

Horizontal Zonation  
of  
Water Quality  
in  
Hanks Marsh

Upper Klamath Lake, Oregon

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National Biological Service  
Denver, Colorado

September, 1996

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## Introduction

Upper Klamath Lake and its northerly extension, Agency Lake, form a large hypertrophic system which is dominated by *Aphanizomenon flos aquae* blooms throughout much of the growing season (Hazel 1969; Miller and Tash 1967; Ehinger 1992; Kann and Smith 1993). Poor water quality conditions in the lake associated with the algae blooms include: extremely high pH; widely fluctuating concentrations of dissolved oxygen and carbon dioxide; ammonia toxicity, and interference with visual prey selection by fish; (Coleman, et al. 1988). Previous researchers have noted that *A. flos aquae* does not flourish in larger littoral areas of the lake (Peek and Phinney 1962; Hazel 1969), or in large upstream wetland complexes such as the Klamath Marsh located on the Williamson River (Perdue et al. 1981).

At present there is little ecological and water quality information concerning the lake's littoral areas. To investigate various physical, chemical and biological characteristics of littoral areas around Upper Klamath Lake, the U.S. Bureau of Reclamation and National Biological Survey undertook a background study of Hanks Marsh, a remnant wetland on the eastern edge of Upper Klamath Lake. The purpose of the study is to:

- 1) investigate the water quality characteristics of this littoral wetland;
- 2) determine how water quality in Hanks Marsh varies temporally and spatially; and
- 3) compare the water quality in Hanks Marsh to that in the pelagic zone of the lake.

## Methods

### *Site Description*

Hanks Marsh occupies about 500 hectares on the southeast shore of Upper Klamath Lake, Oregon (Figure 1). The marsh is part of the Upper Klamath National Wildlife Refuge and is representative of the emergent wetlands that once dominated extensive lowland areas around the lake. The marsh vegetation is primarily wocus (*Nuphar luteum*) and bulrush (*Scirpus acutus*). Cattails (*Typha* sps.), pondweeds (*Potamogeton* sps.), duckweed (*Lemna* sps.) and other common macrophytes are also present (Figure 2).

Agricultural lands bordering the marsh were diked and drained decades ago. Pipes from both of these fields drain into Hanks Marsh, with flows heaviest in the early spring. The field to the east drains into the northeast corner of Hanks Marsh and the field to the south drains into the southeast corner of Hanks Marsh. Although the mean hydraulic residence time of the lake is approximately four months, Hanks Marsh may experience hydraulic short-circuiting and thus has an unknown hydraulic residence time.

Figure 1. Hanks Marsh and Upper Klamath Lake, Oregon

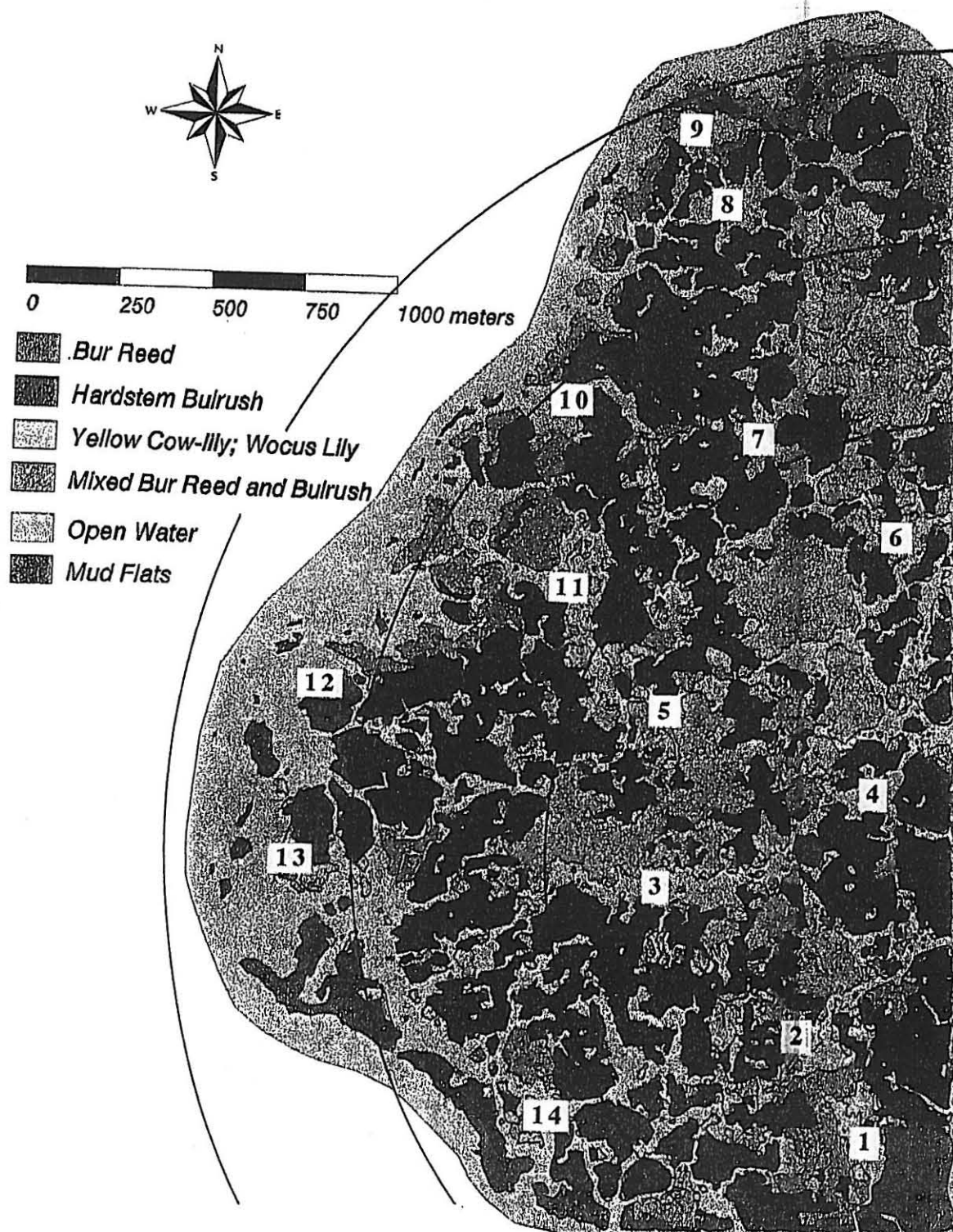


Figure 2. Hanks Marsh Sampling Zones and 14 sampling stations. Courtesy of Remote Sensing and Geographic Information Group, Bureau of Reclamation, Denver, Co.

Figure 2. Hanks Marsh, showing zones and vegetation.

To establish sampling stations, Hanks Marsh was divided into three zones by placing three concentric half circles of increasing radii onto a map of the marsh. Fourteen sample stations were placed throughout the three zones, with the result that Zones I and II contained four stations each and Zone III contained 6 stations (Figure 2). Because of the irregular shape of the marsh, Station 8 was placed in Zone II and Station 10 was placed in Zone I. This adjustment results in Zone I stations having the shortest distance to pelagic waters, Zone III stations the largest distance from pelagic waters and so forth.

### *Sampling Methods*

Water samples were collected on six two-day trips: May 20-21, 1992; June 9-10, August 17-18, and October 6-7, 1993; May 24-25 and July 12-13, 1994. Normally, stations were visited in numerical order: Stations 1 through 6 on the first day and Stations 7 through 14 on the second day. This procedure resulted in some unavoidable variations resulting from the different hour that samples were collected.

Grab samples were collected from open water areas located adjacent to dense stands of vegetation, usually *Scirpus* and *Nuphar*. Water samples were kept on ice and air freighted to certified laboratory facilities the same day that they were collected. Water depth, temperature, pH, dissolved oxygen, conductivity, total dissolved and suspended solids, turbidity, phosphate and total phosphorus, ammonia, nitrite+nitrate, total Kjeldahl nitrogen, and total chlorophyll-a were measured for each station. Samples of the drain pipe from the southern agricultural field were collected and analyzed on four occasions: August and October 1993, May and July 1994.

Periphyton samples were collected from submerged macrophytes during the October 1993 and July 1994 visits. The samples were analyzed by the author for mass (dry weight), biomass (ash-free dry weight) and chlorophyll-a concentrations. The diatom community of the July samples was examined.

The Klamath Tribe has an ongoing lake monitoring program. They routinely measure twelve water quality parameters at North Buck Island, a pelagic station near Hanks Marsh (Figure 1). These data were collected near the same dates as the Hanks Marsh visits (zero to ten days difference). Thus a gross comparison can be made between water quality in the pelagic zone of Upper Klamath Lake and Hanks Marsh. Water quality data from other Upper Klamath Lake studies are also included for comparative purposes.

Table 1. Hanks Marsh Sample Stations, Zones and Approximate (straight-line) Distance to the Lake's Pelagic Zone.

Sample Station	Distance to Open Water (m)	Zone
1	800	III
2	950	III
3	950	III
4	1500	III
5	1150	III
6	1100	III
7	650	II
8	300	II
9	150	I
10	150	I
11	550	II
12	0	I
13	0	I
14	250	II

### *Data Analyses*

To analyze statistical distribution, data from all dates and stations were combined. Distributions were examined using arithmetic and log probability plots (Appendix A). Seasonal trends in each parameter were examined with bar graphs, showing the six sampling visits in chronological order. Within each sample visit (14 bars), the stations are shown in numerical order. One-way analysis of variance (ANOVA) was calculated for two factors: sampling trip (temporal) and zone (spatial). Pearson's correlation coefficient ( $r$ ) was used to determine relationships between variables. Because of the high seasonal variations, relationships between parameters were examined for each sampling trip, as well as the entire data set. Only correlations deemed of interest to the goals of this project are discussed.

Additional analyses were performed on the periphyton data: autotrophic indices were calculated for each date and station, and diversity indices were calculated for the July samples. These results were incorporated into spatial, temporal and correlation analyses described above.



## Results

Parameter statistics for combined Hanks Marsh data (all fourteen sites and all six sample dates) are presented in Table 2. The complete data set is in Appendix A. North Buck Island data is summarized in Table 3, with the raw data in Appendix B. Most Hanks Marsh parameters approximated a log-normal distribution; a few parameters exhibited a Gaussian (normal) distribution. For parameters with a log-normal distribution, the geometric mean is used as the best estimate of the average. Average values for most parameters fell within what would be considered a "normal" range. However, most parameters fluctuated widely over both time and space. Thus the numerical average does not represent a typical condition in the marsh.

Bar graphs (in chronological order), as well as ANOVA (Table 4), indicate that season has a highly significant influence on all of the water quality parameters except phosphate-phosphorus ( $\text{PO}_4\text{-P}$ ). Location (by zone) had a significant effect on eight of the eighteen parameters (Table 4). Seasonal and spatial variations for each parameter are discussed below.

### *Depth*

Water depth in Hanks Marsh varied between 0.5 feet and 5.1 feet, with levels highest in spring and lowest in October (Figure 3). The North Buck Island depth fluctuations followed a similar seasonal pattern (open circles), but mean depth and standard deviation were  $7.0 \pm 1.7$  feet compared to a mean depth of  $2.2 \pm 1.2$  feet in the marsh. Hanks Marsh water depths did not vary significantly between zones.

### *Temperature*

Hanks Marsh water temperatures varied between 7.7 C and 22.8 C (Figure 4), with a mean temperature of  $16.7 \pm 3.1$  C. As would be expected, temperature varied significantly by date ( $p < 0.001$ ), with the mean temperature of the marsh exceeding 15 C during all but the October 1993 trip. Mean North Buck Island water temperature was slightly higher ( $17.1 \pm 3.1$  C). As Figure 4 illustrates, temperatures increased with the time of day during two sampling trips: May 1992 ( $r = 0.949$ ) and October 1993 ( $r = 0.814$ ).

Temperature did not vary significantly by zone except during the May 1992 trip. In fact, temperatures were correlated to several parameters on the May 1992 trip: pH, turbidity, total suspended solids (TSS), chlorophyll-a, and the N/P ratio.



Table 3. Statistical summary of North Buck Island water quality based on data collected during the same months as Hanks Marsh visits. Data Source: Klamath Tribe

Parameter	Mean	Geomean	Median	n	Std Dev	Max	Min
Depth (ft)	7.0	6.9	6.2	30	1.7	9.5	5.2
Temperature (C)	17.1	16.9	16.4	30	3.1	23.0	12.8
pH	8.6	8.6	8.7	30	0.9	10.1	7.0
Percent Saturation D.O.	98	96	96	30	21	139	62
Conductivity ( $\mu\text{S}/\text{cm}$ )	109	109	114	30	11	125	97
SRP (mg/L)	0.024	0.020	0.022	9	0.018	0.068	0.008
TP (mg/L)	0.106	0.094	0.110	9	0.050	0.187	0.039
NH <sub>3</sub> -N (mg/L)	0.047	0.021	0.019	9	0.069	0.213	0.005
NO <sub>3</sub> -N (mg/L)	0.046	0.013	0.010	9	0.107	0.332	0.005
TN (mg/L)	1.378	1.209	1.320	9	0.694	2.740	0.435
N/P	13.3	12.8	11.8	9	4.2	22.0	9.3
Total Chl-a (mg/m <sup>3</sup> )	52	28	22	9	60	191	6

SRP=soluble reactive phosphate, approximately equal to phosphate (PO<sub>4</sub>-P)

Table 2. Statistical summary of Hanks Marsh water quality.

Parameter	Dist	Mean	Geomean	Median	n	Std Dev	Max	Min
Depth (ft)	N	2.2	1.8	1.9	83	1.2	5.1	0.5
Temperature (C)	*	16.7	16.4	17.3	83	3.1	22.8	7.7
pH	*		7.5	7.4	83	0.8	9.6	6.6
Percent Sat D.O.	N	86.4	79.8	86.0	83	30.5	141.0	20.0
Conductivity ( $\mu\text{S}/\text{cm}$ )	N	126.7	125.2	126.0	83	19.2	179.0	95.0
TDS (mg/L)	LN	109.5	104.9	104.0	83	28.4	225.0	9.0
Turbidity (NTU)	LN	10.9	7.1	7.3	83	11.8	61.3	1.2
TSS (mg/L)	*	23.1	9.3	15.6	69	30.6	160.6	0.2
PO <sub>4</sub> -P (mg/L)	LN	0.054	0.042	0.043	83	0.041	0.210	0.011
TP (mg/L)	LN	0.173	0.146	0.150	83	0.132	1.060	0.049
NH <sub>3</sub> -N (mg/L)	*	0.128	0.049	0.040	83	0.209	0.950	0.005
(NO <sub>3</sub> +NO <sub>2</sub> )-N (mg/L)	*	0.026	0.013	0.010	83	0.047	0.260	0.005
TKN (mg/L)	LN	1.853	1.463	1.490	83	1.529	10.800	0.520
Organic-N (mg/L)	LN	1.729	1.378	1.370	83	1.449	10.710	0.510
TIN (mg/L)	LN	0.154	0.067	0.050	83	0.225	1.010	0.010
TN (mg/L)	LN	1.883	1.487	1.495	83	1.537	10.820	0.530
N/P	LN	10.9	10.2	10.7	83	4.0	23.8	4.0
Total Chl-a (mg/m <sup>3</sup> )	LN	68.9	24.1	23.9	83	139.6	918.2	2.0

N = normal, LN = log-normal

\* distribution not determined

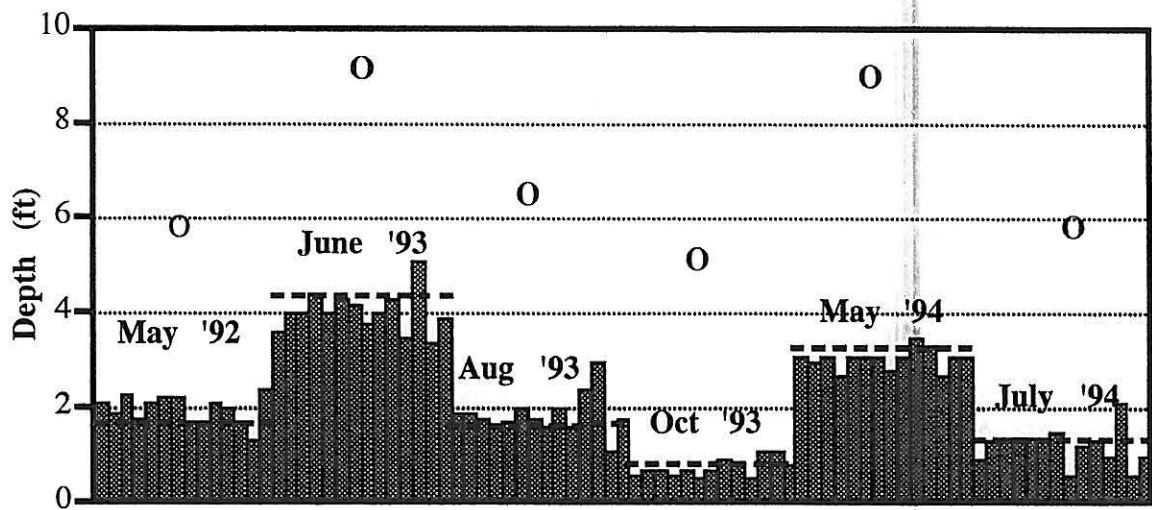


Figure 3. Hanks Marsh water depths by sampling date. Each bar represents a station and stations are in numerical order (1-14). The dotted lines represent the mean for that date. North Buck Island water depths are indicated with circles.

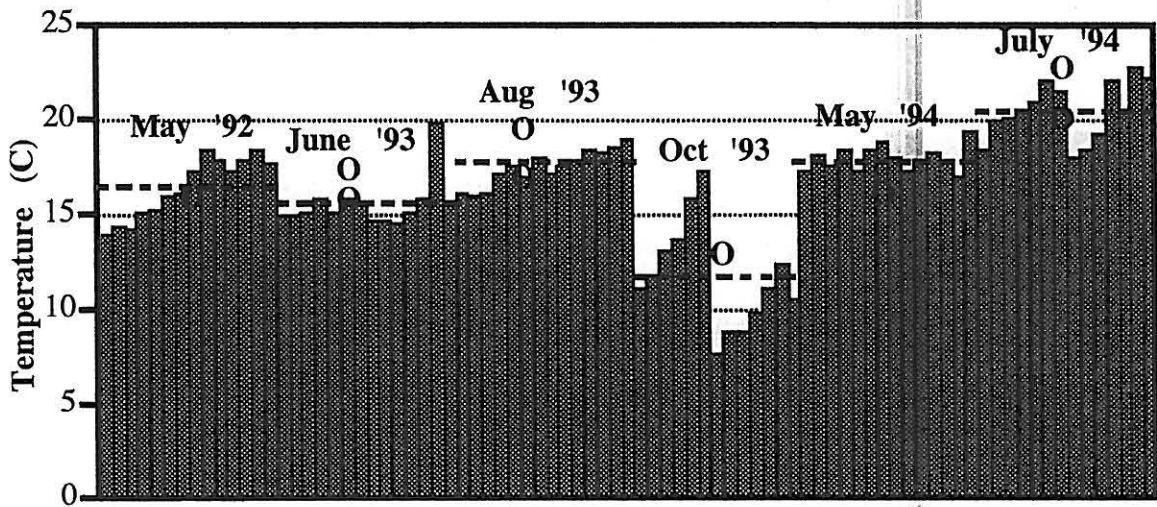


Figure 4. Hanks Marsh water temperatures by sampling date. Each bar represents a station and stations are in numerical order (1-14). North Buck Island temperatures are indicated with circles. The dotted lines represent the mean for that date.

Table 4. One-way ANOVA of Hanks Marsh water quality parameters by date and zone.

PARAMETER	VARIATION					
	df	Date F-ratio	P-value	df	Zone F-ratio	P-value
Depth	5	173.68	<0.001	2	0.06	0.937
Temperature	5	44.77	<0.001	2	0.17	0.843
pH	5	14.83	<0.001	2	4.82	0.011
DO % sat	5	12.33	<0.001	2	1.38	0.257
Conductivity	5	15.58	<0.001	2	10.05	<0.001
TDS	5	10.78	<0.001	2	2.60	0.081
Turbidity	5	15.23	<0.001	2	2.64	0.078
TSS	4	14.88	<0.001	2	0.42	0.659
PO4-P	5	0.82	0.539	2	18.30	<0.001
TP	5	7.37	<0.001	2	3.39	0.038
NH <sub>3</sub> -N	5	7.57	<0.001	2	3.43	0.037
(NO <sub>2</sub> +NO <sub>3</sub> )-N	5	13.04	<0.001	2	3.16	0.048
TKN	5	16.66	<0.001	2	0.20	0.821
TIN	5	11.32	<0.001	2	3.78	0.027
Organic-N	5	13.47	<0.001	2	0.51	0.602
TN	5	18.23	<0.001	2	0.16	0.853
N/P	5	8.59	<0.001	2	12.34	<0.001
Chl-a	5	8.00	<0.001	2	0.21	0.808
Periphyton						
biomass <sup>a</sup>			0.055 <sup>a</sup>	2	5.22	0.048 <sup>b</sup>
AIC <sup>c</sup>			<0.001	2	2.89	0.065 <sup>b</sup>
DI <sup>d</sup>				2		0.425

a. Two-sample t-test  
b. July 1994 samples only  
c. Autotrophic Index  
d. Diversity Index (Brillouin)

## pH

The median pH throughout the study period was 7.4; however, the range of pH in Hanks Marsh was dramatic, with a low of 6.6 and a high of 9.6 (Figure 5). North Buck Island median pH was over a point higher (8.7) with a similarly large range (7.0 to 10.1). Sample date was a significant factor for Hanks Marsh pH variability ( $p < 0.001$ ). The greatest seasonal difference occurred between the May 1994 trip (6.85) and the July 1994 trip (9.05). On all sampling dates except October 1993, average pH's at North Buck Island were noticeably higher than those in Hanks Marsh (Figure 5).

Location by zone was also a significant factor for pH ( $p = 0.011$ ), with Zones II and III having similar pH medians of 7.4 and Zone I showing a higher median pH of 8.0 (Figure 6). May 1992 pH's were correlated to dissolved oxygen ( $r = 0.802$ ), chlorophyll-a ( $r = 0.724$ ) (Figure 7) turbidity ( $r = 0.858$ ) and time ( $r = 0.638$ ). Similar correlations were observed in the August 1993 samples. Although July 1994 was the period with the highest pH values, those values were not correlated to other measured water quality variables in the marsh.

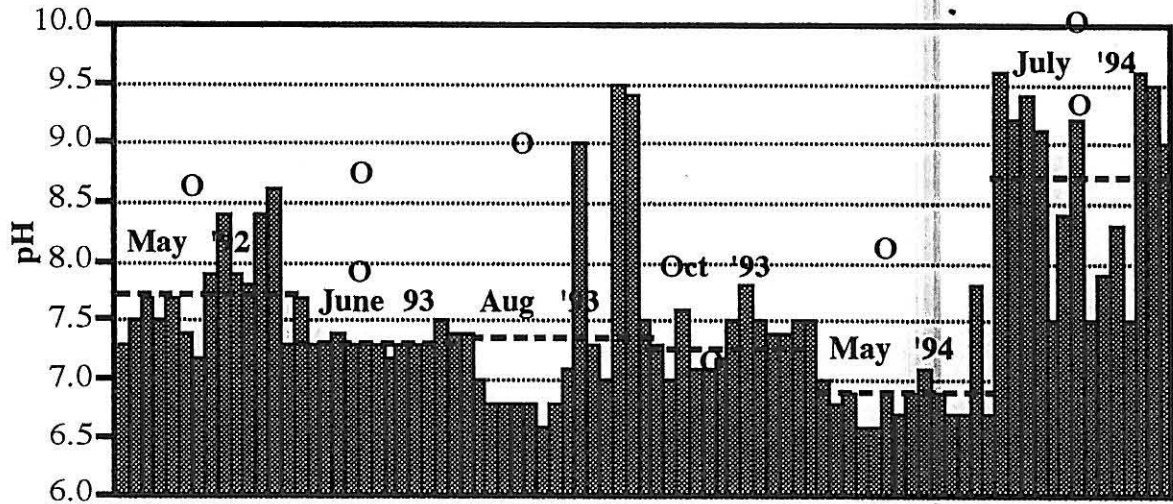


Figure 5. Hanks Marsh pH by sampling date. Each bar represents a station and stations are in numerical order (1-14). North Buck Island pH's are indicated with circles. The dotted lines represent the mean for that date.

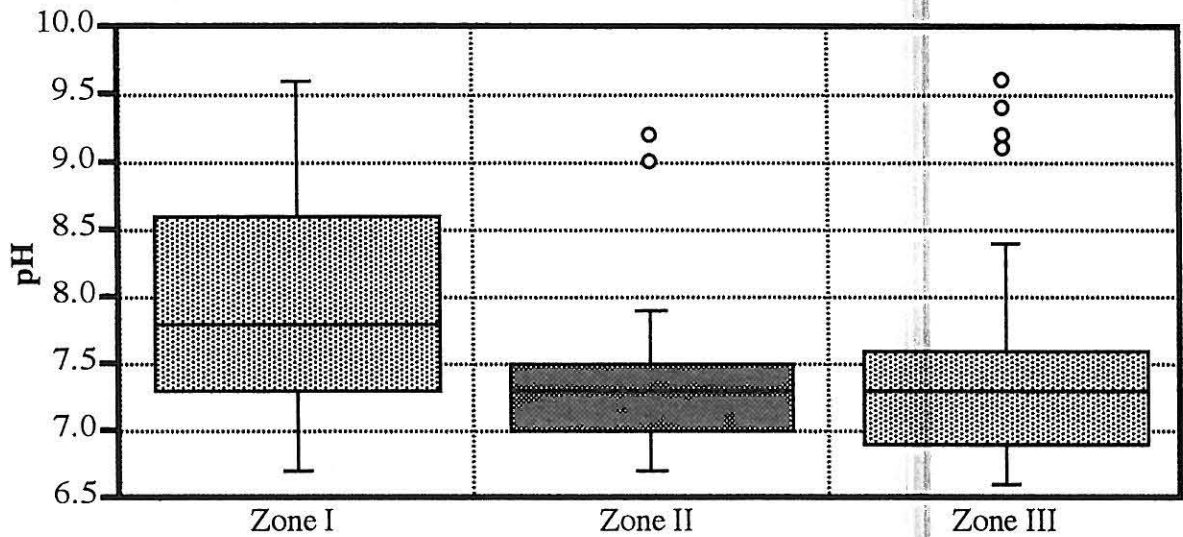


Figure 6. Hanks Marsh pH by zone ( $p=0.011$ ). Open circles are outliers.



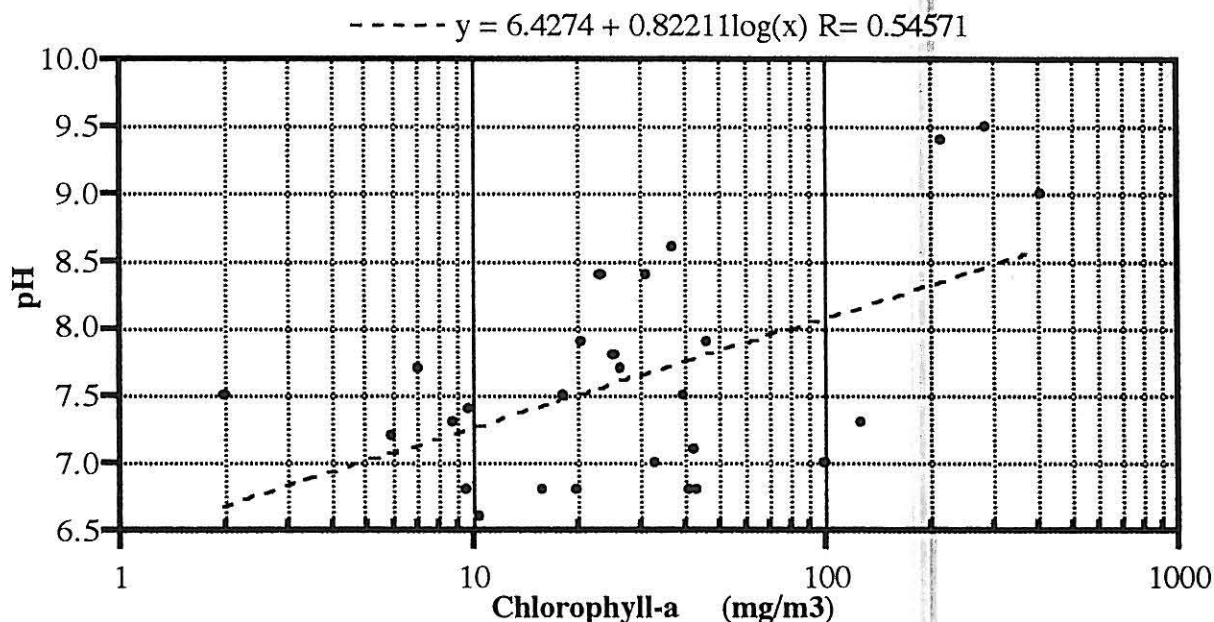


Figure 7. Hanks Marsh pH versus chlorophyll-a (May and August samples combined resulted in a lower  $r$  value).

### *Conductivity*

Hanks Marsh conductivity ranged from 95 to 179  $\mu\text{S}/\text{cm}$  throughout the study (mean  $126.7 \pm 19.2$   $\mu\text{S}/\text{cm}$ ); North Buck Island conductivity was lower (mean  $109 \pm 11$   $\mu\text{S}/\text{cm}$ ). Date was a significant factor ( $p < 0.001$ ) due to a low mean of 100.5  $\mu\text{S}/\text{cm}$  which occurred during June 1993 (Figure 8). Conductivity and total dissolved solids were highest in July 1994.

Location by zone was highly significant as well ( $p < 0.001$ ). Conductivity was greatest in Zone III (mean 136  $\mu\text{S}/\text{cm}$ ), and lowest in Zone I (116  $\mu\text{S}/\text{cm}$ ; Figure 9). Conductivity was strongly correlated to  $\text{PO}_4\text{-P}$  during May 1992 ( $r = 0.957$ ) and October 1993 ( $r = 0.967$ ), and moderately correlated to  $\text{PO}_4\text{-P}$  in August 1993 ( $r = 0.674$ ) (Figure 10). During May 1992, conductivity was negatively correlated to turbidity ( $r = -0.816$ ), total suspended solids ( $r = -0.763$ ) and chlorophyll-a ( $r = -0.666$ ).

### *Total Dissolved Solids*

Total dissolved solids (TDS) had a large range (216 mg/L), and a moderate average ( $105 \pm 28.4$  mg/L). TDS were significantly different by date ( $p < 0.001$ ) due to elevated values in October 1993, primarily in Zone III (Figure 11). Although TDS concentrations followed a pattern similar to conductivity, i.e. lowest in Zone I and highest in Zone III, location by zone was only moderately significant ( $p = 0.081$ ).

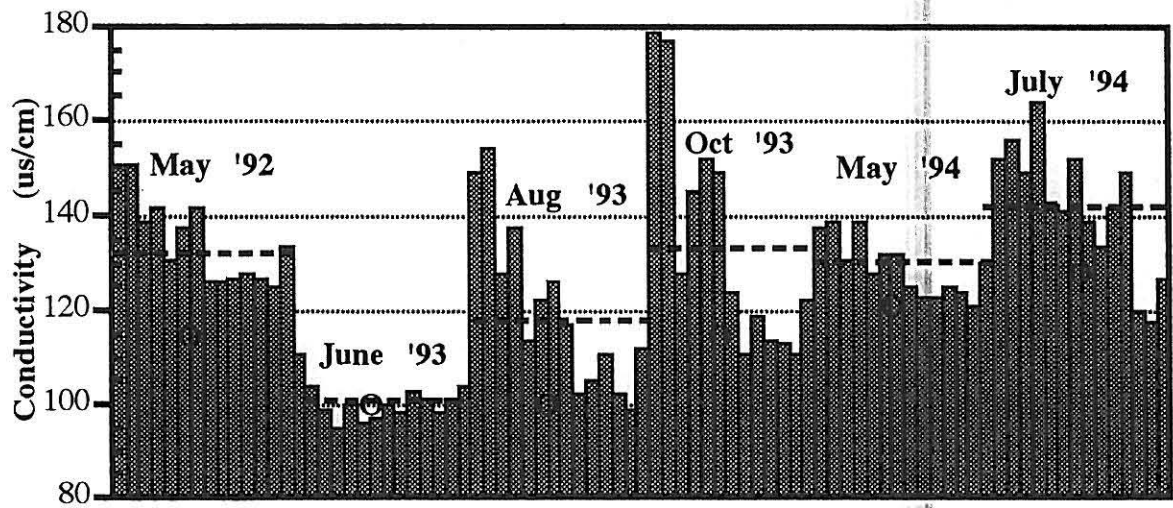


Figure 8. Hanks Marsh conductivity by sampling date. Each bar represents a station and stations are in numerical order (1-14). North Buck Island conductivities indicated with circles. The dotted lines represent the mean for that date.

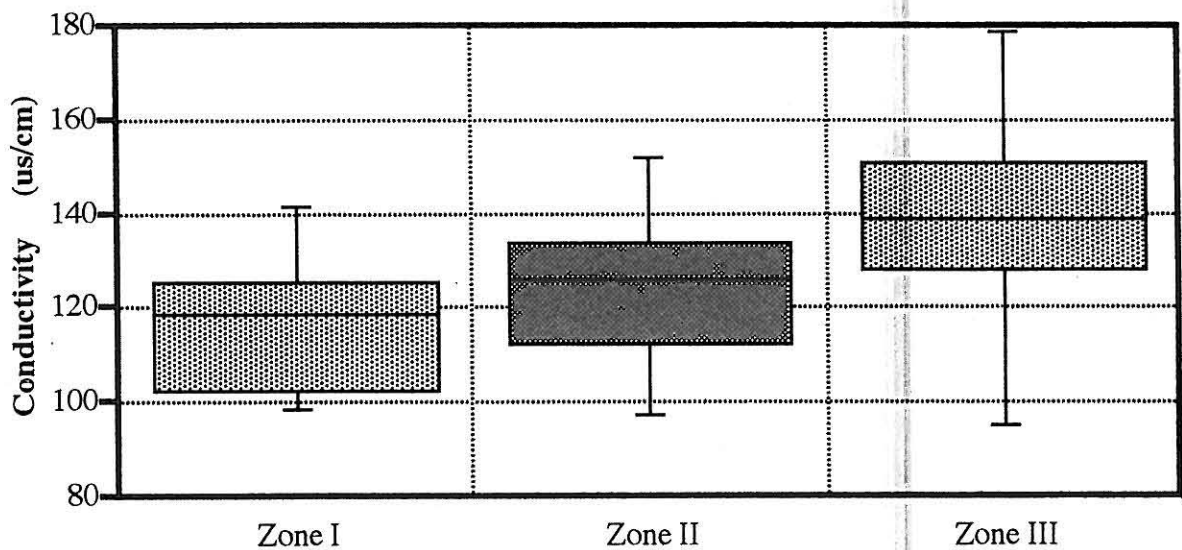


Figure 9. Hanks Marsh conductivity by zone. ANOVA indicates location is a significant factor ( $p < 0.001$ ).

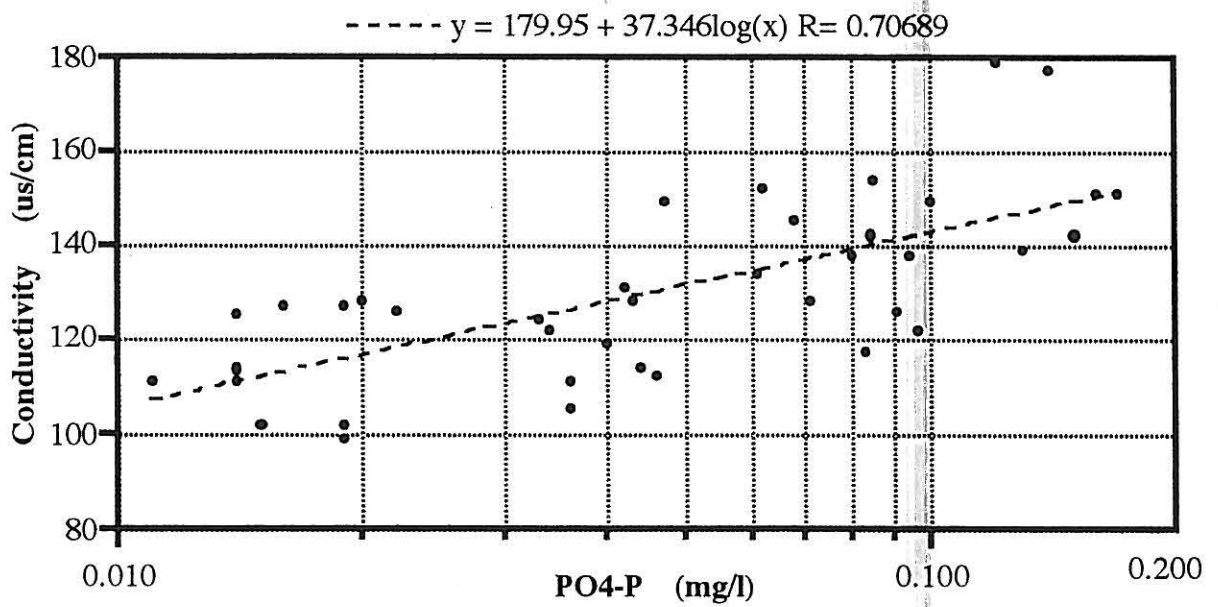


Figure 10. Hanks Marsh conductivity versus phosphate-phosphorus (May '92, August and October '93).

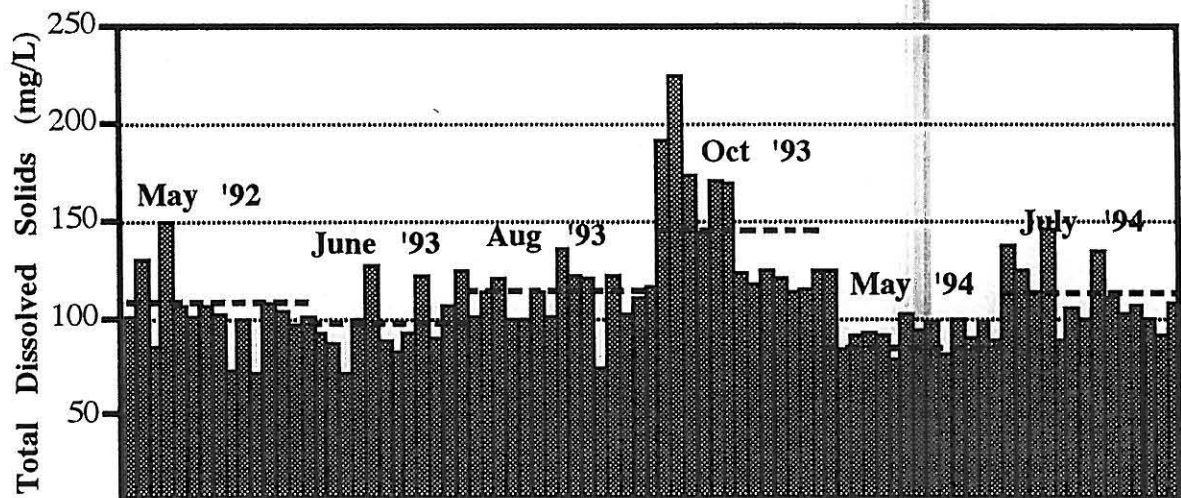


Figure 11. Hanks Marsh total dissolved solids (TDS) by sampling date. Each bar represents a station and stations are in numerical order (1-14). The dotted lines represent the mean for that date.



### Total Suspended Solids

Average total suspended solids concentration (TSS) was  $9.3 \pm 28.4$  mg/L, with a large range (160.4 mg/L). As with TDS, TSS concentrations were highest during October 1993 ( $64.5 \pm 46.0$  mg/L) and lowest during May 1994 ( $1.59 \pm 1.96$  mg/L) (Figure 12). Zone was not a significant factor, but TSS were correlated to total nitrogen (all dates  $r=0.697$ ; Figure 13). In July 1994, TSS were correlated to  $\text{NH}_3\text{-N}$  ( $r=0.912$ ). In May 1992, TSS were correlated to chlorophyll-a ( $r=0.895$ ) and negatively correlated to  $\text{PO}_4\text{-P}$  ( $r=-0.742$ ). In August 1993, TSS were positively correlated to total phosphorus ( $r=0.836$ ).

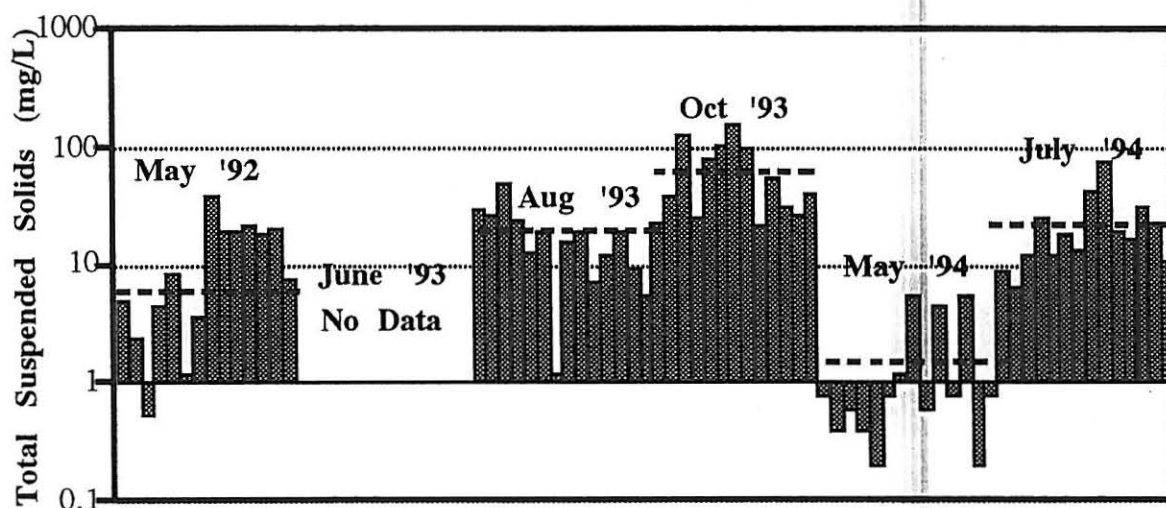


Figure 12. Hanks Marsh total suspended solids (TSS) by sampling date. Each bar represents a station and stations are in numerical order (1-14). The dashed lines represent the mean for that date.

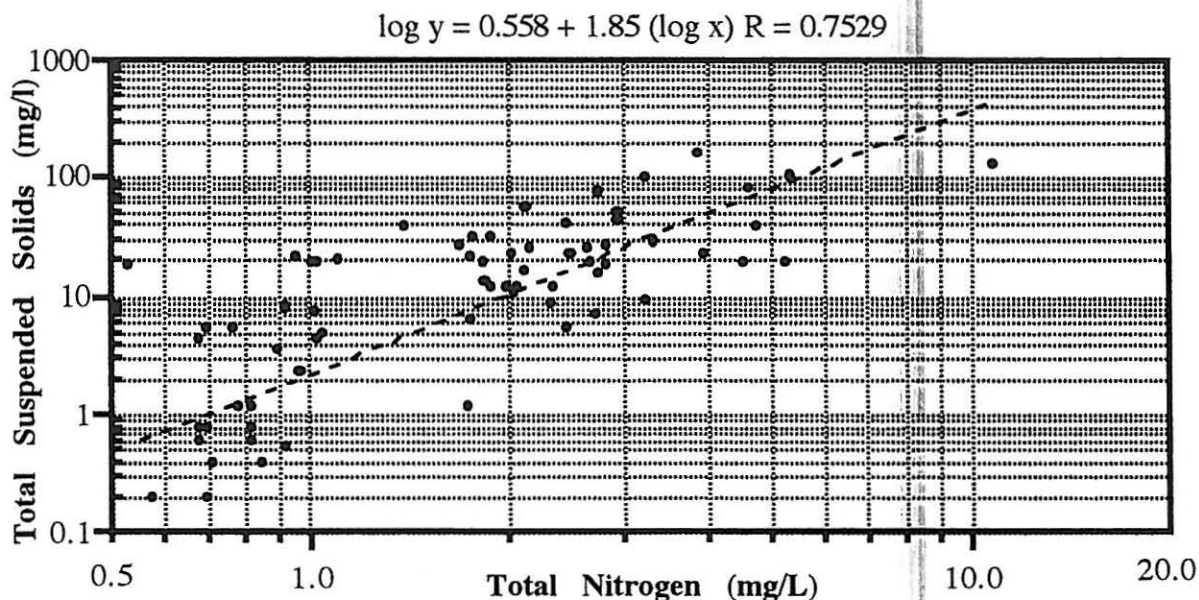


Figure 13. Hanks Marsh TSS versus total nitrogen (all dates).

### *Turbidity*

Turbidity was highly variable (Figure 14), with a minimum of 1.2 NTU and a maximum of 61.3 NTU. Sample date significantly influenced turbidity ( $p < 0.001$ ) with a very high mean (29 NTU) in October 1993, the period with the lowest depth and the highest chlorophyll-*a* concentrations. Although Zone I mean turbidity was twice that in Zone III, high seasonal variability contributed to location having only a moderately significant influence ( $p = 0.078$ ; Figure 15). On a study-wide basis (all dates), turbidity was correlated to TSS ( $r = 0.831$ ), total nitrogen ( $r = 0.751$ ), and chlorophyll-*a* ( $r = 0.735$ ).

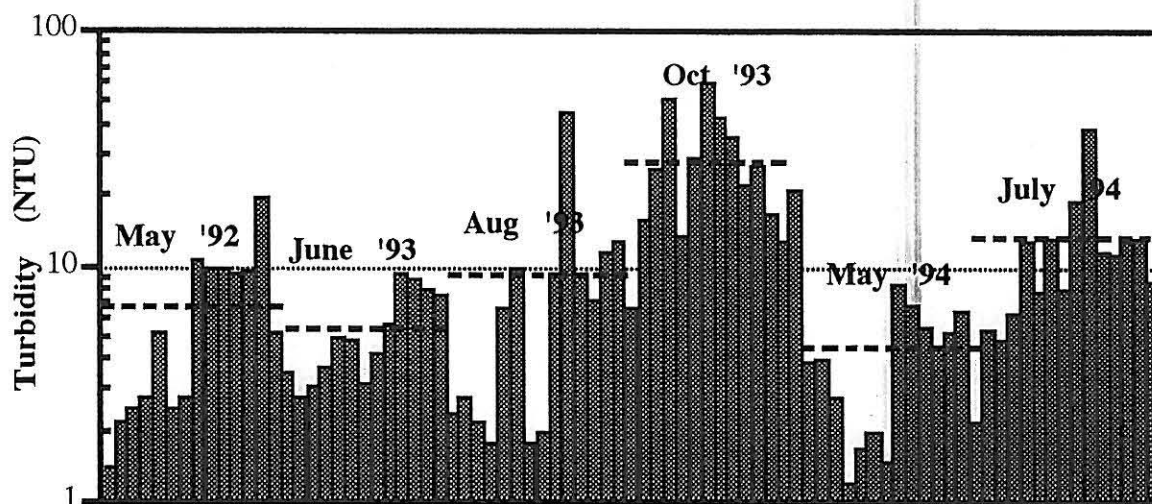


Figure 14. Hanks Marsh turbidity by sampling date. Each bar represents a station and stations are in numerical order (1-14). The dotted lines represent the mean for that date.

### *Dissolved Oxygen*

The mean dissolved oxygen (percent saturation) was a healthy  $86.4 \pm 30.5$ , but the values ranged between 20.0 and 141 percent saturation, indicating widely fluctuating conditions (Figure 16). North Buck Island had a higher mean ( $98 \pm 21$  percent), with values ranging from 62 to 139 percent. Date was a significant factor, with mean D.O. exceeding 100 percent during the May 1992 and July 1994 dates.

Dissolved oxygen concentrations fluctuated widely at all stations, with Zone I values higher than those in Zones II and III (not statistically significant). Percent saturation D.O. was correlated to chlorophyll-a only during May 1992 ( $r=0.626$ ).

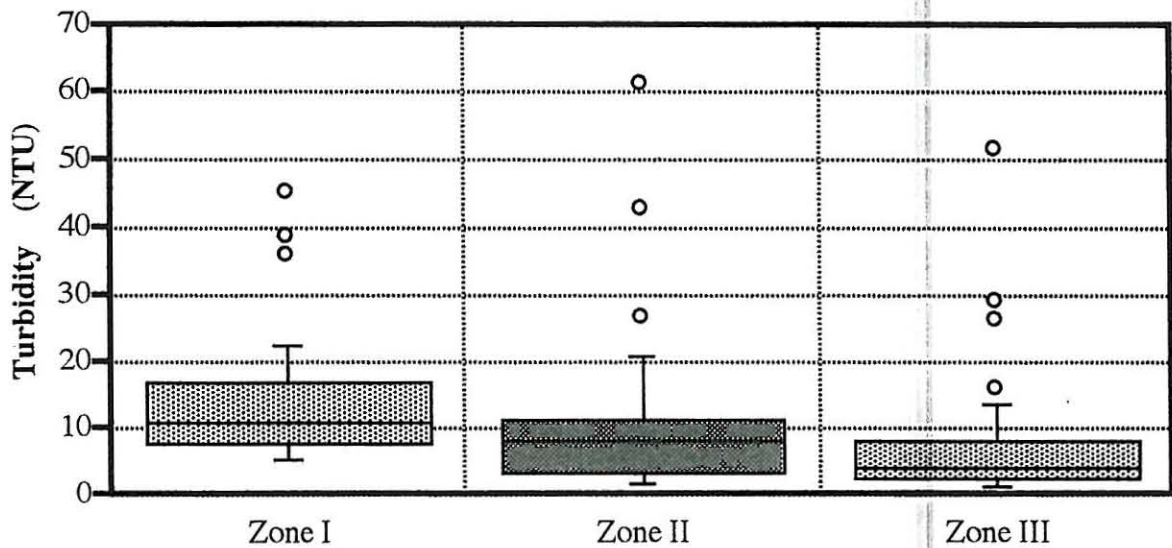


Figure 15. Hanks Marsh turbidity by zone ( $p=0.078$ ). Open circles are outliers.

## Nitrogen

Ammonia-nitrogen ( $\text{NH}_3\text{-N}$ ) was higher in Hanks Marsh ( $0.049 \pm 0.209$  mg/L) than at the North Buck Island station ( $0.021 \pm 0.069$  mg/L) (Figure 17). Elevated  $\text{NH}_3\text{-N}$  concentrations during August and October 1993 made date a significant factor ( $p<0.001$ ). Location by zone was also a significant factor ( $p=0.037$ ), with Zone II having the largest mean ( $0.212$  mg/L) and Zone III the smallest ( $0.071$  mg/L) (Figure 18). The July 1994  $\text{NH}_3\text{-N}$  concentrations were correlated to turbidity ( $r=0.919$ ).

Nitrate+nitrite-nitrogen ( $\text{NO}_3\text{-N}$ ) mean concentration was  $0.026 \pm 0.047$  mg/L in Hanks Marsh, and  $0.047 \pm 0.107$  mg/L at North Buck Island. Date was a significant factor due to an elevated marsh-wide  $\text{NO}_3\text{-N}$  concentration during October 1993 ( $0.097 \pm 0.086$  mg/L) (Figure 19). Location was also significant factor ( $p=0.048$ ) (Figure 20), with Zone III having the lowest concentrations and Zone I the highest.

Average organic nitrogen was  $1.38 \pm 1.45$  mg/L in Hanks Marsh. Date had a significant effect on organic nitrogen ( $p<0.001$ ), with elevated concentrations during August, October and July (Figure 21). Location within Hanks Marsh did not significantly influence organic nitrogen concentrations. Based on all sample dates, organic nitrogen concentrations were correlated to turbidity ( $r=0.700$ ), total phosphorus ( $r=0.895$ ), and chlorophyll-a ( $0.901$ ) (Figure 22).

Average total nitrogen concentrations were  $1.49 \pm 1.54$  mg/L in Hanks Marsh and  $1.21 \pm 0.07$  mg/L at North Buck Island. Hanks Marsh total nitrogen was approximately 93 percent organic, thus the influences of date and location on total nitrogen were very similar to those on organic nitrogen.

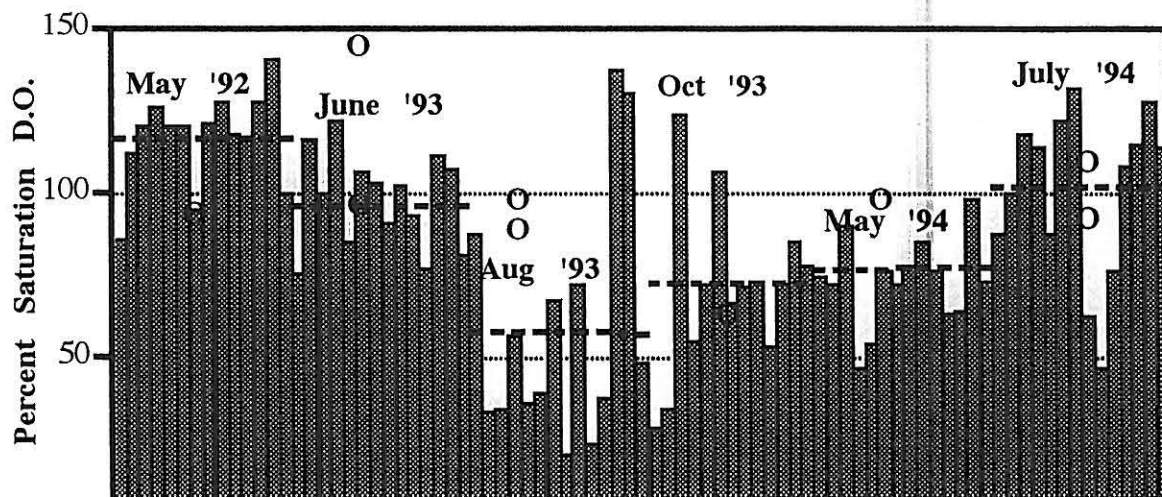


Figure 16. Hanks Marsh dissolved oxygen by sampling date. Each bar represents a station and stations are in numerical order (1-14). North Buck Island dissolved oxygen indicated with circles. The dotted lines represent the mean for that date.

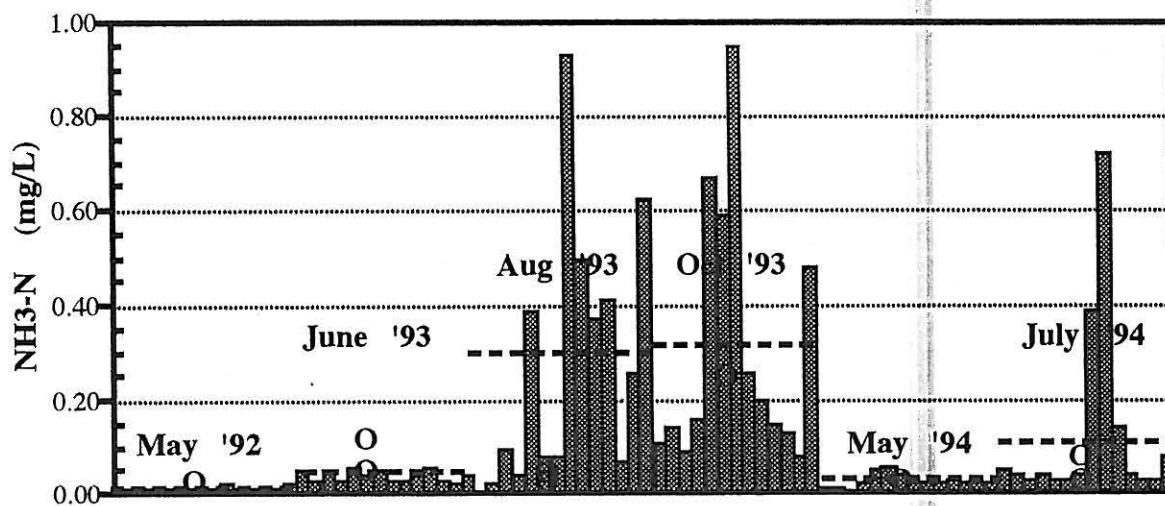


Figure 17. Hanks Marsh ammonia-nitrogen by sampling date. Each bar represents a station and stations are in numerical order (1-14). North Buck Island ammonia-nitrogen indicated with circles. The dotted lines represent the mean for that date.



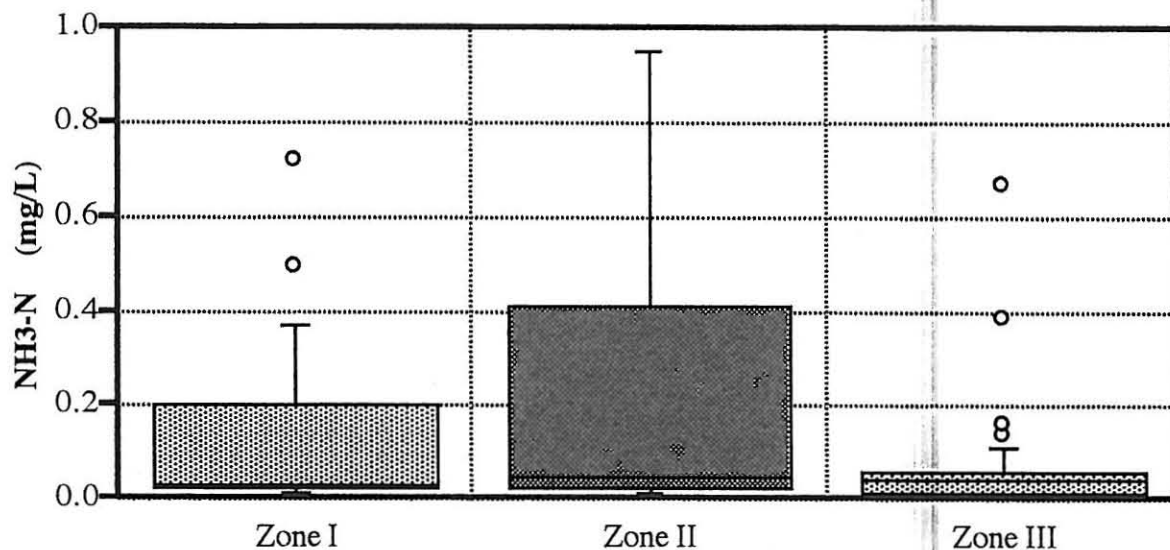


Figure 18. Hanks Marsh ammonia-nitrogen by zone ( $p=0.037$ ). Open circles are outliers.

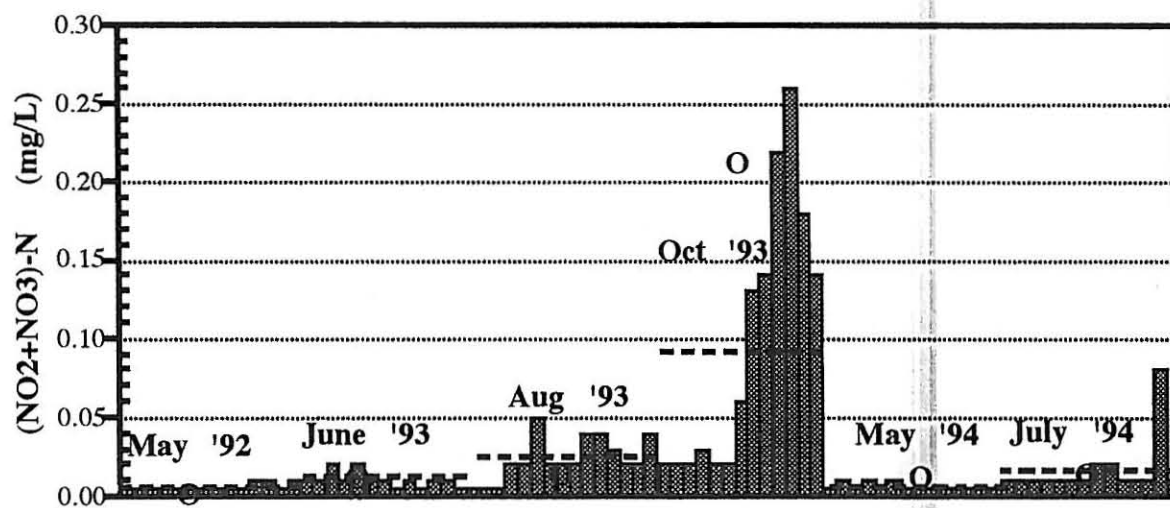


Figure 19. Hanks Marsh nitrate+nitrite-nitrogen by sampling date. Each bar represents a station and stations are in numerical order (1-14). North Buck Island values indicated with circles. The dotted lines represent the mean for that date.

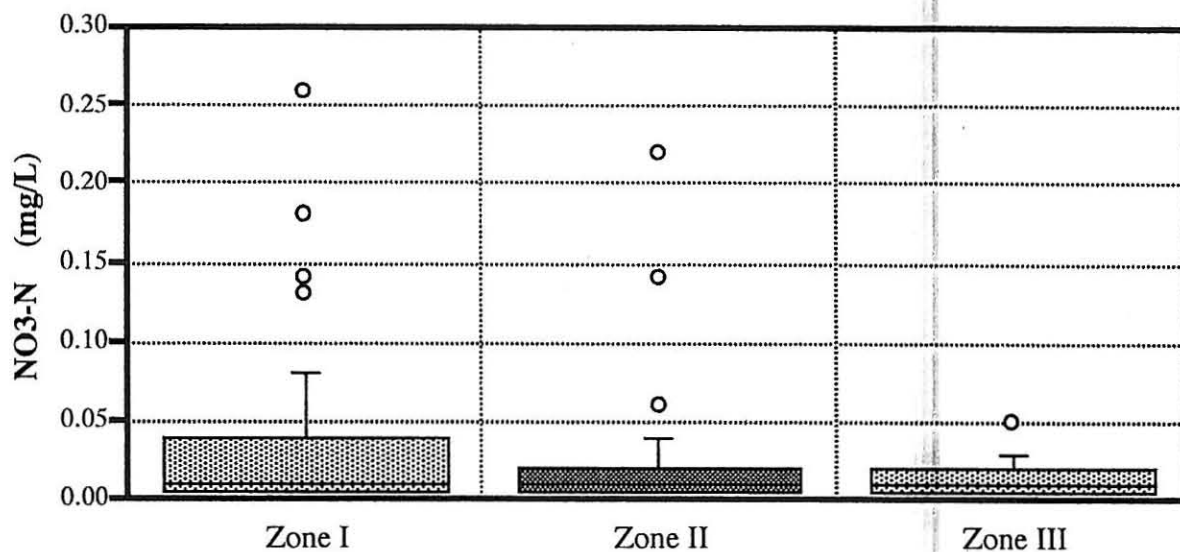


Figure 20. Hanks Marsh NO<sub>3</sub>-N by zone ( $p=0.048$ ). Open circles are outliers.

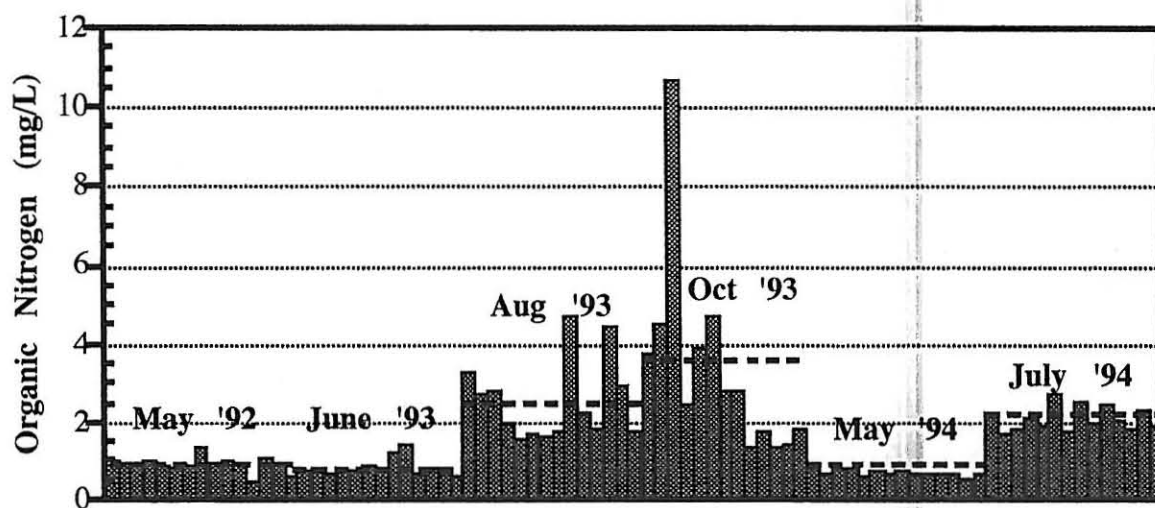


Figure 21. Hanks Marsh organic-nitrogen by sampling date. Each bar represents a station and stations are in numerical order (1-14). The dotted lines represent the mean for that date.

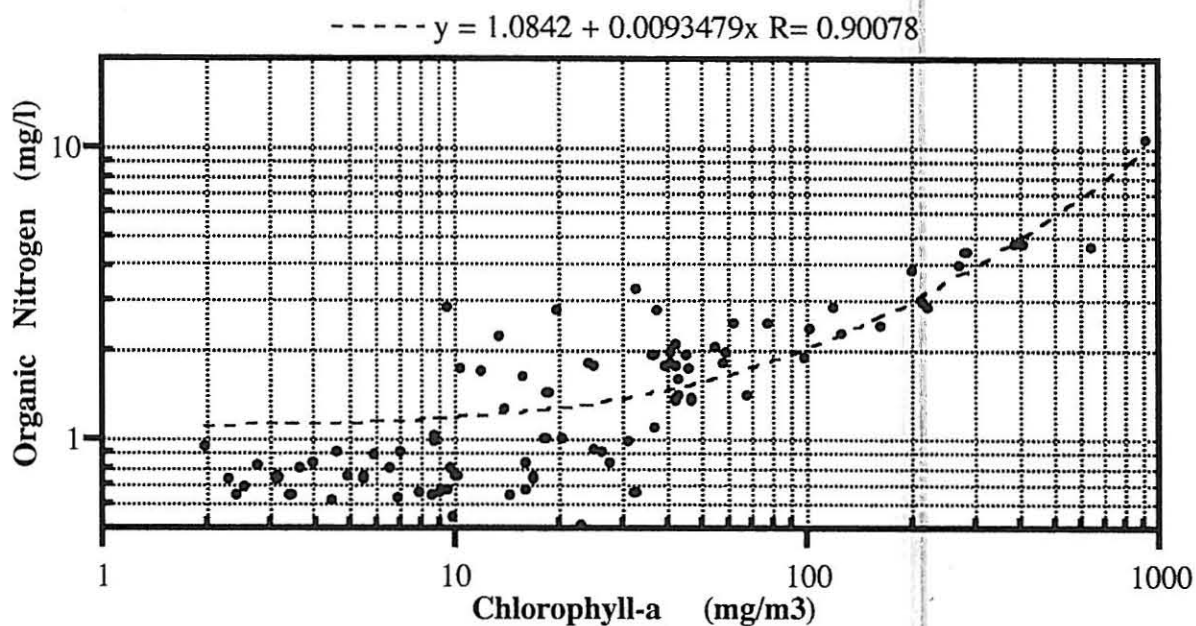


Figure 22. Hanks Marsh organic nitrogen versus chlorophyll-a (all dates).

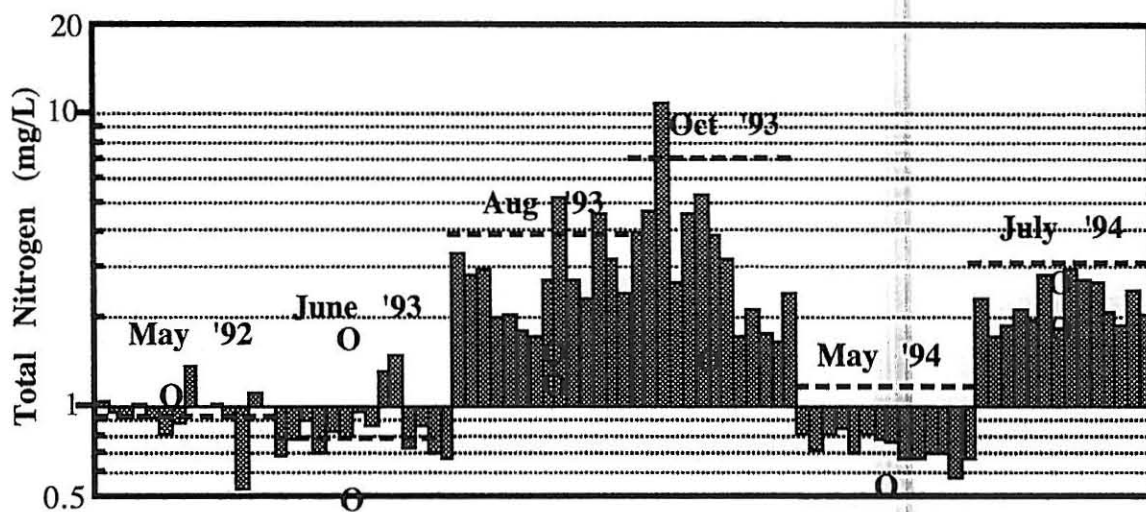


Figure 23. Hanks Marsh total nitrogen by sampling date. Each bar represents a station and stations are in numerical order (1-14). North Buck Island total nitrogen indicated with circles. The dotted lines represent the mean for that date.



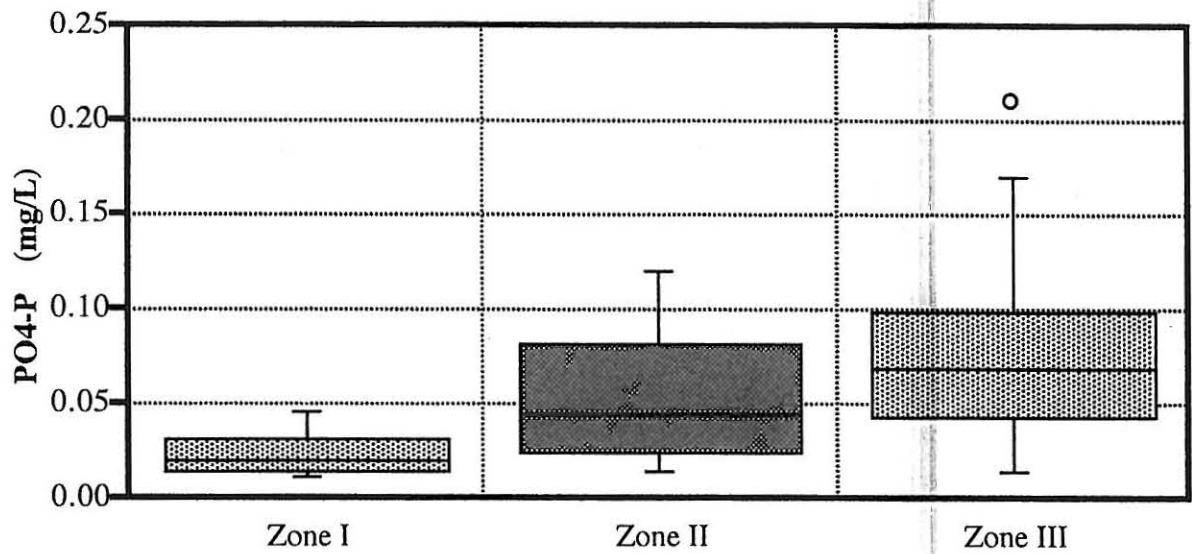


Figure 25. Hanks Marsh PO<sub>4</sub>-P by zone ( $p < 0.001$ ). Open circle is an outlier.

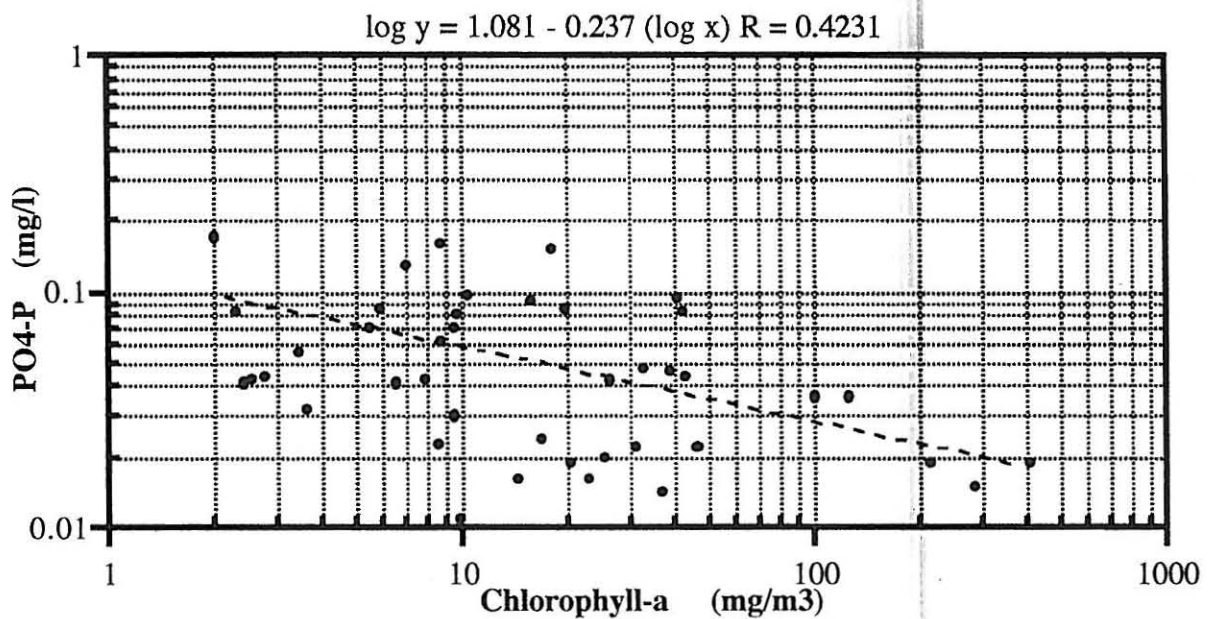


Figure 26. Hanks Marsh phosphate phosphorus versus chlorophyll-a (May '92, May '94 and August '93).

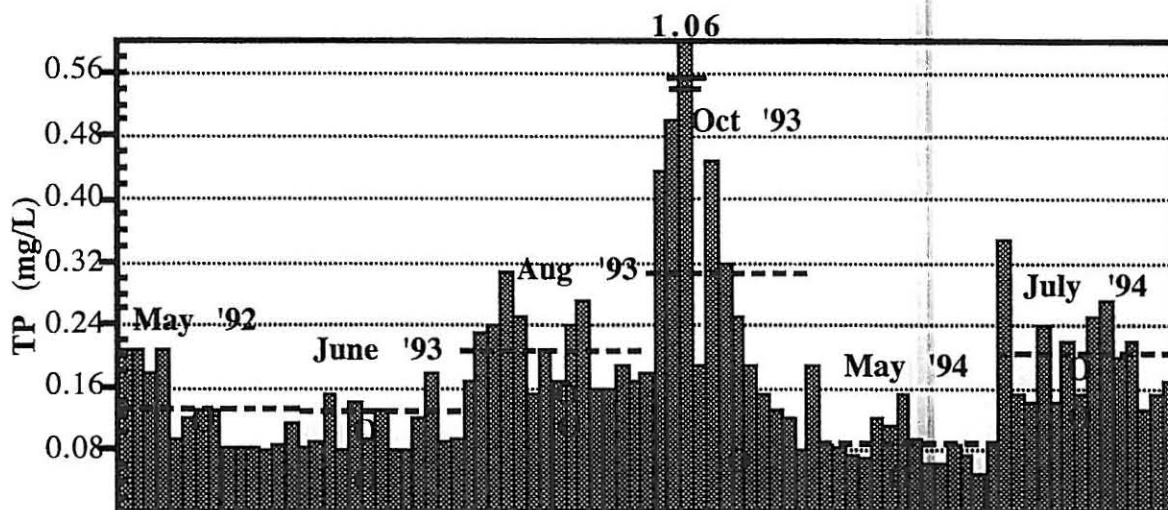


Figure 27. Hanks Marsh total phosphorus by sampling date. Each bar represents a station and stations are in numerical order (1-14). North Buck Island total phosphorus indicated with circles. The dotted lines represent the mean for that date.

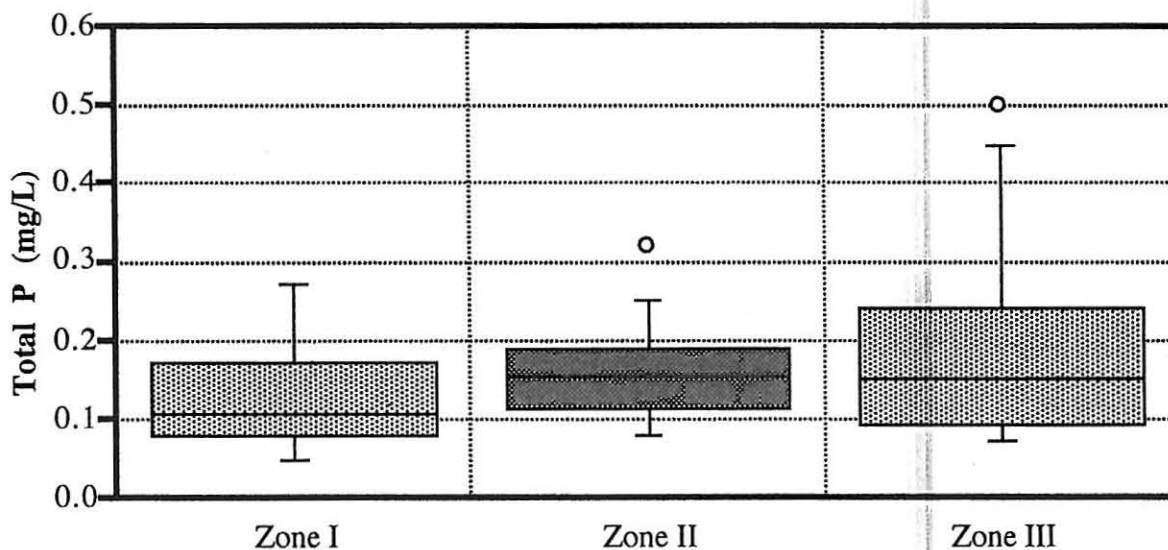


Figure 28. Hanks Marsh total phosphorus by zone ( $p=0.038$ ). Open circles are outliers. An outlier at 1.06 mg/L in Zone III is not shown.

## Phosphorus

Average  $\text{PO}_4\text{-P}$  in Hanks Marsh was  $0.042 \pm 0.041$  mg/L compared to  $0.020 \pm 0.018$  mg/L at the North Buck Island station. Phosphate was the only parameter that was not significantly influenced by season ( $p=0.539$ ) (Figure 25). Location within the marsh was a significant factor ( $p<0.001$ ), with  $\text{PO}_4\text{-P}$  concentrations in Zone III nearly three times those in Zone I (Figure 24). In May 1992,  $\text{PO}_4\text{-P}$  was negatively correlated to chlorophyll-a ( $r=-0.727$ ), temperature ( $r=-0.889$ ) and time ( $r=-0.842$ ). Phosphate was also negatively correlated to chlorophyll-a during August 1993 ( $r=-0.759$ ) and May 1994 ( $r=-0.654$ ) (Figure 26).

Average total phosphorus (TP) was also higher in Hanks Marsh than at North Buck Island ( $0.146 \pm 0.132$  mg/L versus  $0.094 \pm 0.050$  mg/L). Study-wide, TP concentrations were significantly higher in August 1993, October 1993 and July 1994 ( $p<0.001$ ) (Figure 27). Location within the marsh was also a significant factor for TP ( $p=0.038$ ), echoing  $\text{PO}_4\text{-P}$  trends with Zone III greatest and Zone I lowest (Figure 28). Based on all sampling dates, TP was positively correlated to organic nitrogen ( $r=0.895$ ) and chlorophyll-a ( $r=0.888$ ) (Figure 29). These relationships were strongest during October 1993, when marsh chlorophyll-a concentrations were highest.

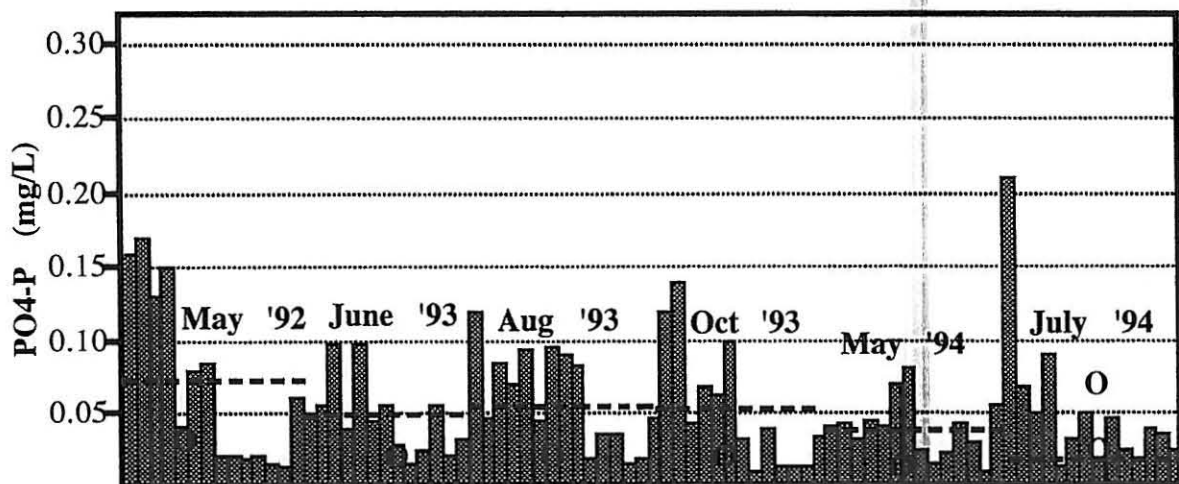


Figure 24. Hanks Marsh phosphate-phosphorus by sampling date. Each bar represents a station and stations are in numerical order (1-14). North Buck Island phosphate-phosphorus indicated with circles. The dotted lines represent the mean for that date.

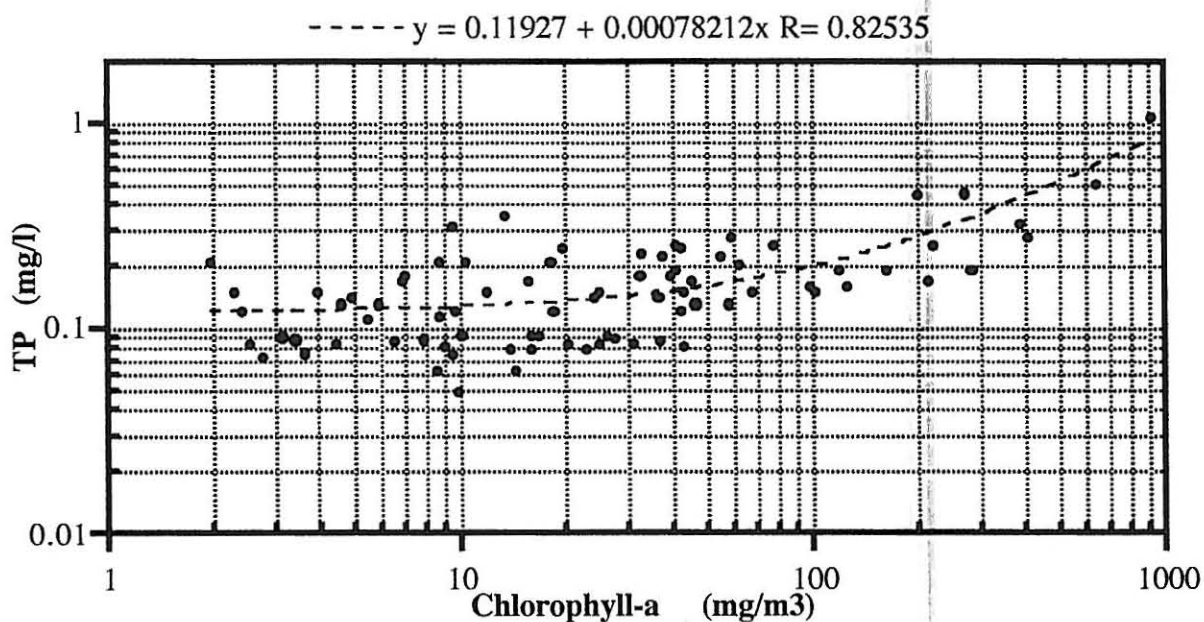


Figure 29. Hanks Marsh total phosphorus versus chlorophyll-a (all dates).

### *N/P ratio*

The ratio of total nitrogen to total phosphorus (TN:TP) was slightly higher at North Buck Island ( $12.8 \pm 4.2$ ) than in Hanks Marsh ( $10.2 \pm 4.0$ ). Date was a significant factor ( $p < 0.001$ ) due to higher ratios during August, October and July (Figure 30). Location by zone was also highly significant ( $p < 0.001$ ), with Zone I having a mean N:P of 13.8, while Zones II and III were 10.4 and 9.2 respectively (Figure 31). N:P values were correlated to turbidity ( $r = 0.811$ ) and time ( $r = 0.770$ ) in May 1992.

### *Chlorophyll-a*

Chlorophyll-a pigments varied greatly with date (Figure 32) both in Hanks Marsh ( $p < 0.001$ ) and at the North Buck Island station. Average marsh chlorophyll-a concentrations were  $24 \pm 140$  mg/m<sup>3</sup>, compared to  $28 \pm 60$  mg/m<sup>3</sup> at the pelagic station. Values were ten-fold higher in the marsh during the October trip ( $243 \pm 266$  mg/m<sup>3</sup>), with the greatest activity in Zone III. Throughout the study, however, location by zone was not a significant factor. As previously stated, chlorophyll-a was correlated to TP ( $r = 0.825$ ), organic nitrogen ( $r = 0.901$ ), turbidity ( $r = 0.735$ ), and TDS ( $r = 0.601$ ).

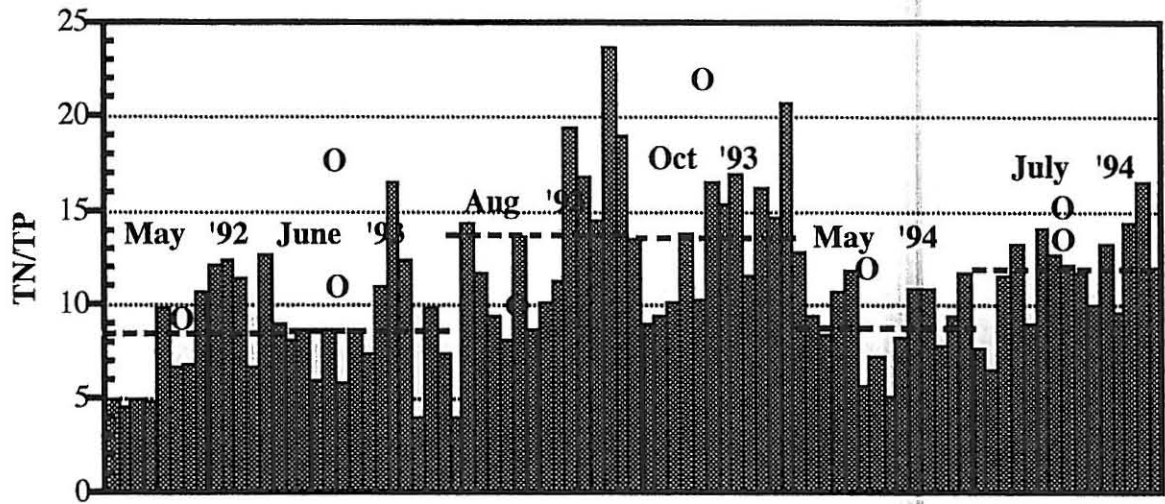


Figure 30. Hanks Marsh nitrogen to phosphorus ratio (N:P) by sampling date. Each bar represents a station and stations are in numerical order (1-14). North Buck Island N:P indicated with circles. The dotted lines represent the mean for that date.

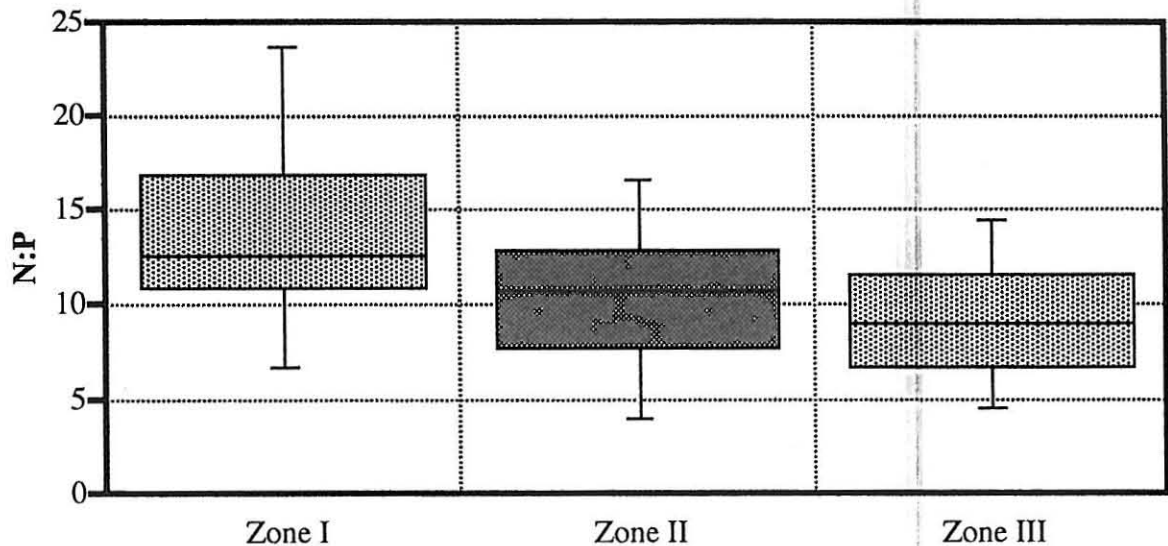


Figure 31. Hanks Marsh N:P by zone ( $p < 0.001$ ).

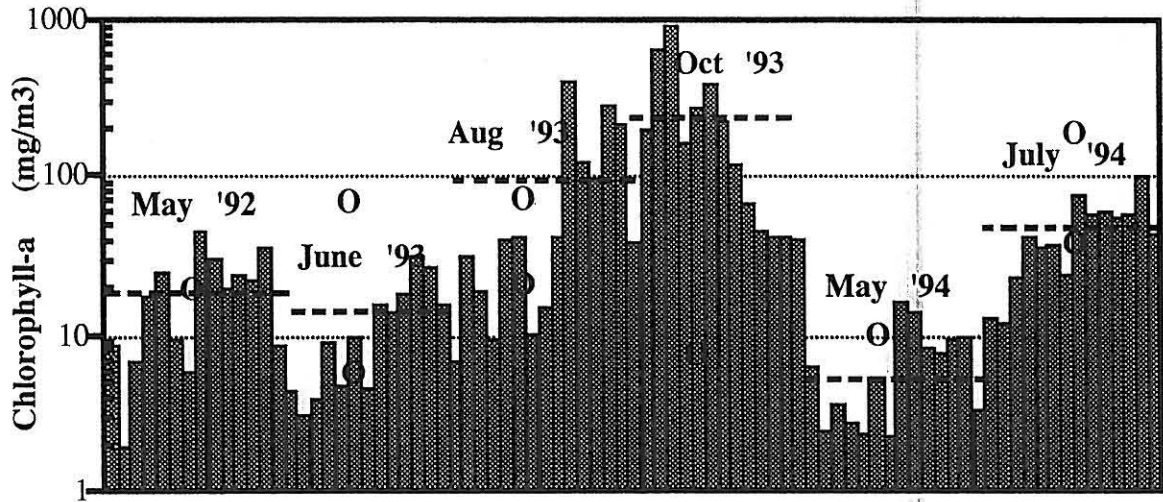


Figure 32. Hanks Marsh chlorophyll-a by sampling date. Each bar represents a station and stations are in numerical order (1-14). North Buck Island chlorophyll-a indicated with circles. The dotted lines represent the mean for that date.

### *Periphyton*

Marsh-wide, the ash-free dry weight (organic mass) of periphyton taken from Hanks Marsh did not vary significantly between the two dates (Figure 33). The variation by zone was significant in July ( $p=0.048$ ), with Zone III having periphyton biomass nearly twice that of Zones I or II. This trend was reversed in the October samples, however. The autotrophic index (ash-free dry weight:chlorophyll-a) was much greater in October 1993 than in July 1994 ( $p<0.001$ ), but did not vary significantly by zone (Figure 34). High levels of phaeophytin in the October samples indicate that productivity in the marsh was in decline, probably due to the onset of cold temperatures (Forbes 1996). Diatom diversity indices calculated from the July 1994 samples were not significantly different by zone.



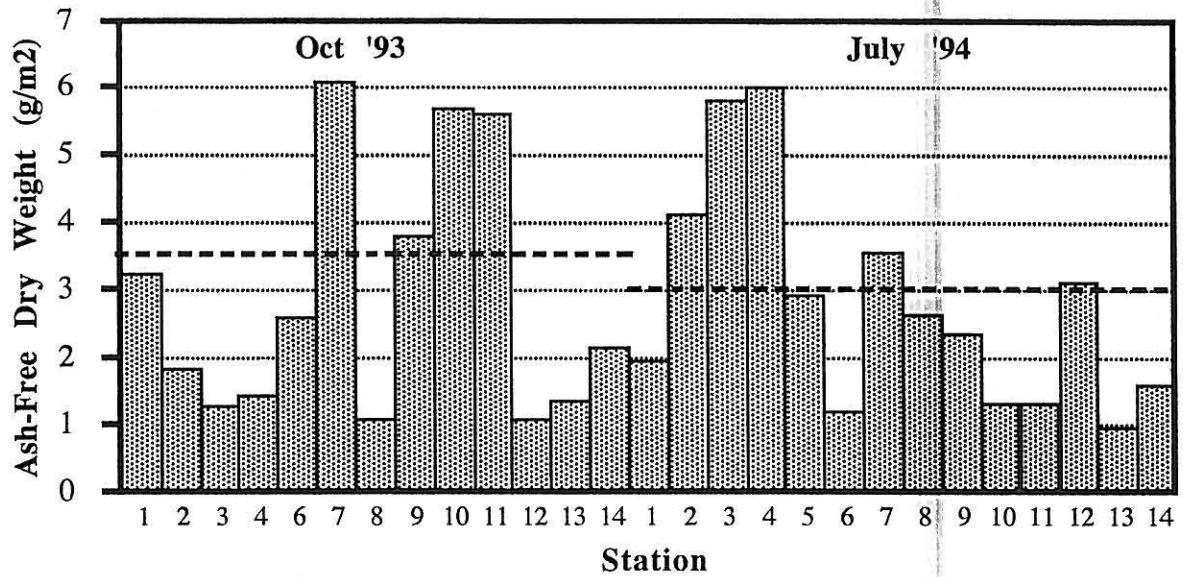


Figure 33. Hanks Marsh periphyton ash-free dry weight by sampling date. The dotted lines represent the mean for that date.

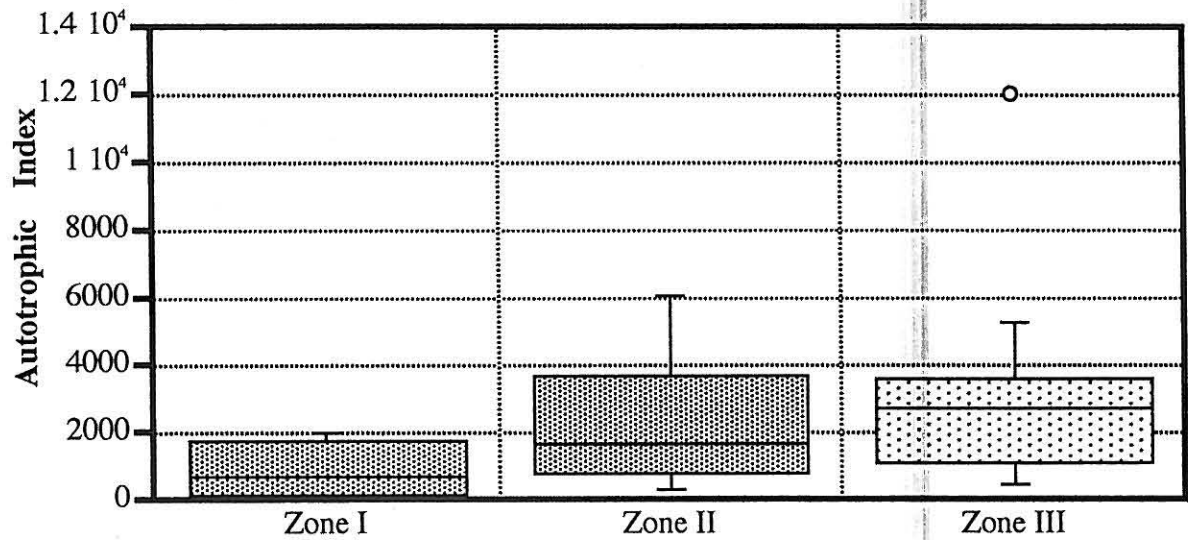


Figure 34. Hanks Marsh periphyton autotrophic index by zone (October and July samples).

## Discussion

### *Hydrology*

The hydrological regime in Hanks Marsh has not been determined. Construction of a water budget will be necessary to determine nutrient fluxes to and from the marsh. The marsh is largely submerged in late winter and early spring, at which time the lake and marsh waters mix. As seasonal draw down progresses, the interior of the marsh becomes increasingly isolated from the lake hydrologically. This is primarily due to the dense stands of emergent vegetation which create a physical barrier to wind and currents.

On most sampling trips, Zone I stations were quite windy, while Zones II and III were not. Water velocities were estimated to be zero at all Zone II and Zone III stations (Forbes 1996). For the purpose of discussion, we will assume that surface inflows and groundwater discharge are minimal. In other words, the primary source of Hanks Marsh water is the lake.

Hazel (1969) studied the limnology of Upper Klamath Lake and included a station on the perimeter of Hanks Marsh, near Stations 12 and 13 of this study. Hazel (1969, p. 21) stated that this station was "situated in the main circulation pattern of open lake water and therefore contained abundant algae" but that inside the marsh "the water is relatively clear and *Aphanizomenon* is not abundant..." Visual observations made during our Hanks Marsh study were identical. Very few *A. flos aquae* flakes were visible in interior zones of the marsh. Waters tended to be calm and darkly stained. With the exception of a few areas, submersed vegetation did not dominate the open water areas within the marsh. By contrast, in Pelican Bay, *Potamogeton crispus* dominates the open water areas.

### *Seasonal Trends*

All but one water quality parameter ( $\text{PO}_4\text{-P}$ ) exhibited high seasonal variability during this study. Each sampling visit provided an instantaneous snapshot of conditions in the marsh. However, there are such large gaps between sample visits that precise seasonal trends cannot be determined. The following discussion attempts to make qualitative statements concerning the seasonal processes that are supported by the data.

During the first spring visit (May 1992) some of the parameters suggest that the onset of the annual growth cycle was occurring. Dissolved oxygen concentrations were slightly supersaturated and correlated to chlorophyll-a levels. Also at relatively low concentrations in the water column were total phosphorus and total nitrogen.

August 1993 and July 1994, represent a highly productive summer phase: August mean depth was low (1.9 feet) and mean temperature warm (17.4 C). Total phosphorus (0.209 mg/L) and organic nitrogen (2.54 mg/L) were elevated, along with chlorophyll-a (98.8 mg/m<sup>3</sup>). Higher concentrations of ammonia-nitrogen (0.277 mg/L) suggest that decomposition was occurring as well. Conditions were severe in July. Depth was 1.2 feet, temperatures were the highest in the study (20.5 C), and



median pH was 9.05. Although average D.O. saturation was 100 percent, values ranged from a low of 46 percent at Station 9 to a high of 132 percent at Station 7. Conductivity was at a study maximum (142  $\mu\text{S}/\text{cm}$ ), but nutrients were low compared to the other study dates. Surprisingly, chlorophyll-a concentrations were only moderate (46.2 mg/L). The extremely high pH values were not correlated to the chlorophyll-a concentrations ( $r = -0.265$ ).

October 1993 represents the onset of colder temperatures and associated senescence. Several peak values were observed that indicate a period of decomposition and release of nutrients. Simultaneously, an algal bloom was occurring. Although the dominant species of this bloom is not known, *Aphanizomenon* flakes were not visible in the areas with the elevated chlorophyll-a concentrations. Depth was at a study minimum in October (0.75 feet), as was temperature (11.7 C). Conductivity and total dissolved solids were high. Turbidity and total suspended solids were about three times higher than at any other date. The oxygen content of the littoral zone may be severely reduced when large populations of vascular hydrophytes and macro algae senesce at the end of their growing season (Wetzel 1983). During October 1993, several stations had D.O.'s below 50 percent saturation, suggesting senescence and decomposition. On that same sampling trip, D.O.'s at Stations 12 and 13, which are located at the lake-marsh edge, were supersaturated (138 and 130 percent saturation respectively). Total phosphorus, organic nitrogen, nitrate-nitrogen and chlorophyll-a were also much higher compared to the other dates. Seasonal pulses of nutrient release in littoral zones have been well documented (Gearheart et al. 1995). The October samples reflect decomposition of macrophytes and their associated microflora, with the associated release of nitrate, ammonia, and phosphate. This release of material to the water may have supported the plankton bloom that was occurring in Zone III. Of interest also is the lack of correlation between the chlorophyll-a concentrations during October and July and the paired pH values (Figure 35).

### *Spatial Trends*

Littoral areas are interfaces between land and open water, and are structurally and functionally distinct from both terrestrial and pelagic zones. Littoral flora contribute significantly to lake productivity, and in some lakes may regulate the metabolism of the entire lake ecosystem (Wetzel 1983). These areas support a more complex food web because littoral vegetation provides habitats for photosynthetic and heterotrophic microflora, zooplankton and larger invertebrates. Many of the water quality trends observed in this study can be interpreted in light of what is known about biochemical processes in littoral areas. In Hanks Marsh, it was assumed that the interior stations (Zone III) will reflect these littoral processes. Conversely, stations at the lake-marsh interface (Zone I) will show a greater influence by pelagic processes. Six water quality parameters were strongly influenced by distance from pelagic waters (zone): pH, conductivity, phosphate, total phosphorus, nitrite + nitrate, ammonia, and the N:P ratio. Turbidity and total dissolved solids were moderately influenced by zone. Following is a discussion of these results in relation to littoral processes and to previous Upper Klamath Lake studies.

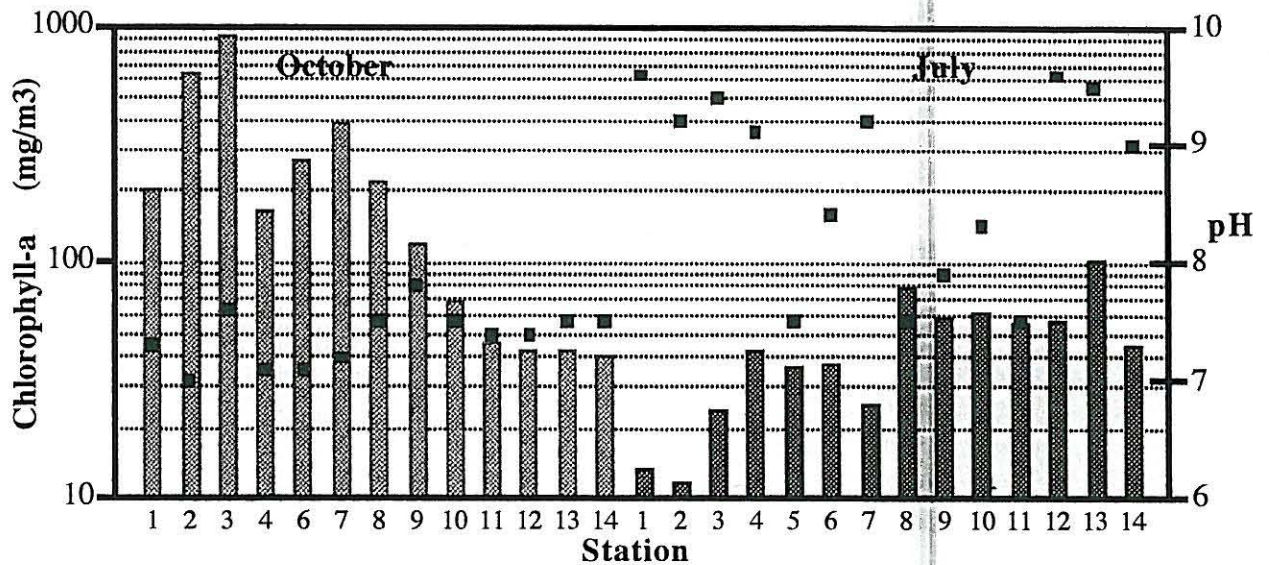


Figure 35. Hanks Marsh chlorophyll-a (bars) and pH (red squares) for October 1993 and July 1994.

### pH

During the degradation of plant material, humic and fulvic acids and various products such as ammonia, carbon dioxide, methane and hydrogen sulfide are released. Waters that contain large amounts of plant material are heavily stained as a result of the abundance of dissolved humic compounds (Wetzel 1983). Photosynthetic rates of phytoplankton are generally low in highly stained waters.

Common constituents of humic materials include compounds which inhibit bacterial fermentation and fungi processes (Wetzel 1983). These inhibitory compounds and associated acidity frequently result in an environment with slow rates of degradation and antiseptic qualities. Recent work by Kim and Wetzel (1993) has demonstrated that humic substances consistently inhibit alkaline phosphatase, an enzyme that hydrolyzes phosphoric acid esters at pH 7-8, liberating phosphate ions (Hawley 1977). Humic substances not only combine with proteins and phosphates; they may also occupy the active and non-active sites of enzymes, altering their activity (Kim and Wetzel 1993). Kim and Wetzel found, using varying concentrations of humic materials and different algal species, that humic substances enhanced or suppressed algal growth, with differences appearing to be both species and concentration related. Growth of the diatom *Nitzschia palea* was stimulated while growth of two green algae were stimulated or unaffected. *Anabaena flos-aquae* was inhibited by 20 mg/L of *Typha* humic acids, but slightly stimulated at lower concentrations. *Microcystis aeruginosa* growth was inhibited by all concentrations of humic acids for about 7 days, at which time the cyanobacteria grown in concentrations of 1 and 2 mg/L increased. *M. aeruginosa* growth remained inhibited by the 5



mg/L humic acid solution for the length of the study (over 12 days) (Kim and Wetzel 1993). Dissolved organic acid concentrations of 4-8 mg/L or more are common in littoral regions. Thus the humate content of waters in Zones II and III undoubtedly play a role in the low numbers of planktonic blue-green algae species observed there.

Phinney and Peek (1960) observed that *Aphanizomenon* does not survive in waters with pH less than 7.5. Phinney et al. (1959) tested the effects of Klamath Marsh waters on the blue-green alga *Anabaena cylindrica*. They replaced one-fourth of an algal medium with Klamath Marsh water, which resulted in the death of the test algae. When the same experiments were repeated, but the pH raised with NaOH, algal growth was stimulated.

Perdue et al. (1981) observed that the time of cessation of flow from Klamath Marsh coincides with the beginning of nuisance blooms of *Aphanizomenon flos-aquae*. Re-establishment of the flow coincides with cessation of the blooms. Analyses of the Klamath Marsh water indicated that most of the year, the marsh effluent is highly colored with aquatic humus and has high concentrations of iron, total organic carbon (TOC), and amino acids. More than 50 percent of TOC appeared to be humic material. Iron was apparently chelated by this humic material. "Prior to going through the Klamath Marsh, iron is transported primarily as >0.8  $\mu$ m suspended particulate, while after, it is primarily iron-aquatic humus complexes of a size <0.025  $\mu$ m." (Perdue et al. 1981)

Background (non growing season) Upper Klamath Lake pH is near neutrality. During photosynthetic activity, pH in pelagic areas frequently reaches levels above 10.0 (Kann and Smith 1993; Gearheart et al. 1995). Kann and Smith (1993) found that afternoon pelagic pH is correlated to planktonic chlorophyll-a concentrations. The relationship (Equation 1) predicted that a chlorophyll-a concentration of 93  $\mu$ g/L would result in a pH of 9.5.

$$\text{pH} = 7.107 + 1.112(\log\text{CHL}) \quad (r=0.73; p<0.0001) \quad (1)$$

Hazel (1969) determined that lakewide pH was correlated to temperature and intensity of *Aphanizomenon* blooms. Inside littoral marshes however, pH ranged between 6.5 and 7.5. Hazel observed a pH gradient between the marsh and the lake:

"Inside marsh areas, pH varied from about 6.5 to 7.5 throughout the year. At Hanks Marsh on July 23, pH was 7.4 seventy-five yards inside the marsh, 9.4 at its edge and 9.8 twenty-five yards into the lake".

In this study, Hanks Marsh pH decreased as distance from the pelagic zone increased (with the exception of July). This is most likely due to the following conditions in Zones II and III: 1) the absence of intense planktonic photosynthesis; and 2) greater concentrations of organic acids, particularly humic and fulvic acids, associated with the decomposition of higher plant material. This gradient was evident in overall marsh pH by zone (Figure 6) and on all dates except June 1993 and July 1994 (Figure 35). July pH's remained low in Zone II but not in Zone III. It unlikely that the high July pH's were related to photosynthetic activity by epiphytic algae because periphyton chlorophyll-a and periphyton organic weight were poorly correlated to pH ( $r=0.004$  and  $0.3095$  respectively). It is not clear what



caused the high July pH values, but nearby pelagic pH was 10.1 on July 7 and 9.3 on July 19. A diffusion gradient of hydrogen ions similar to the one observed by Hazel (1969) may have been responsible for the pH observations, with the important difference that pelagic carbon dioxide demand, which reduces hydrogen ion concentrations, exceeded the buffering capacity of the marsh water.

## Nitrogen

Ammonia, and subsequently nitrate, are the major nitrogenous end products of the bacterial decomposition of organic matter (Hutchinson 1975). Uptake of inorganic nitrogen by bacteria and algae, as well as nitrification and denitrification, are the major inorganic nitrogen removal mechanisms.

Previous studies of Upper Klamath Lake have shown that inorganic nitrogen species are at very low concentrations during the growing season, and exhibit an inverse relationship to chlorophyll-a concentrations. Between October and January, ammonia concentrations increase as a result of algal decomposition and lack of recycling by aquatic biomass. Conversely, total nitrogen, which is largely organic nitrogen, exhibits a linear relationship to chlorophyll-a ( $R^2=0.95$ ,  $p<0.001$ ; Kann 1993b). Atmospheric nitrogen fixed by *A. flos aquae* and other cyanobacteria can contribute large quantities of nitrogen to systems they dominate.

In Hanks Marsh, ammonia concentrations increased by roughly an order of magnitude during August, October and July. These increases were primarily in Zone II stations, particularly at Station 8. It is not clear what proportion of the elevated concentrations were related to decomposition in the marsh, as opposed to influence of pelagic conditions. Stations 8 and 9 are located at the northwest corner of the marsh, directly in the path of wind-driven lake currents. Thus water quality at these stations is most likely influenced by conditions in the lake.

Nitrate concentrations spiked in October at Stations 9 through 14, but still remained below 0.30 mg/L. This event was coincident with a pelagic spike of  $\text{NO}_3^-$ . In October, Zone III continued to have low nitrate and moderate ammonia concentrations, probably due to uptake by plankton during that period. Organic nitrogen (and thus total nitrogen) were also higher during the August, October, and July trips. Elevated total nitrogen is to be related to chlorophyll-a concentrations in the marsh (Figure 22).

Figures 36 and 37 compare Hanks Marsh nitrogen concentrations to those in Upper Klamath Lake and its major tributaries. Kann (1993) found that the mean total nitrogen for Agency Lake (June through September) was 2.033 mg/L, slightly higher than the study mean in Hanks Marsh (1.883 mg/L). Klamath Consulting Service, Inc. (1983) measured nitrate, ammonia and total nitrogen at various lake sites during 1981 and 1982. As the box plots illustrate, Hanks Marsh nitrogen levels are at or below those in the lake.

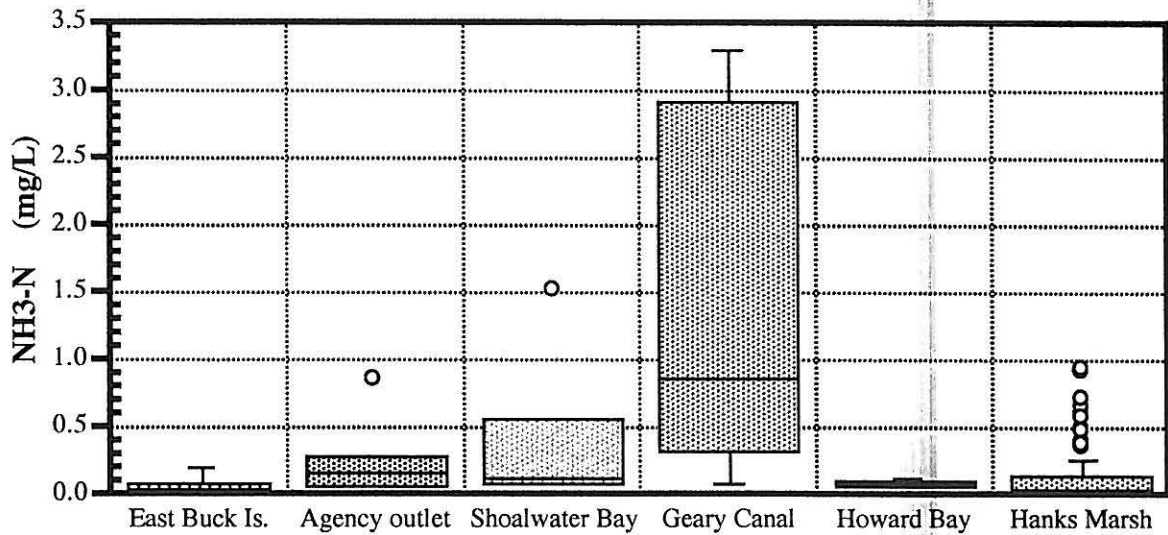


Figure 36. Lake-wide  $\text{NH}_3\text{-N}$  concentrations from May through September. Data Source: Klamath Consulting Service Inc. (1983). East Buck Island includes Klamath Tribe data.

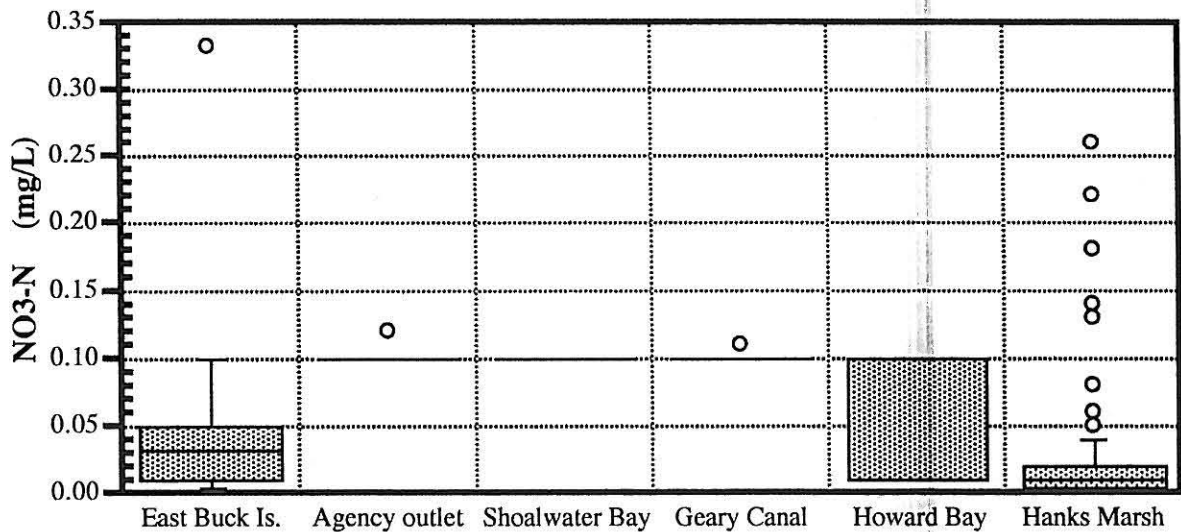


Figure 37. Lake-wide  $\text{NO}_3\text{-N}$  concentrations from May through September. Data Source: Klamath Consulting Service Inc. (1983). East Buck Island includes Klamath Tribe data.



## Phosphorus

The relationship between phosphorus loading and cultural eutrophication of aquatic systems is well established (Wetzel 1983; Harper 1992). It has been demonstrated in many studies that lakes experience increased algal productivity when phosphorus inputs are increased, and that the trend is reversible. On a smaller time scale, the instantaneous availability of phosphorus (i.e. soluble phosphate) is an important factor in determining algal growth rates. The turnover time between the various forms of phosphorus can be extremely rapid (a few minutes). Thus measures of soluble phosphate reflect instantaneous conditions, and probably do not reflect annual loads. For example, phosphate is often at very low levels in the water column during intense algal growth. Furthermore, assimilation of surplus amounts of phosphorus by algae, often referred to as "luxury" consumption, can provide sufficient phosphorus to maintain algal growth in the epilimnion, even though the external concentration of phosphorus may be very low or depleted:

"Algal requirements for phosphorus are variable among species and can lead to selective advantages of certain algae as phosphorus supplies change seasonally or as P loadings to a fresh water change over a longer period of time. Algae must compete with bacteria for phosphorus sources; if organic substrates for bacterial growth are high, algal growth may be seriously impeded." Wetzel (1983 pp. 295-297)

The  $\text{PO}_4\text{-P}$  concentrations in Hanks Marsh did not vary seasonally ( $p=0.539$ ), but did vary spatially ( $p<0.001$ ). These results may be due to differences in nutrient supply and demand as the systems shifts from pelagic to littoral. The reservoir of particulate detrital material in wetlands is very large and in various stages of senescence and decomposition. As stated above, this may result in significant competition for soluble phosphates between bacteria and algae. This large detrital reservoir also results in large organic loadings that are more or less continuous. The growth of attached microflora and fauna, which can account for a significant portion of the productivity in littoral areas, also obtains its nutrients from the water column. Thus, soluble nutrients are in more or less continuous flux between the epiphytic component and the water column, as well as between the detrital component and the water column. Finally, conditions that do not support high concentrations of planktonic algae, such as reduced light penetration, humic acid content, and low pH, lessen the demand for soluble phosphate. Hanks Marsh demonstrates that, although the levels of soluble phosphorus and other nutrients are not growth-limiting, this detrital-based system does not support levels of algal productivity comparable to those in adjacent pelagic waters.

Table 5 and Figures 38 through 41 provide a comparison between phosphorus concentrations in Hanks Marsh to those in the lake and its major tributaries. Three of the Hanks Marsh  $\text{PO}_4\text{-P}$  outliers occurred in May of 1992 in Zone III. The maximum value occurred at Station 1 during July. The four TP outliers occurred during October in Zone III. These elevated TP concentrations were most likely a result of senescence, exacerbated by very low water depths. Tributary  $\text{PO}_4\text{-P}$  is also comparable to that in Hanks Marsh. Tributary TP however, is lower than Hanks Marsh (Figure 41). This



is most likely a result of other growth limiting factors such as temperature and water velocity. With the exception of periodic pulses of phosphorus in Hanks Marsh, TP concentrations are similar to those in the lake, and PO<sub>4</sub>-P concentrations similar to those in local tributaries. Because elevated phosphorus in the marsh usually occurs at the end of the growing season, the nutrients are not available for the critical summer plankton blooms. This is in contrast to tributary inputs, which typically delivers peak loads during spring runoff events (Gearheart et al. 1995).

Table 5. Summary of selected Upper Klamath Lake watershed studies that analyzed PO<sub>4</sub>-P and TP. Only data from the growing season is included.

Location	Data Source	Years Studied	Mean PO <sub>4</sub> -P (mg/L)	Mean TP (mg/L)	OP:TP
Williamson River mouth	Perdue et al. (1981)	1979-1980	0.090	0.125	0.72
Wood River mouth	Campbell & Ehinger (1993a); Campbell, Ehinger and Kann (1993)	1990-1992	0.112	0.133	0.84
Upper Klamath Lake various sites	Klamath Consulting Service, Inc. (1983)	1981	0.603	2.040	0.30
Agency Lake south station	Kann (1993a,b)	1990	0.099	0.240	0.41
		1991	0.162	0.357	0.45
		1992	0.061	0.072	0.85
Upper Klamath Lake North Buck Island	Klamath Tribes (present study)	1992-1994	0.024	0.106	0.23
Hanks Marsh	National Biological Service (present study)	1992-1994			
		Zone I	0.023	0.127	0.18
		Zone II	0.050	0.161	0.31
		Zone III	0.078	0.214	0.36

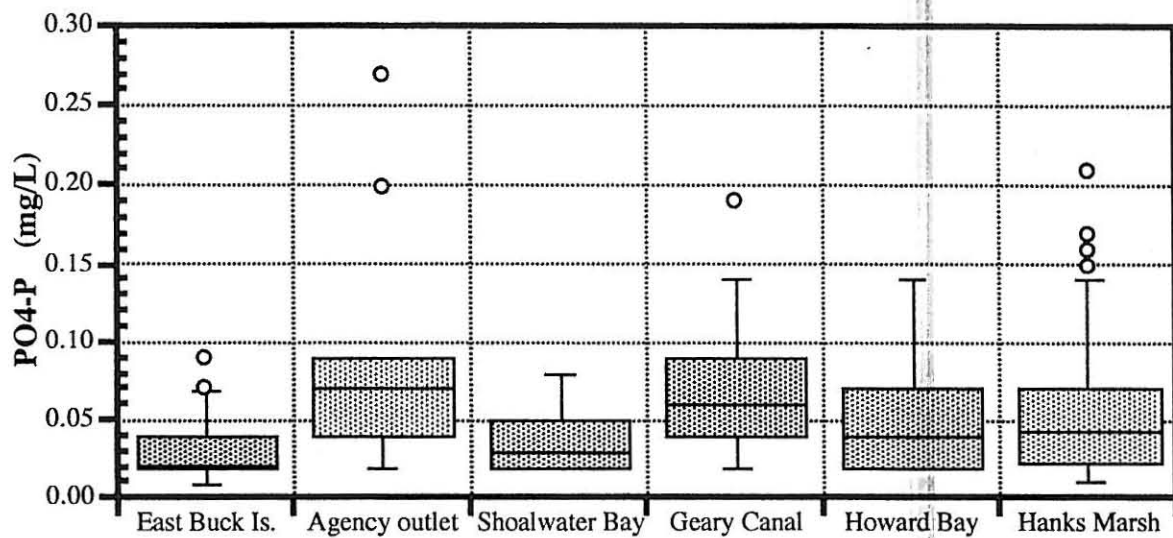


Figure 38. Lake-wide  $\text{PO}_4\text{-P}$  concentrations from May through September. Data Source: Klamath Consulting Service Inc. (1983). East Buck Island includes data from Klamath Tribe.

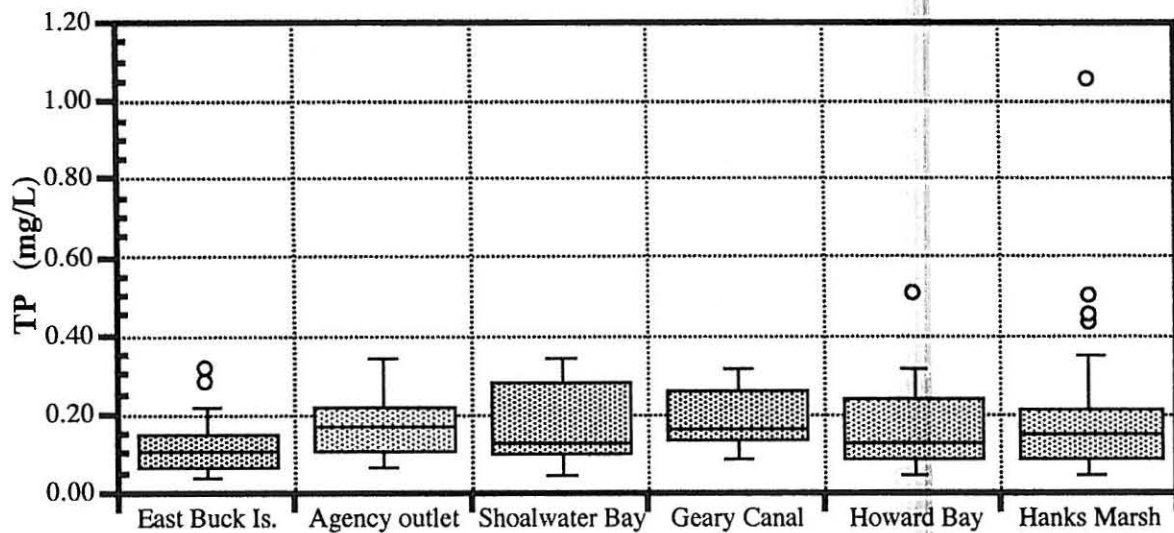


Figure 39. Lake-wide TP concentrations from May through September. Data Source: Klamath Consulting Service Inc. (1983). East Buck Island includes data from Klamath Tribe.

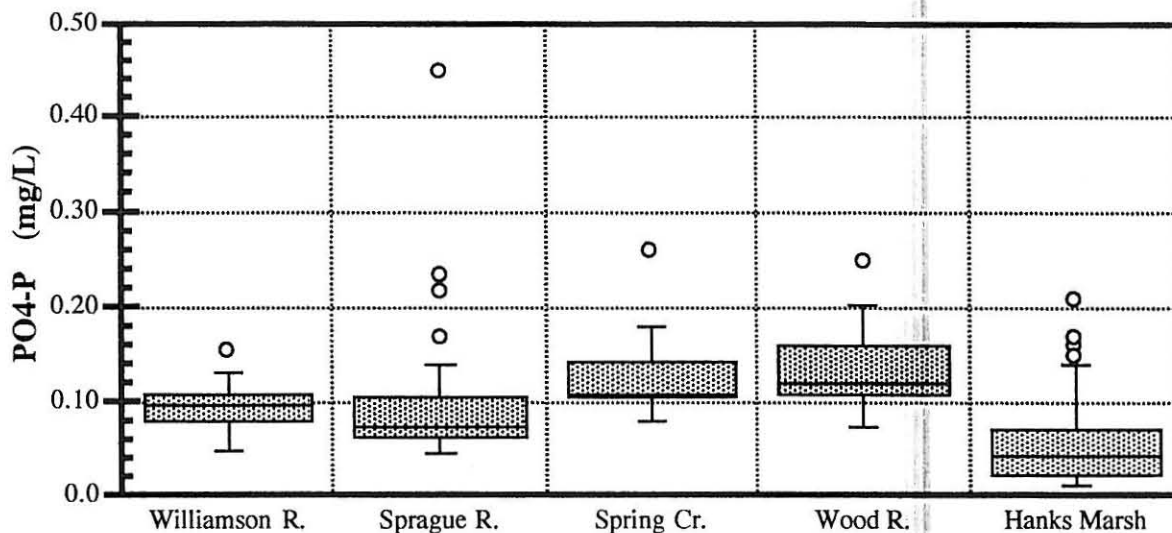


Figure 40. Tributary  $\text{PO}_4\text{-P}$  concentrations. Data sources: Williamson R. above confluence with Sprague, Sprague R. above confluence, Spring Cr. near mouth from Perdue et al. 1983. Wood R. at Agency Lake dike road from Campbell et al. 1993.

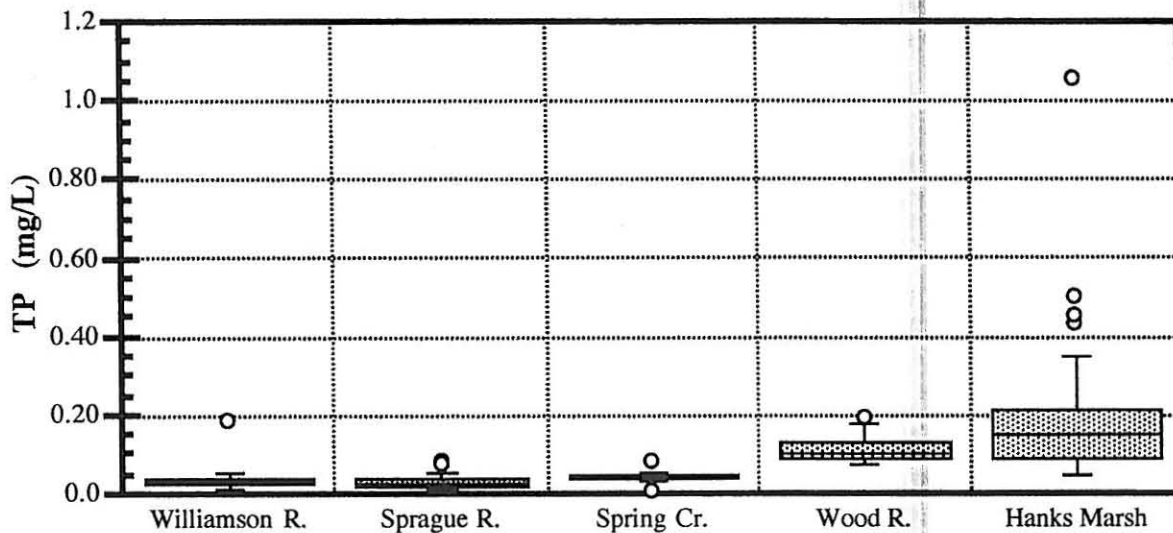


Figure 41. Tributary TP concentrations. Data sources: Williamson R. above confluence with Sprague, Sprague R. above confluence, Spring Cr. near mouth from Perdue et al. 1983. Wood R. at Agency Lake dike road from Campbell et al. 1993. The outlier at 1.06 mg/L in Hanks Marsh occurred in October at Station 3.

## *N:P*

The "ideal" ratio of total nitrogen to total phosphorus (dry weight) for algal uptake is 16:1. Human influences on catchment land uses generally reduce the N:P ratio of inflows through enhanced phosphorus sources. When inflow ratios are lower, nitrogen fixing cyanobacteria are able to out-compete other taxa. Studies found that nitrogen fixation contributed between 6 and 82 percent of the total nitrogen in eutrophic lakes (Harper 1992). In experiments where inputs have low ratios of nitrogen and carbon with higher levels of phosphorus, an increase in the ratio has occurred as a result of  $N_2$  fixing by algae. Furthermore, phosphorus tends to be more tightly conserved in a lake system than nitrogen or carbon, which are lost to outflows and the atmosphere (Ibid).

Higher N:P ratios were observed in Zone I and at the North Buck Island station (range 9.3 to 22.0) than in Zone II and III of the marsh. This is consistent with the higher phosphate concentrations observed in the inner marsh. Where nitrogen remained quite low at the onset of the growing season, phosphate concentrations were maintained. The higher N:P ratio nearer the pelagic zone may be a result of nitrogen fixation by cyanobacteria. Nitrogen fixation rates by photosynthetic bacteria are several orders of magnitude greater than fixation rates by heterotrophic bacteria commonly found in littoral areas. Thus in waters rich in dissolved humic compounds, N-fixation rates are very low (Wetzel 1983).

## *Chlorophyll-a*

There was a phytoplankton "bloom" in Zone III (interior) of Hanks Marsh in October 1993. Given the lower temperatures that existed at that time, the bloom was most likely diatoms or green algae. The bloom was probably a result of the nutrient pulse that occurred in October, which contributed significant amounts of soluble nitrogen and phosphorus to the water column. With the exception of the October bloom, Hanks Marsh exhibits lower concentrations of chlorophyll-a in the water column than other pelagic sites (Figure 42).



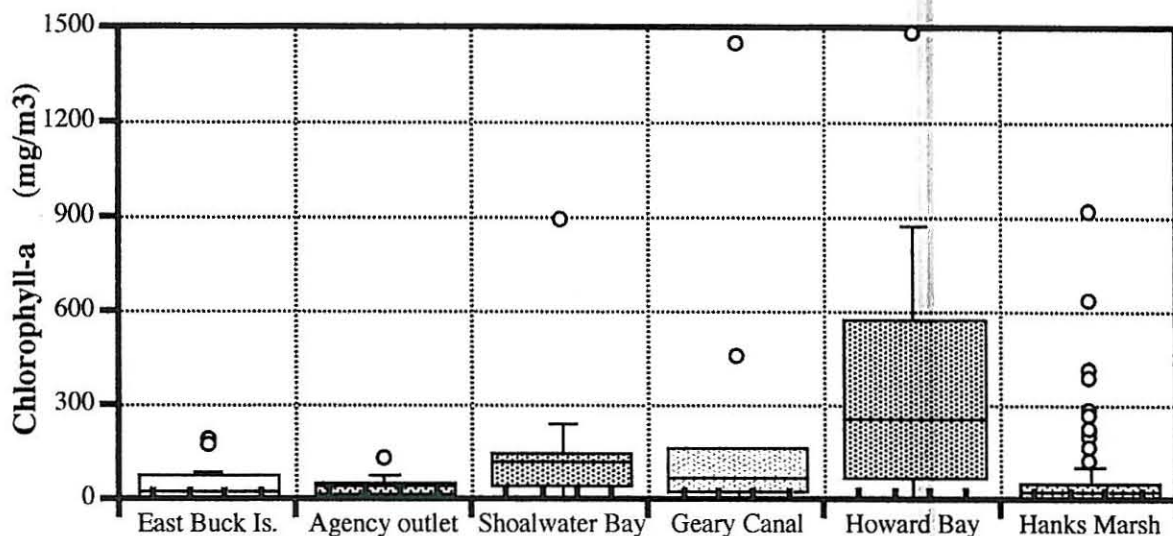


Figure 42. Lake-wide chl-a concentrations from May through September. Data Source: Klamath Consulting Service Inc. (1983). East Buck Island includes data from Klamath Tribe.

## Conclusions

Results of this study are for the most part consistent with what is known about physical and chemical conditions in littoral areas. Several parameters are distinctly different from open waters, forming a horizontal gradient as distance from the pelagic zone increased. These differences are related to the dominance by emergent macrophytes and resulting sheltered conditions which lead to hydrologic isolation. Conductivity, dissolved solids, hydrogen, phosphate, and nitrate ions, and total phosphorus formed a horizontal gradient of increasing concentration.

This gradient may be attributed to two factors. One is the abundant detrital pool that forms in littoral areas as a result of decomposition of higher plants. This pool remains in various stages of decomposition and thus maintains a relatively constant supply of nutrients. This appeared to be the case for Hanks Marsh phosphate, which did not vary significantly between sampling trips.

The second is the unique condition within the marsh that does not support planktonic algal blooms. Although the exact mechanisms are not well understood, the relationship between humate content and inhibition of many planktonic algae species has been established on both a local and national level (Phinney and Peek 1959; Perdue et al. 1981; Wetzel 1993). Other contributing factors include light limitation and low pH. The lack of heavy seston in the marsh may have contributed to the "excess" phosphate. By contrast, stations nearer the lake had very low phosphate concentrations during the summer.

Most parameters exhibited highly significant seasonal variation. On a study-wide basis, however, phosphorus, inorganic nitrogen, and chlorophyll-a levels were more similar to lake water than to levels found in selected tributaries. The results of this study do not address the flux of material between the pelagic and littoral zones. Some of the data suggest, however, that pelagic conditions influence the marsh stations in Zone I. Examples include low  $\text{PO}_4\text{-P}$  concentrations, coincident spikes of  $\text{NO}_3\text{-N}$ , and elevated pH values. Conversely, processes within the marsh may form water quality gradients that extend into the pelagic zone. Hazel (1969) documented a hydrogen ion gradient extending into the lake from Hanks Marsh, and Perdue et al. (1981) suspected that the cessation of flow from humate-rich Klamath Marsh contributed to the onset of the *A. flos aquae* blooms in the lake.

The physical and chemical characteristics of large littoral areas around Upper Klamath Lake may historically have played an important role in regulating the algal community and other characteristics of the system. Early travelers to the area described the lake waters as highly stained:

" The exploring party camped on a hilly promontory which projected into the lake, where the eastern shore contained a wide band of tule. The party was greeted by two squaws with lake fish. The water taken from the lake had a dark color and a disagreeable taste, occasioned apparently by decayed tule".  
(Anon. 1857)

According to Akins (1970) and Carlson (1993), 27,400 acres of littoral wetlands originally bordered the lake, with current acreage estimated at 3,510 (Table 6). This represents an 87 percent loss. Furthermore, since the lake is now between three and six feet deeper, significant areas of marshes may have been submerged during reclamation.

This survey of water quality in a littoral wetland is an important step in determining the role that wetland restoration can play in the recovery of Upper Klamath Lake. There is much that is not well understood about the ecology of these areas. Some topics for future studies include:

- 1) mechanisms involved in littoral inhibition of planktonic algal growth;
- 2) use of littoral wetlands as refugial areas for aquatic organisms during periods of acute water quality;
- 3) the role of littoral areas in the lake's food web; and
- 4) the role of emergent vegetation in providing refugia for juvenile sucker species.



Table 6. Historical wetland acreage around Upper Klamath Lake (Akins 1970; Carlson 1993) and estimated present sizes of those wetlands.

Name	Original Size (acres)	Present Size (acres)	When Altered
Pelican Bay	2,800	500	1900
Williamson Delta	12,000	1,160	>1940
Wocus and Caledonia	7,000	0	1916
Squaw Point	300	300	unknown
Shoalwater and Ball Bays	2,300	500	1930
Algoma Marsh	1,000	0	1914
Hanks Marsh	2,000	1050	1914
<b>TOTAL</b>	<b>27,400</b>	<b>3,510</b>	

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APPENDIX A  
Hanks Marsh Water Quality Data

Appendix A  
Hanks Marsh Water Quality Data

station	zone	date	depth (ft)	temp (C)	pH	DO %sat	cond (uS/cm)	tds mg/L
1	3	5/92	2.1	14.0	7.3	86	151	101
2	3	5/92	1.9	14.4	7.5	112	151	130
3	3	5/92	2.3	14.3	7.7	120	139	85.9
4	3	5/92	1.8	15.2	7.5	126	142	150
5	3	5/92	2.1	15.3	7.7	120	131	107
6	3	5/92	2.2	16.0	7.4	120	138	101
7	2	5/92	2.2	16.1	7.2	95	142	106
8	2	5/92	1.7	17.3	7.9	121	126	102
9	1	5/92	1.7	18.4	8.4	128	126	73.6
10	1	5/92	2.1	17.9	7.9	118	127	98.8
11	2	5/92	2.0	17.3	7.8	117	128	72.3
12	1	5/92	1.7	17.9	8.4	128	127	108
13	1	5/92	1.3	18.4	8.6	141	125	104
14	2	5/92	2.4	17.7	7.3	100	134	97.3
1	3	6/93	3.6	15.0	7.7	75	111	101
2	3	6/93	4.0	15.0	7.3	116	104	92
3	3	6/93	4.0	15.1	7.3	100	99	87
4	3	6/93	4.4	15.8	7.4	122	95	71
5	3	6/93	4.0	15.2	7.3	85	100	99
6	3	6/93	4.3	15.9	7.3	106	96	128
7	2	6/93	4.2	15.6	7.3	103	97	89
8	2	6/93	3.8	14.7	7.2	91	100	83
9	1	6/93	4.0	14.7	7.3	102	98	92
10	1	6/93	4.3	14.6	7.3	93	103	122
11	2	6/93	3.5	15.2	7.3	77	101	90
12	1	6/93	5.1	15.8	7.5	111	98	106
13	1	6/93	3.4	19.9	7.4	107	101	125
14	2	6/93	3.9	15.7	7.4	81	104	101
1	3	8/93	1.9	16.2	7	88	149	114
2	3	8/93	1.9	16.0	6.8	33	154	121
3	3	8/93	1.8	16.1	6.8	34	128	100
4	3	8/93	1.6	17.1	6.8	56	138	100
5	3	8/93	1.7	17.5	6.8	36	114	113
6	3	8/93	2.0	17.0	6.6	39	122	101
7	2	8/93	1.8	18.0	6.8	67	126	135
8	2	8/93	1.6	17.2	7.1	20	117	122
9	1	8/93	2.0	17.5	9	72	102	120
10	1	8/93	1.6	17.9	7.3	23	105	74
11	2	8/93	2.4	18.4	7	37	111	122
12	1	8/93	3.0	18.3	9.5	138	102	102
13	1	8/93	1.1	18.6	9.4	130	99	111
14	2	8/93	1.8	19.0	7.5	48	112	116

Appendix A  
Hanks Marsh Water Quality Data

						DO	cond	tds
station	zone	date	depth (ft)	temp (C)	pH	%sat	(uS/cm)	mg/L
1	3	10/93	0.6	11.1	7.3	28	179	192
2	3	10/93	0.7	11.8	7	34	177	225
3	3	10/93	0.7	13.1	7.6	124	128	174
4	3	10/93	0.6	13.7	7.1	55	145	144
5	3	10/93	*	*	*	*	*	*
6	3	10/93	0.7	15.9	7.1	72	152	171
7	2	10/93	0.5	17.3	7.2	106	149	170
8	2	10/93	0.7	7.7	7.5	66	124	123
9	1	10/93	0.9	8.9	7.8	71	111	117
10	1	10/93	0.8	8.9	7.5	73	119	125
11	2	10/93	0.5	9.8	7.4	53	114	121
12	1	10/93	1.1	11.1	7.4	72	113	114
13	1	10/93	1.1	12.4	7.5	85	111	115
14	2	10/93	0.8	10.6	7.5	78	122	124
1	3	5/94	3.1	17.3	7	74	138	125
2	3	5/94	3.0	18.1	6.8	72	139	84
3	3	5/94	3.1	17.5	6.9	90	131	91
4	3	5/94	2.7	18.5	6.6	46	139	92
5	3	5/94	3.1	17.3	6.6	54	128	91
6	3	5/94	3.1	18.4	6.9	76	132	79
7	2	5/94	3.1	18.9	6.7	72	132	103
8	2	5/94	2.8	18.0	6.9	78	125	94
9	1	5/94	3.1	17.3	7.1	85	123	98
10	1	5/94	3.5	17.9	6.9	76	123	81
11	2	5/94	3.3	18.3	6.7	63	125	99
12	1	5/94	2.7	17.8	6.7	64	124	90
13	1	5/94	3.1	17.0	7.8	98	121	98
14	2	5/94	3.1	19.4	6.7	73	130	89
1	3	7/94	0.9	18.4	9.6	87	152	137
2	3	7/94	1.3	20.0	9.2	100	156	125
3	3	7/94	1.4	20.1	9.4	118	149	113
4	3	7/94	1.3	20.6	9.1	114	164	145
5	3	7/94	1.4	21.0	7.5	88	143	88
6	3	7/94	1.3	22.2	8.4	122	141	105
7	2	7/94	1.5	21.6	9.2	132	152	100
8	2	7/94	0.6	18.0	7.5	62	139	134
9	1	7/94	1.2	18.4	7.9	46	134	110
10	1	7/94	1.3	19.3	8.3	76	142	103
11	2	7/94	1.0	22.2	7.5	108	149	107
12	1	7/94	2.1	20.4	9.6	115	120	99
13	1	7/94	0.6	22.8	9.5	128	118	91
14	2	7/94	1.0	22.3	9	114	127	108



Appendix A  
Hanks Marsh Water Quality Data

		turb	tss	PO4-P	TP	NH3-N	NO3+NO2-N
station	date	NTU	mg/L	mg/L	mg/L	mg/L	mg/L
1	5/92	1.4	4.93	0.160	0.210	0.010	0.005
2	5/92	2.2	2.39	0.170	0.210	0.010	0.005
3	5/92	2.5	0.55	0.130	0.180	0.010	0.005
4	5/92	2.8	4.41	0.150	0.210	0.010	0.005
5	5/92	5.2	8.19	0.042	0.093	0.010	0.005
6	5/92	2.5	1.22	0.080	0.120	0.010	0.005
7	5/92	2.8	3.66	0.084	0.130	0.010	0.005
8	5/92	10.8	39.00	0.022	0.130	0.010	0.005
9	5/92	10	19.00	0.022	0.083	0.020	0.005
10	5/92	9.9	19.20	0.019	0.083	0.010	0.005
11	5/92	9.3	22.00	0.020	0.083	0.010	0.010
12	5/92	9.7	18.10	0.016	0.079	0.010	0.010
13	5/92	19.7	20.80	0.014	0.087	0.010	0.005
14	5/92	5.2	7.40	0.061	0.112	0.020	0.010
1	6/93	3.5	*	0.046	0.084	0.050	0.010
2	6/93	2.8	*	0.055	0.090	0.030	0.010
3	6/93	3.1	*	0.098	0.150	0.050	0.020
4	6/93	3.7	*	0.039	0.080	0.030	0.010
5	6/93	5	*	0.098	0.140	0.060	0.020
6	6/93	4.8	*	0.045	0.092	0.040	0.010
7	6/93	3.2	*	0.055	0.130	0.050	0.010
8	6/93	4.3	*	0.028	0.079	0.030	0.005
9	6/93	5.7	*	0.016	0.079	0.030	0.010
10	6/93	9.3	*	0.025	0.120	0.040	0.005
11	6/93	9	*	0.055	0.180	0.060	0.010
12	6/93	8	*	0.021	0.089	0.030	0.010
13	6/93	7.7	*	0.031	0.093	0.020	0.005
14	6/93	2.4	*	0.120	0.170	0.040	0.005
1	8/93	2.8	29.00	0.047	0.230	0.005	0.005
2	8/93	2.2	27.20	0.085	0.240	0.020	0.005
3	8/93	1.8	50.00	0.071	0.310	0.100	0.020
4	8/93	6.7	23.40	0.094	0.250	0.040	0.020
5	8/93	10	12.40	0.044	0.150	0.390	0.050
6	8/93	1.8	19.60	0.096	0.210	0.080	0.020
7	8/93	2	1.20	0.091	0.170	0.080	0.020
8	8/93	9.3	15.60	0.083	0.240	0.930	0.020
9	8/93	45.3	19.60	0.019	0.270	0.500	0.040
10	8/93	9.3	7.00	0.036	0.160	0.370	0.040
11	8/93	7.3	12.20	0.036	0.160	0.410	0.030
12	8/93	11.7	19.00	0.015	0.190	0.070	0.020
13	8/93	13	9.40	0.019	0.170	0.260	0.020
14	8/93	6.7	5.40	0.046	0.180	0.620	0.040

Appendix A  
Hanks Marsh Water Quality Data

		turb	tss	PO4-P	TP	NH3-N	NO3+NO2-N
station	date	NTU	mg/L	mg/L	mg/L	mg/L	mg/L
1	10/93	16	23.10	0.120	0.436	0.110	0.020
2	10/93	26.3	39.40	0.140	0.500	0.140	0.020
3	10/93	51.7	130.10	0.043	1.060	0.090	0.020
4	10/93	13.7	26.00	0.068	0.190	0.160	0.030
5	10/93	*	*	*	*	*	*
6	10/93	29.3	79.60	0.062	0.450	0.670	0.020
7	10/93	61.3	102.00	0.100	0.320	0.590	0.020
8	10/93	42.7	160.60	0.033	0.250	0.950	0.060
9	10/93	36.3	101.40	0.011	0.190	0.260	0.130
10	10/93	22.3	21.71	0.040	0.150	0.200	0.140
11	10/93	26.7	55.40	0.014	0.130	0.150	0.220
12	10/93	16.7	31.50	0.014	0.120	0.130	0.260
13	10/93	13	26.80	0.014	0.081	0.080	0.180
14	10/93	21	40.40	0.034	0.190	0.480	0.140
1	5/94	3.9	0.80	0.041	0.086	0.010	0.005
2	5/94	4	0.40	0.043	0.084	0.010	0.010
3	5/94	2.8	0.60	0.032	0.075	0.005	0.005
4	5/94	1.2	0.40	0.044	0.071	0.020	0.010
5	5/94	1.7	0.20	0.041	0.120	0.050	0.005
6	5/94	2	0.80	0.071	0.110	0.060	0.010
7	5/94	1.5	1.20	0.082	0.150	0.040	0.005
8	5/94	8.4	5.60	0.024	0.092	0.020	0.005
9	5/94	6.8	0.60	0.016	0.062	0.020	0.005
10	5/94	5.6	4.40	0.023	0.062	0.020	0.005
11	5/94	4.6	0.80	0.043	0.088	0.030	0.005
12	5/94	5.2	5.40	0.030	0.074	0.020	0.005
13	5/94	6.5	0.20	0.011	0.049	0.020	0.005
14	5/94	2.2	0.80	0.056	0.088	0.020	0.005
1	7/94	5.4	9.00	0.210	0.350	0.050	0.010
2	7/94	4.9	6.40	0.069	0.150	0.040	0.010
3	7/94	6.4	12.00	0.051	0.140	0.030	0.010
4	7/94	13	25.20	0.090	0.240	0.040	0.010
5	7/94	7.8	12.00	0.014	0.140	0.030	0.010
6	7/94	13.3	18.80	0.032	0.220	0.030	0.010
7	7/94	8	13.40	0.051	0.150	0.040	0.010
8	7/94	19.3	42.00	0.019	0.250	0.390	0.020
9	7/94	39	74.40	0.046	0.270	0.720	0.020
10	7/94	11.5	19.40	0.025	0.200	0.140	0.010
11	7/94	11.3	16.40	0.019	0.220	0.040	0.010
12	7/94	12.7	31.00	0.039	0.130	0.030	0.010
13	7/94	13.3	22.60	0.036	0.150	0.030	0.080
14	7/94	8.6	10.80	0.025	0.170	0.080	0.010

Appendix A  
Hanks Marsh Water Quality Data

		TKN	Organic-N	TIN	TN	N/P	Total Chl-a
site	date	mg/L	mg/L	mg/L	mg/L	TIN/TP	mg/m3
1	5/92	1.04	1.03	0.015	1.045	0.07	8.74
2	5/92	0.96	0.95	0.015	0.965	0.07	1.97
3	5/92	0.91	0.90	0.015	0.915	0.08	6.98
4	5/92	1.02	1.01	0.015	1.025	0.07	18.06
5	5/92	0.91	0.90	0.015	0.915	0.16	26.00
6	5/92	0.81	0.80	0.015	0.815	0.13	9.62
7	5/92	0.89	0.88	0.015	0.895	0.12	5.87
8	5/92	1.38	1.37	0.015	1.385	0.12	46.48
9	5/92	1.00	0.98	0.025	1.005	0.30	31.26
10	5/92	1.02	1.01	0.015	1.025	0.18	20.28
11	5/92	0.94	0.93	0.020	0.950	0.24	25.04
12	5/92	0.52	0.51	0.020	0.530	0.25	22.94
13	5/92	1.10	1.09	0.015	1.105	0.17	37.00
14	5/92	1.00	0.98	0.030	1.010	0.27	8.70
1	6/93	0.67	0.62	0.060	0.680	0.71	4.42
2	6/93	0.77	0.74	0.040	0.780	0.44	3.13
3	6/93	0.88	0.83	0.070	0.900	0.47	3.93
4	6/93	0.69	0.66	0.040	0.700	0.50	9.02
5	6/93	0.81	0.75	0.080	0.830	0.57	4.94
6	6/93	0.79	0.75	0.050	0.800	0.54	10.06
7	6/93	0.95	0.90	0.060	0.960	0.46	4.60
8	6/93	0.86	0.83	0.035	0.865	0.44	15.92
9	6/93	1.30	1.27	0.040	1.310	0.51	13.91
10	6/93	1.49	1.45	0.045	1.495	0.38	18.37
11	6/93	0.72	0.66	0.070	0.730	0.39	32.42
12	6/93	0.86	0.83	0.040	0.870	0.45	27.45
13	6/93	0.69	0.67	0.025	0.695	0.27	15.92
14	6/93	0.67	0.63	0.045	0.675	0.26	6.88
1	8/93	3.30	3.30	0.010	3.310	0.04	32.75
2	8/93	2.80	2.78	0.025	2.805	0.10	19.62
3	8/93	2.90	2.80	0.120	2.920	0.39	9.53
4	8/93	2.00	1.96	0.060	2.020	0.24	40.78
5	8/93	2.00	1.61	0.440	2.050	2.93	43.12
6	8/93	1.80	1.72	0.100	1.820	0.48	10.32
7	8/93	1.70	1.62	0.100	1.720	0.59	15.58
8	8/93	2.70	1.77	0.950	2.720	3.96	42.36
9	8/93	5.20	4.70	0.540	5.240	2.00	410.67
10	8/93	2.40	2.30	0.410	2.710	2.56	124.38
11	8/93	2.30	1.89	0.440	2.330	2.75	99.00
12	8/93	4.50	4.43	0.090	4.520	0.47	282.81
13	8/93	3.20	2.94	0.280	3.220	1.65	212.60
14	8/93	2.40	1.78	0.660	2.440	3.67	39.16

Appendix A  
Hanks Marsh Water Quality Data

		TKN	Organic-N	TIN	TN	N/P	Total Chl-a
site	date	mg/L	mg/L	mg/L	mg/L	TIN/TP	mg/m3
1	10/93	3.90	3.79	0.130	3.920	0.30	199.67
2	10/93	4.70	4.56	0.160	4.720	0.32	637.07
3	10/93	10.80	10.71	0.110	10.820	0.10	918.17
4	10/93	2.60	2.44	0.190	2.630	1.00	161.43
5	10/93	*	*	*	*	*	*
6	10/93	4.60	3.93	0.690	4.620	1.53	268.93
7	10/93	5.30	4.71	0.610	5.320	1.91	390.94
8	10/93	3.80	2.85	1.010	3.860	4.04	221.10
9	10/93	3.10	2.84	0.390	3.230	2.05	118.70
10	10/93	1.60	1.40	0.340	1.740	2.27	67.70
11	10/93	1.90	1.75	0.370	2.120	2.85	46.38
12	10/93	1.50	1.37	0.390	1.760	3.25	42.44
13	10/93	1.50	1.42	0.260	1.680	3.21	42.78
14	10/93	2.30	1.82	0.620	2.440	3.26	40.57
1	5/94	0.81	0.80	0.015	0.815	0.17	6.50
2	5/94	0.70	0.69	0.020	0.710	0.24	2.53
3	5/94	0.80	0.80	0.010	0.810	0.13	3.63
4	5/94	0.83	0.81	0.030	0.840	0.42	2.75
5	5/94	0.69	0.64	0.055	0.695	0.46	2.41
6	5/94	0.80	0.74	0.070	0.810	0.64	5.46
7	5/94	0.77	0.73	0.045	0.775	0.30	2.29
8	5/94	0.76	0.74	0.025	0.765	0.27	16.70
9	5/94	0.67	0.65	0.025	0.675	0.40	14.32
10	5/94	0.67	0.65	0.025	0.675	0.40	8.58
11	5/94	0.69	0.66	0.035	0.695	0.40	7.89
12	5/94	0.69	0.67	0.025	0.695	0.34	9.50
13	5/94	0.57	0.55	0.025	0.575	0.51	9.85
14	5/94	0.67	0.65	0.025	0.675	0.28	3.42
1	7/94	2.30	2.25	0.060	2.310	0.17	13.27
2	7/94	1.73	1.69	0.050	1.740	0.33	11.82
3	7/94	1.86	1.83	0.040	1.870	0.29	23.86
4	7/94	2.15	2.11	0.050	2.160	0.21	42.04
5	7/94	1.97	1.94	0.040	1.980	0.29	36.43
6	7/94	2.80	2.77	0.040	2.810	0.18	37.48
7	7/94	1.82	1.78	0.050	1.830	0.33	24.91
8	7/94	2.90	2.51	0.410	2.920	1.64	77.54
9	7/94	2.70	1.98	0.740	2.720	2.74	58.64
10	7/94	2.64	2.50	0.150	2.650	0.75	61.37
11	7/94	2.10	2.06	0.050	2.110	0.23	55.17
12	7/94	1.86	1.83	0.040	1.870	0.31	57.50
13	7/94	2.40	2.37	0.110	2.480	0.73	102.04
14	7/94	2.03	1.95	0.090	2.040	0.53	45.04

APPENDIX B

North Buck Island Water Quality Data

	Date	Depth (ft)	Temp (C)	DO (mg/L)	DO %sat	pH	Cond us/cm	TP mg/m3	SRP mg/m3	TN mg/m3	NO3-N mg/m3	NH3-N mg/m3	chl-a mg/m3	N/P
5/20-21	5/20/92	5.91	15.81	9.02	92	8.6	114	128	30	1190	5	34	21.5	9.3
6/9-10	6/3/93	9.51	14.23	8.30	96	7.8	98	39	12	435	10	19	5.9	11.2
	6/17/93	9.19	17.14	11.31	139	8.7	100	101	8.5	1805	5	8	84	17.9
8/17-18	8/12/93	6.23	19.72	7.67	98	8.9	98	110	26	1100	14	5	21	10.0
	8/25/93	6.23	16.43	7.20	87	9.0	97	149.5	13	1490	16	28	83	10.0
10/6-7	10/13/93	5.25	12.79	5.53	62	7.0	116	60	22	1320	332	213	7.6	22.0
5/24-55	5/24/94	9.19	15.95	8.17	99	8.2	119	48	12	568	5	11	11	11.8
5/7/12-13	7/7/94	5.91	18.94	8.64	111	10.1	125	187	25	2740	10	5	191	14.7
45	7/19/94	5.91	22.97	6.67	93	9.3	118	132	68	1750	14	97	40	13.3
	mean	7.04	17.11	8.06	98	8.6	109	106.1	24.1	1378	46	47	52	13.3
	geomean	6.86	16.87	7.91	96	8.6	109	94.3	19.8	1209	13	21	28	12.8
	sd	1.72	3.06	1.62	21	0.9	11	49.5	18.1	694	107	69	60	4.2
	max	9.51	22.97	11.31	139	10.1	125	187.0	68.0	2740	332	213	191	22.0
	min	5.25	12.79	5.53	62	7.0	97	39.0	8.5	435	5	5	6	9.3
	median	6.23	16.43	8.17	96	8.7	114	110.0	22.0	1320	10	19	22	11.8