient (Table 1; Figs. 5, 6, 7). In the November 30 samples, both ammonium and nitrate increased from Site 1 through Sites 2 and 3 before sharp reductions occurred in the tidal dam pond. This was not the case for phosphate, which showed reduced concentration at each site. Since the pH was relatively high and bacterial levels were so low, it may be that the effluent at Site 1 was diluted by runoff with lower nutrient concentrations from the milkhouse or other source.

Although the initial concentrations of all the nutrients were lower than several other dates in the March 30 samples, the poorest reduction in concentration was observed in these samples. This sample date was during the time of spring snowmelt and high runoff, therefore the reduced initial concentrations were probably due to dilution, and the high concentrations in the Squamscott River reflect the influence of innumerable pollution sources in addition to Stuart Farm. Wetland plant growth was also minimal at this time as well. The May 13 samples, which were preceded by a period of dry weather, had the highest concentrations of ammonium and phosphate at site 1. Effective reductions in concentrations were observed at each site for all three nutrients, and the concentrations in the river samples were all low.

In the June 2 samples, nitrate concentration at Site 1 was relatively low, and effective reduction at each subsequent site was observed. The river sample, however, was higher than the tidal dam pond sample. Ammonium concentrations increased at Sites 2 and 3, were much lower in the tidal dam pond, and higher in the river sample, while phosphate concentration increased between Sites 2 and 3 before dramatic reduction occurred in the tidal dam pond. Though there was no observed increase in phosphate concentration in the river sample as there was with ammonium and nitrate, the river sample sample concentration was high relative to the other sample dates. On June 15, both ammonium and nitrate concentrations were higher at Site 3 than Site 2, however effective reductions were observed at Site 4 for both nitrogen compounds. Phosphate concentration was reduced at each site along the transect. In the June 27 samples, both ammonium and nitrate concentrations showed sharp reductions between Sites 1 and 2, and consistent reduction through the rest of the transect. Phosphate was slightly higher at site two than at Site 1, and the greatest change was observed between the second impoundment and the tidal dam sample.

More effective reductions in nutrient levels were observed in the late spring samples than in either the fall or early spring. This was probably due to the warmer temperatures stimulating greater microbiological activity, longer detention times resulting from plugging a leak in the second pond dam, or a more established plant community along the transect. Additional sampling as the vegetation becomes more established would probably be needed to document the success of the mitigation effort.

Interannual Comparisons and Conclusions

These results do not indicate any favorable effect of the construction on bacterial levels. Greater reductions in bacterial levels within the first three sites would be expected on any given sample date. The obvious reason for this conclusion is that it takes time for the wetland plants to grow and initiate processes that would decrease contaminant levels through uptake or longer detention times. Because of delays in construction, no plant growth was possible during the fall of 1993, so the wetland would not be expected to function until plants began growing in the late spring of 1994. In fact, we did observe some decreases in levels of two of the three bacterial indicators during June, 1994, in the effluent from the second pond. However, because we did not see reductions in levels of the spore-forming *C. perfringens*, we concluded that the reductions were a function of increased temperature, and probably not from natural treatment processes that may have occurred within the constructed wetland area. Additional analysis of data comparing before- to post-construction data supports this conclusion.

A comparison of data from before and after construction was made for the fecal coliforms, enterococci, and dissolved nutrients using geometric mean values for bacteria and arithmetic mean values for nutrients (Table 2). Since the sites were slightly different as a result of pond construction, only four sites common to both years could be compared. The small database cannot support rigorous statistical evaluation, so simple ratios were used to determine if there were obvious trends for contaminants at the different sites between years. Ratio values <1 indicated lower levels after construction and values >1 indicated lower levels before construction. To assess the impact of the construction, consideration was given to source concentrations, concentrations in the river, and the effect of passage through the ditch ending in the tidal dam pond. Ammonium and phosphate concentrations from the manure pile source (Site 1) were much greater, while fecal coliform concentrations were much less after construction. Enterococci, ammonium and phosphate concentrations were much greater in the Squamscott River in the second year. Thus, we could expect to see less of an apparent 'treatment' of contaminants through the ditch because some source and endpoint levels were elevated in the second year. There was no second pond before construction, so data for the tidal dam pond would best reflect any construction-related differences in the efficiency of treatment of contaminants in the whole ditch. The data for the tidal dam poznd (Site 4, 1993-94) do not indicate any major potential affects of construction, although enterococci and ammonium levels were ~7x and ~5x higher, respectively. However, enterococci and ammonium levels were higher in the first pond effluent and the river the second year as well. Thus, the impact of construction does not appear to have either negatively or positively affected contaminant levels. As the vegetation become established in the constructed wetland and detention time for runoff is increased, more effective reductions in contaminant levels should occur. Future sampling of the area after establishment of a stable wetland and functioning water level controls would be useful to document the success of this management practice.

Table 1. Summary of data for Stuart farm study: 8/93-6/94.

	SITES/#	Ditch below manure pile	1st pond effluent	2nd pond effluent	Tidal dam pond	Squamscott River
Parameter	Date	1	2	3	4	5
Fecal coliform	30-Nov	1	1.18E+05	6.60E+05	4.70E+04	2.00E+02
per 100 ml	30-Mar	9.90E+05	7.80E+05	3.50E+05	3.40E+03	4.10E+03
	13-May	8.60E+05	3.40E+05	4.40E+04	1.12E+03	1.20E+02
	2-Jun	5.60E+05	1.22E+06	3.50E+04	5.90E+02	4.00E+01
	15-Jun	4.00E+04	1.40E+05	4.00E+03	1.00E+01	4.00E+00
	27-Jun	6.10E+05	1.04E+06	2.30E+03	2.70E+02	1.94E+02
E. coli	30-Nov	<1	1.15E+05	6.00E+05	4.40E+04	1.75E+02
per 100 ml	30-Mar	9.70E+05	7.40E+05	3.50E+05	3.40E+03	4.10E+03
	13-May	8.60E+05	3.30E+05	4.40E+04	9.80E+02	8.80E+01
	2-Jun	2.00E+04	3.80E+05	1.90E+04	2.20E+02	4.00E+01
	15-Jun	4.00E+04	1.30E+05	4.00E+03	1.00E+01	4.00E+00
	27-Jun	5.80E+05	9.50E+05	1.33E+03	1.60E+02	1.50E+02
Enterococci	30-Nov	<10	9.90E+05	4.21E+06	1.47E+05	4.60E+02
per 100 ml	30-Mar	1.54E+06	1.41E+06	4.00E+05	1.22E+04	1.19E+04
	13-May	1.17E+06	6.60E+05	5.00E+04	<100	2.67E+03
	2-Jun	3.47E+05	3.40E+05	3.00E+03	7.50E+01	2.50E+00
	15-Jun	1.05E+06	5.00E+04	2.00E+03	4.06E+02	1.60E+01
	27-Jun	3.50E+05	1.31E+05	3.20E+03	3.10E+02	5.30E+01
C. perfringens	30-Nov	ND	ND	ND	4.40E+02	6.40E+01
per 100 ml	30-Mar	5.80E+03	1.51E+04	3.00E+03	6.50E+01	5.60E+01
	13-May	8.80E+04	2.60E+04	4.10E+04	1.55E+02	1.25E+02
	2-Jun	1.20E+04	2.10E+04	5.00E+03	2.50E+01	2.00E+01
	15-Jun	2.64E+05	6.00E+03	4.00E+03	5.00E+00	8.00E+00
	27-Jun	1.14E+05	6.50E+03	2.37E+04	1.65E+01	4.65E+01

	SITES/#	Ditch below manure pile	1st pond effluent	2nd pond effluent	Tidal dam pond	Squamscott River
Parameter	Date	1	2	3	4	5
NO3	30-Nov	187	815	827	18.4	16.2
µM	30-Mar	1407	689	351	9.1	67.7
	13-May	1939	1060	918	7.9	3.3
	2-Jun	3858	838	105	2.7	0.6
	15-Jun	477	343	787	7.3	9.5
	27-Jun	1807	142	11	7.2	7.4
NH4	30-Nov	1320	7070	34230	2775	11.3
µM	30-Mar	31180	26455	19845	624.3	502.3
	13-May	508346	75893	53474	418.4	7.2
	2-Jun	4052	4262	7556	43.1	81.9
	15-Jun	22886	1724	3942	18.8	13.0
	27-Jun	10174	2475	1858	35.6	15.3
PO4	18-Aug	1289	877	780	85.7	1.6
µM	30-Mar	609	661	284	24.9	16.8
	13-May	14239	4681	3597	18.5	1.4
	2-Jun	347	293	805	7.1	6.5
	15-Jun	2937	1716	1001	1.0	0.8
	27-Jun	1260.0	1529.4	939.9	5.3	1.3
Temperature	30-Nov	16	6	2	0	4
°C	30-Mar	9	12	14	3	3
	13-May	16	18	18	18	15
	2-Jun				19	20
	15-Jun	29	26	23	25	24
	27-Jun	30	30	29		24
pH	30-Nov	9.05	7.95	7.86	7.45	7.36
	30-Mar	8.32	8.53	8.31	7.53	7.67
	13-May	7.57	7.34	7.81	7.30	7.25
	2-Jun	8.56	7.37	9.04	7.57	7.60

Table 2. Annual average and interannual comparisons on bacterial and nutrient concentrations at Stuart Farm: 1992-94.

Geometric average concentrations of bacteria and arithmetic means for nutrients at Stuart Farm:8/93-6/94.

Parameter	units	Below manure pile	1st pond effluent	Tidal dam pond	Squamscott River
Fecal coliforms	cfu/100 ml	28581	351228	1011	110
Enterococci	cfu/100 ml	80012	435481	1222	226
Nitrate	µM	1574	749	9	19
Ammonium	µM	113557	23081	776	123
Phosphate	µM	3884	1645	27	5

Geometric average concentrations of bacteria and arithmetic means for nutrients at Stuart Farm:8/92-6/93.

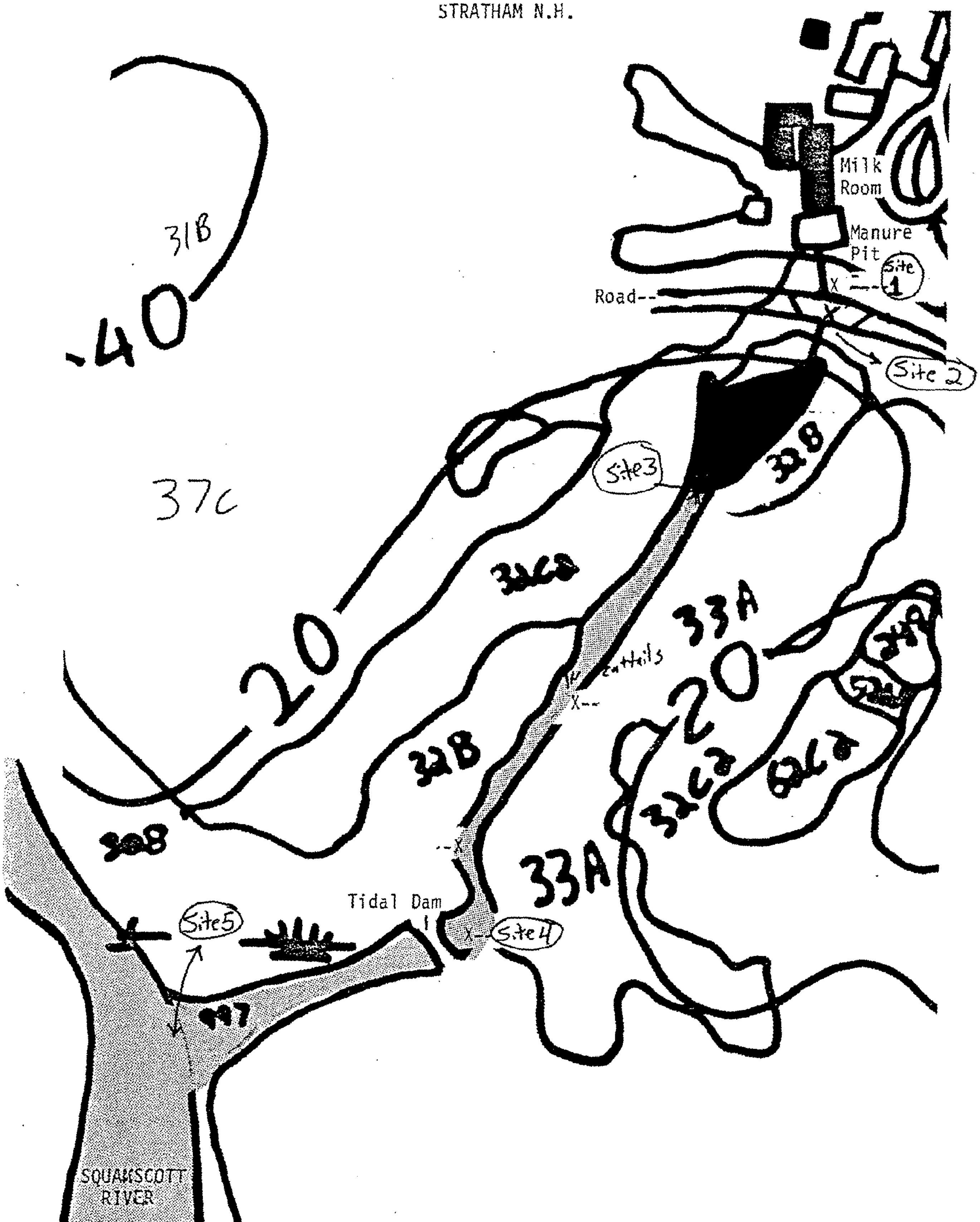
Parameter	units	Below manure pile	1st pond effluent	Tidal dam pond	Squamscott River
Fecal coliform	cfu/100 ml	1367387	232499	1651	62
Enterococci	cfu/100 ml	365021	4858	166	7
Nitrate	µM	443	194	21	11
Ammonium	µM	5362	2262	161	9
Phosphate	µM	435	325	22	1

Ratio of FY94 average values to FY93 values.

	Below manure pile	1st pond effluent	Tidal dam pond	Squamscott River
Fecal coliforms	0.02	1.51	0.61	1.78
Enterococci	0.22	90	7.4	34
Nitrate	3.6	3.9	0.44	1.83
Ammonium	21	10	4.8	13
Phosphate	8.9	5.1	1.23	6.3

Figure 1. STUART FARM

STRATHAM N.H.



Scale-----1"= 250'

Figure 2. Fecal coliform concentrations in Stuart farm constructed wetland, ditch and Squamscott River: 11/93-6/94.

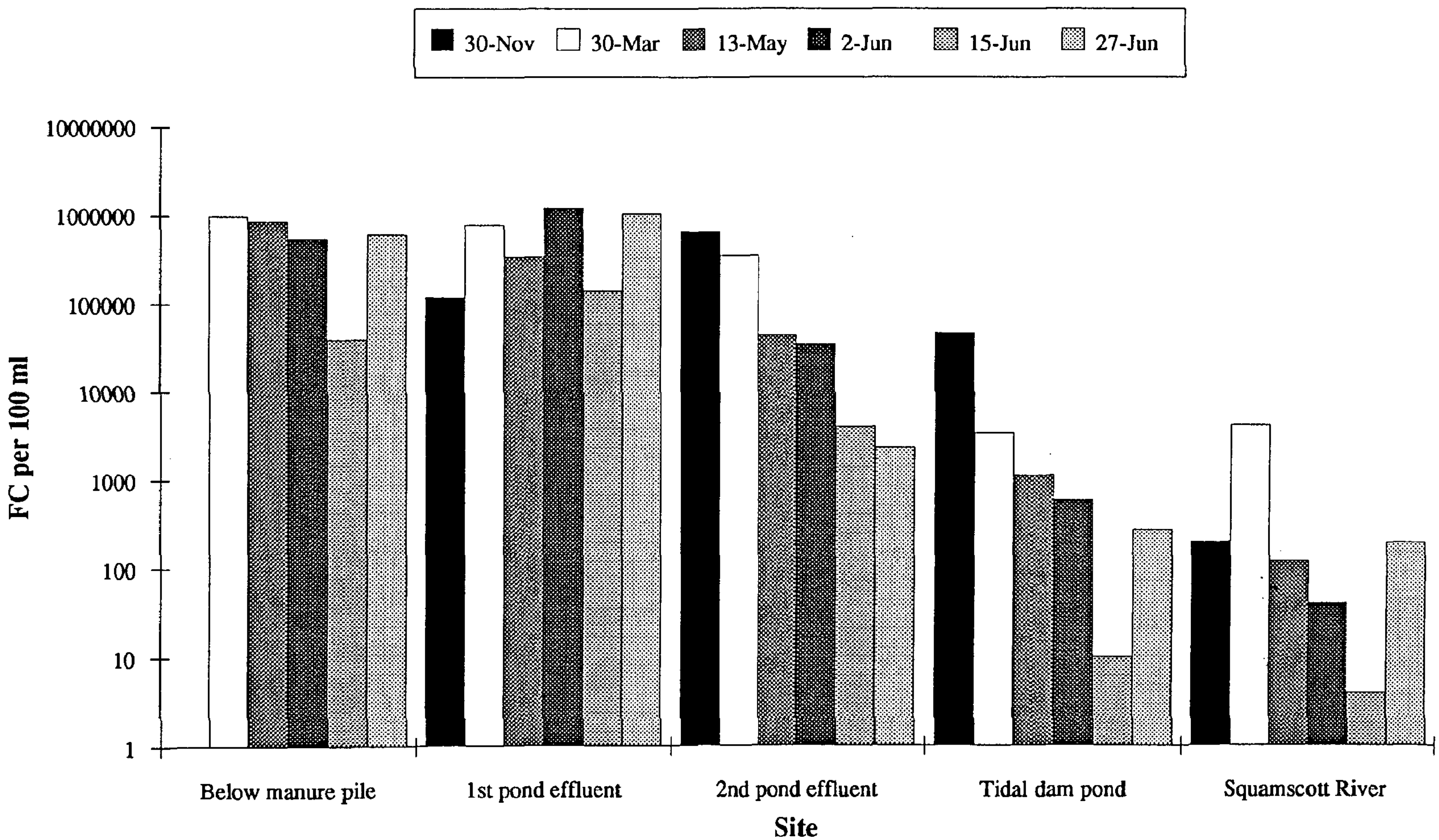


Figure 3. Enterococci concentrations in Stuart farm constructed wetland, ditch and Squamscott River: 11/93-6/94.

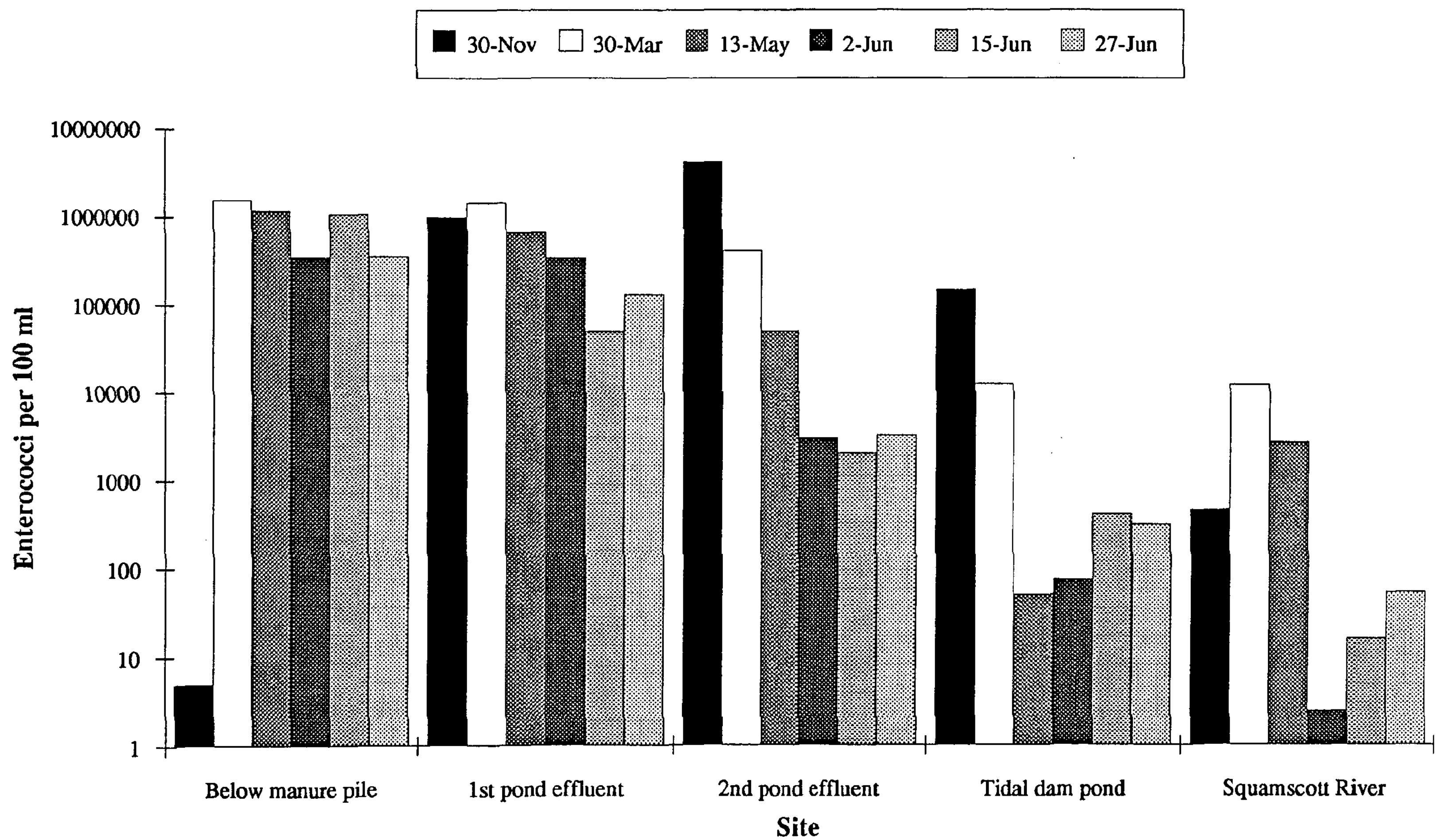


Figure 4. Clostridium perfringens concentrations in Stuart farm constructed wetland, ditch and Squamscott River: 11/93-6/94.

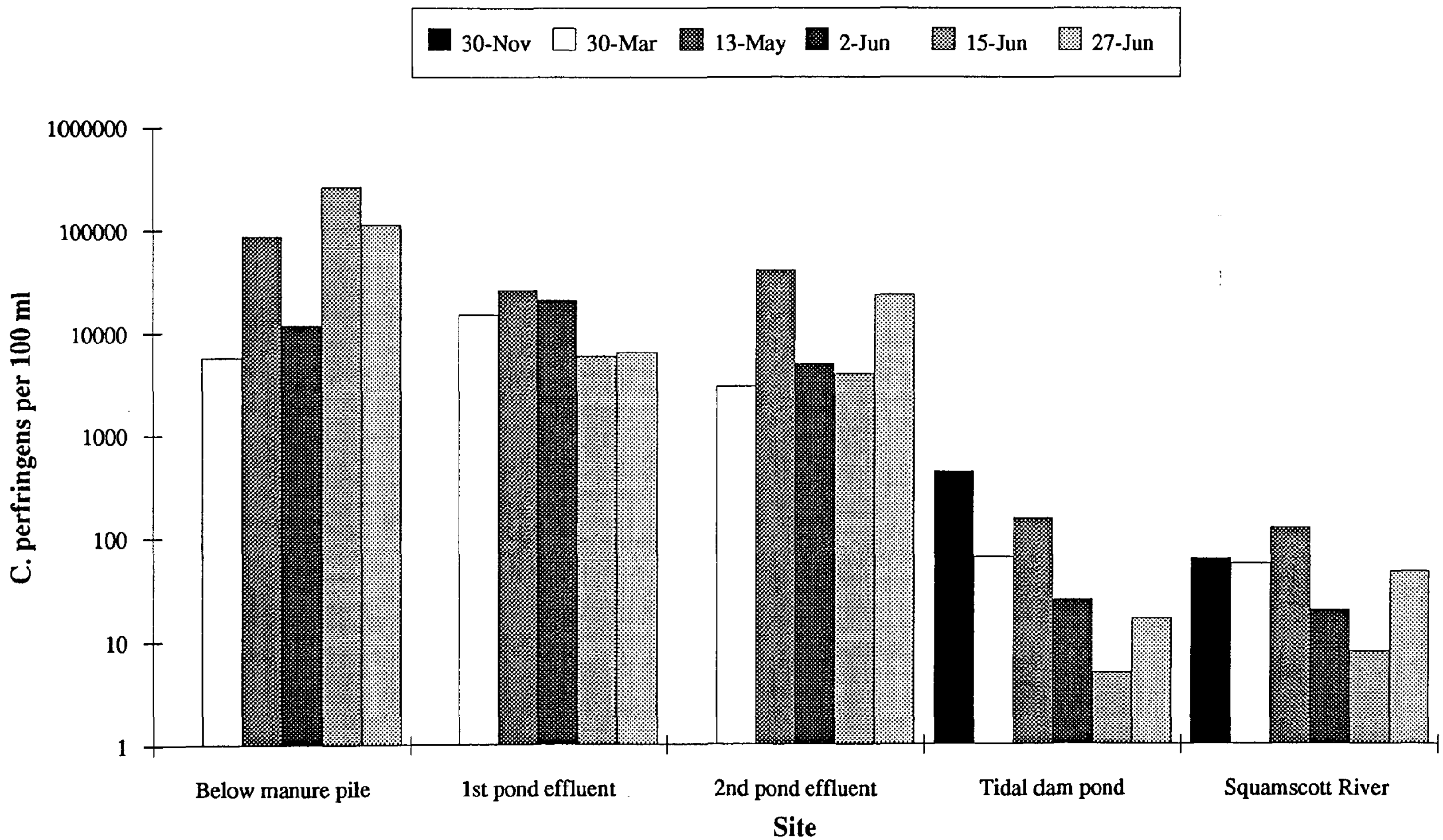


Figure 5. Nitrate concentrations in Stuart farm constructed wetland, ditch and Squamscott River: 11/93-6/94.

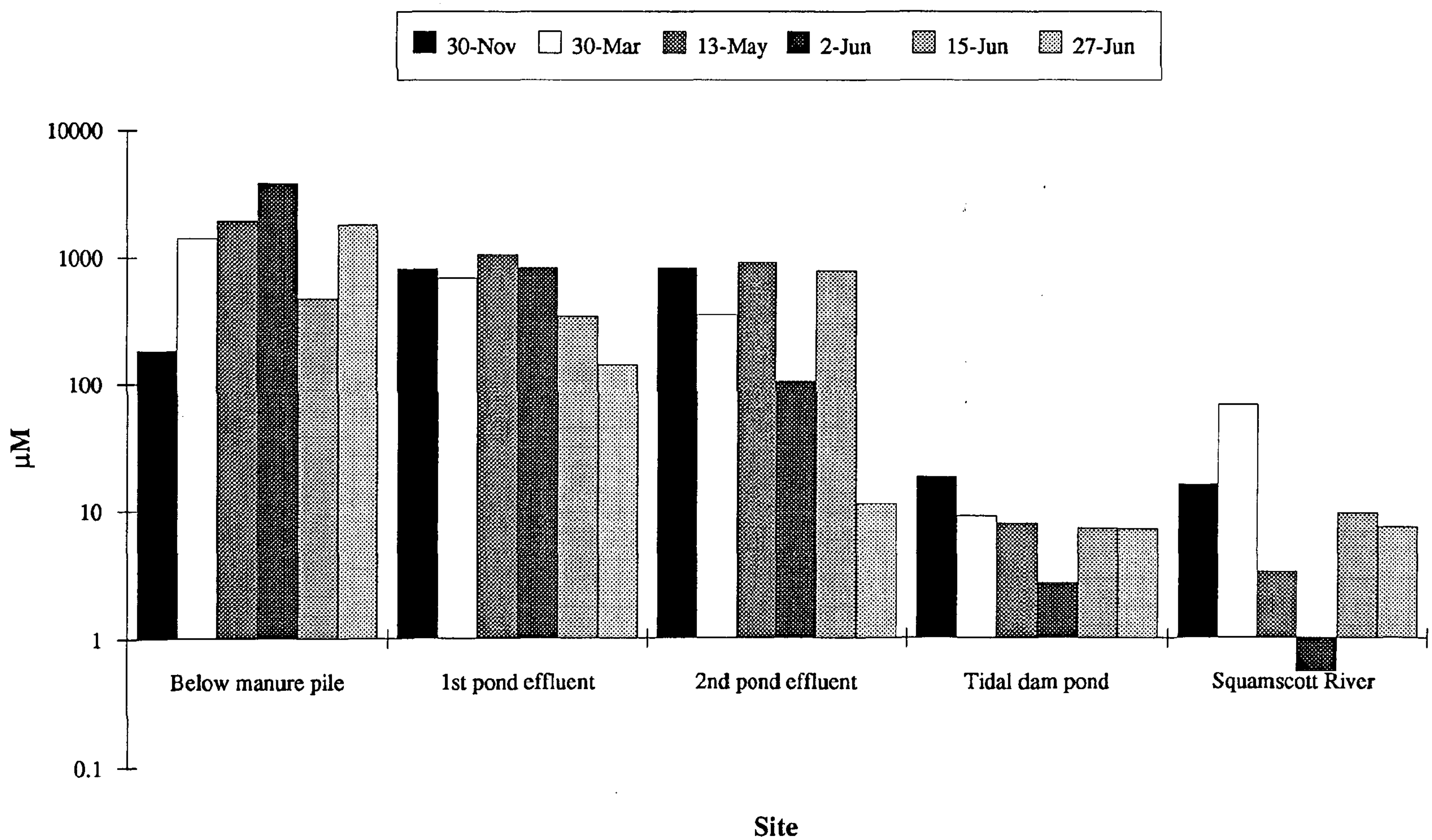


Figure 6. Ammonium concentrations in Stuart Farm constructed wetland, ditch and Squamscott River: 11/93-6/94.

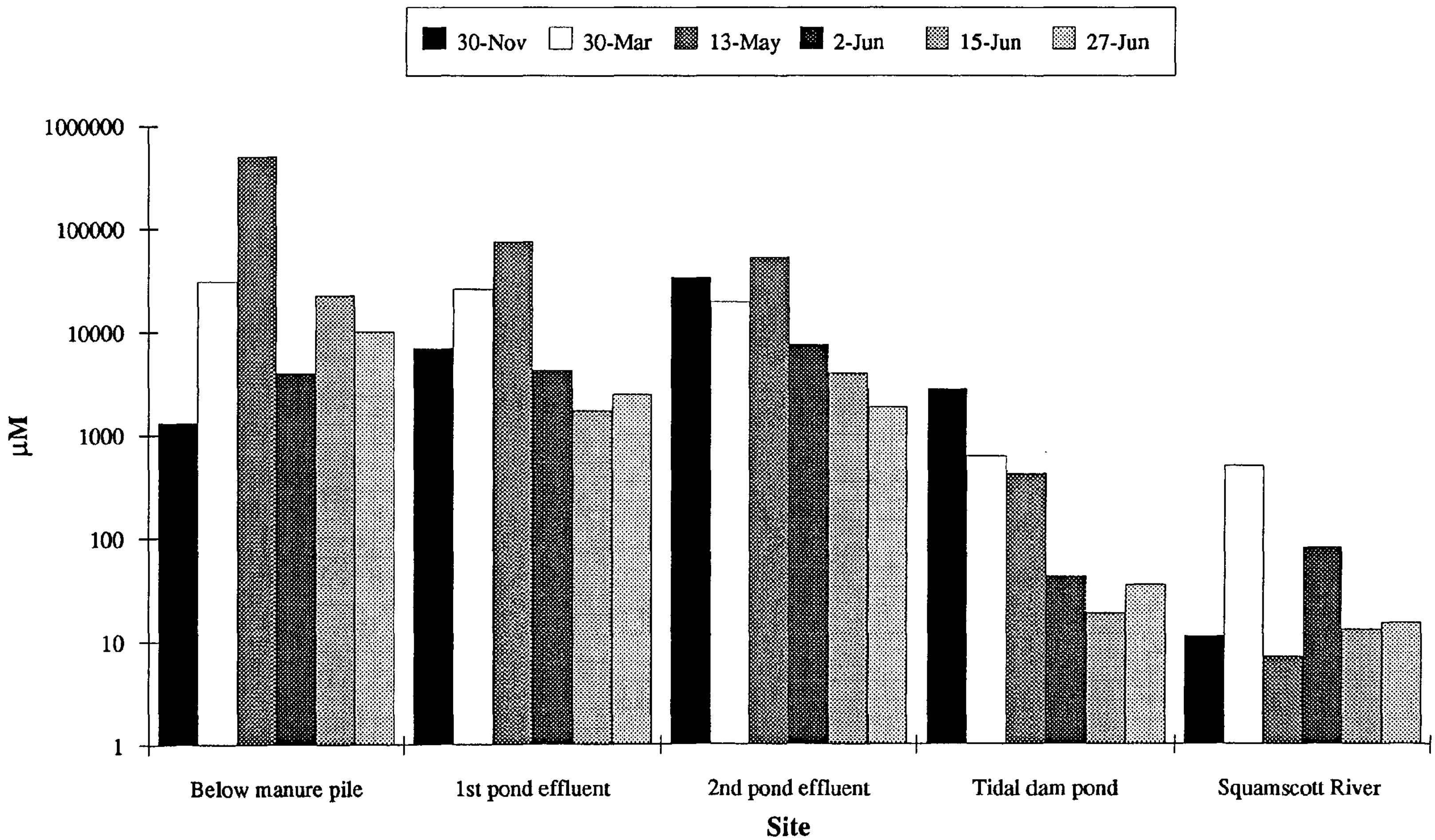


Figure 7. Orthophosphate concentrations in Stuart Farm constructed wetland, ditch and Squamscott River: 11/93-6/94.