WATER AND SEDIMENT SAMPLE COLLECTION AND ANALYSES JULY 1999 - JULY 2002 PRE- AND POST-RESTORATION COMPARISON

HOG CREEK, SARASOTA, FL, AND PALMA SOLA CREEK, BRADENTON, FL

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I. STUDY DESCRIPTION

Mote Marine Laboratory conducted a sampling program which had been designed to evaluate the water and sediment quality and biological indicators of an urbanized, tidally influenced creek in the City of Sarasota, Hog Creek, before and after the completion of a habitat restoration effort. The Creek receives approximately 2.8 MGD of reject water from reverse osmosis treatment at the City of Sarasota's water treatment facility and the habitat restoration was designed to improve the quality and extent of tidally influenced habitats and to provide additional mixing and dilution of the discharge waters by deepening receiving waters. A comparison system, Palma Sola Creek, which does not receive reject water, was also to be sampled. Palma Sola Creek, however, drains a golf course irrigated with reuse water generated by domestic waste treatment in Manatee County. Five stations along Hog Creek and three on Palma Sola Creek were routinely sampled (**Figure 1**). One of the Palma Sola stations was salinity based (endeavoring to sample 10 ppt), and therefore a variable location, while the remainder of the stations were geographically based. Four samplings were completed prior to habitat restoration, as well as a number of post-restoration samplings. Water quality parameters, sediment quality parameters, and benthic infauna were sampled on varying schedules. The project was conducted under a Quality Assurance Project Plan (Scheda, 1999) and under Mote Marine Laboratory's Comprehensive Quality Assurance Plan (MML, 1999), and NELAC certified Quality Plan (MML, 2001). Subcontracted analyses included sediment metals (Sanders Laboratories / Savannah Laboratory), selected water quality analyses (Savannah Laboratories), and radiological analyses (Florida Radiochemistry Services, Inc.), performed under each organization's respective Comprehensive Quality Assurance Plan or Quality Plan. For any questions regarding this report, please contact the authors.

Prior progress reports on this project were submitted as Mote Marine Laboratory Technical Reports #668 (benthic; pre-restoration), #694 (water and sediment quality), # 823 (water and sediment quality) and # 846 (benthic macrofauna; pre- and post- restoration comparison).

II. SAMPLING SITES

II.1. Hog Creek

Hog Creek 1 (HC-1) was located at the culverted opening from beneath Coconut Avenue, on the north side of Pioneer Park, in Sarasota, Florida. The culvert appeared to be a stormwater system draining a moderate density residential area. The culvert was often dry, and there was at times a slight base flow from the surrounding wetland area to the small pool at the culvert opening. There was not even standing water present at 2 of the 6 post-restoration samplings. No samplings occurred during storm events when flow from HC-1 would comprise a large fraction of the f lows below HC-2. Sediments ranged from muddy sand to leaf debris.

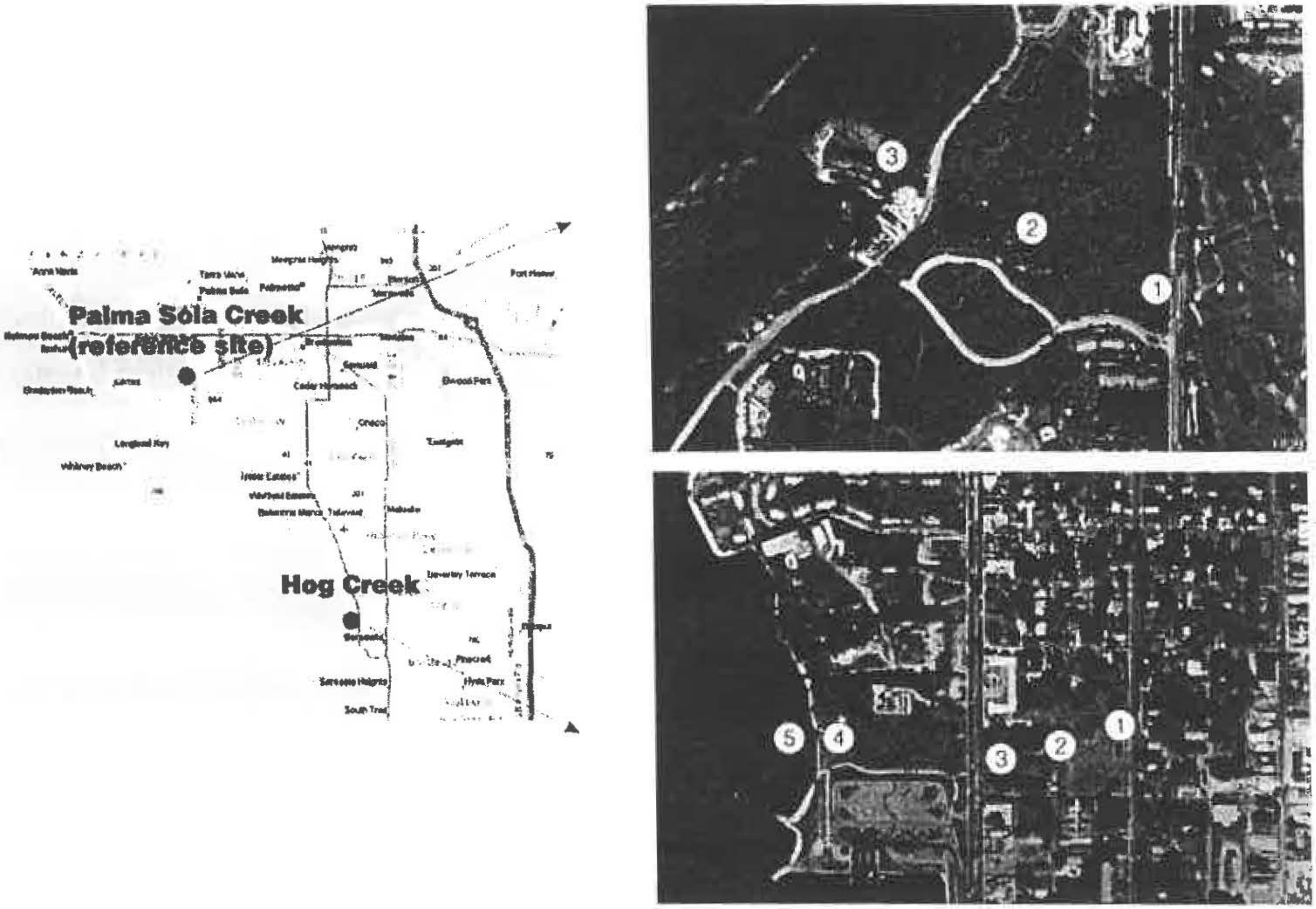

Figure 1. Approximate station locations for Sampling sites in Palma Sola and Hog Creeks. Palma Sola Station PS-2 is a salinity-based, variable location.

Hog Creek 2 (HC-2) was located at the discharge point of the City of Sarasota reverse osmosis plant, at the north west corner of Pioneer Park. Prior to restoration, the 5' culvert opened into a ~3' wide open channel bordered by extensive submerged and emergent vegetation. Current velocities in the narrow channel maintained a fairly coarse sediment on the stream bed. Restoration efforts have created an enlarged 'mixing pond' before entering the existing channel. The water is generally slightly cloudy and blue in appearance with numerous filamentous white particulates. The pond is presently bordered with emergent vegetation. Flow was measured across the opening of the 5' culvert. Sediments were a muddy, dark sand at the edges of the pool grading into coarser sediments as the stream shallows and increases in velocity.

Hog Creek 3 (HC-3) was located where the creek is routed below U.S. Highway 41 in a rectangular box culvert. Flow on the upstream side was constricted and comparatively rapid with a rocky substrate. Immediately downstream of U.S. 41, a larger pool formed and sediments accumulated. For access and substrate reasons, water quality samples were collected on the upstream side and sediments collected on the downstream side of U.S. 41. Waters were generally clear and spring-like in appearance with no filamentous particulates as noted at HC-2. Flow was downstream. Sediments were a dark muddy sand.

Hog Creek 4 (HC-4) was located at the mouth of Hog Creek as it entered Sarasota Bay through a relic box culvert. Surface to bottom salinity differences were substantial at times. Large amounts of rip rap and rocky debris lined the creek bottom and sides and formed a rocky sill at the mouth. The area was a relatively high energy environment even upstream of the sill. Surface flow was downstream, even at high tide. *In situ* salinity data indicated that a lens of fresher water formed over the top of more saline water and persisted out into Sarasota Bay. Sediments were difficult to collect given the lack of navigation access, water velocity, and rocky substrate. The greatest accumulation of sediments appeared in between the large boulders at the mouth and consisted of relatively coarse shell hash material.

Hog Creek 5 (HC-5) was located approximately 50 m offshore of the mouth of Hog Creek and was sampled by boat. Water depths were 1.5-2 m and the area was unprotected from waves in Sarasota Bay. The lens of fresher water generally persisted at this station with surface to bottom differences in salinity. The waters appeared typical in appearance for Sarasota Bay. Sediments were a fine, sandy, unconsolidated, grey mud.

II.2. Palma Sola Creek

Palma Sola 1 (PS-1) was located at the intersection of Palma Sola Creek and 75th Street West, Bradenton, Florida. The creek crossed through a golf course irrigated with treated effluent and crossed under 75th Street in a diagonally oriented 11.6' box culvert. Water depths were relatively uniform across the opening of the culvert and samples were collected on the downstream side. Flows for Palma Sola Creek are measured here. Waters were generally stained with humics. During the period prior to and during Hog Creek restoration. 75th Street was subject to extensive construction for widening and construction of a stormwater retention pond whose outfall is adjacent to PS-1. Sediments were sandy.

Palma Sola 2 (PS-2) was established at or near the location of the 10 PSU isohaline. Typically located upstream of the Palma Sola Boulevard bridge by approximately 75 m, the station location could vary with each sampling. Samples were collected from approximately 20 cm in depth where salinity values were near 10 PSU. The stratified conditions made the definition of a 10 PSU station somewhat subjective. Due to the shallow banks and protected, incised channel, salinity conditions were generally extremely stratified. The station's location varied through an agreement between MML, FDEP (Mr. Charles Kovack), and Scheda Ecological (Mr. Ray Kurz) that the upstream approach would be investigated first and sampled as PS-2 if salinity values were 5 PSU or greater. When accessing the station from the downstream approach, samplers operated from a canoe to the upstream limits of navigation without pruning vegetation.

In the region most frequently sampled for PS-2, the stream was bordered by mangroves growing on shallow banks of peat and mud on both sides at this site. The channel was incised to a depth of 1-1.5 m with sediments alternating between peat deposits, root debris, or sand. Flows appeared to prevent sediment accumulation. Waters were generally humic stained but relatively opaque due to typical precipitation of humics on mixing with salt water.

Palma Sola 3 (PS-3) were located on the upstream side of the Palma Sola Boulevard bridge. The stream was broader than at the upstream sites and sediments were a relatively unconsolidated muddy sand, except for shell fill adjacent to the bridge. Conditions were generally extremely stratified at this site as well. At times surface flows were downstream while bottom waters, as indicated by suspended leaf debris, were moving upstream. Sampling visibly disrupted the fresh and saline layers and made collecting representative samples difficult. Samples and measurements were collected at approximately 20 cm in depth. A sand bar at the mouth of the creek maintains the area in a very low energy, depositional state, and the waters of Palma Sola Bay were quite shallow for some distance offshore.

III. SAMPLINGS

III.1. Pre-restoration

The pre-restoration samplings of Hog and Palma Sola Creeks were conducted on 4 different occasions from July to December 1999. The initial sampling was on July 27, 1999. Samples were collected for water quality, sediment quality and benthic infauna during this effort. The subsequent samplings were conducted on August 25, October 5, and December 7, 1999, and for water quality only. Predicted tides for all sampling dates are illustrated in **Appendix A** with Sarasota Bay, Sarasota shown for Hog Creek, and Cortez, Sarasota Bay for Palma Sola Creek.

III.2. Post-Restoration

The post-restoration sampling of Hog and Palma Sola Creeks was resumed on November 27, 2000. The subsequent samplings were on January 29, July 10, and September 5 and 6, 2001, and January 15, and July 22, 2002. In addition to field measurements and collection of samples for water quality analysis, sediment samples were also collected during July 2001 sampling (for benthic infauna, grain size, TOC, sulfide and metal analysis) and July 2002 sampling (for metal and sulfide analysis only).

As scheduled in the scope of work, the final water quality sampling was for a limited number of analytes. The predicted tides all sampling dates at the closest tidal stations appear in**Appendix A**.

IV. ANALYTICAL METHODS

Analytical methods used for the project were detailed in the project Quality Manual. Precision, accuracy and methods detection limits are listed below (**Tables 1** and **2**).

Table 1. Water Quality data quality objectives.

Analyte	Analytical Method	P	A	MDL
Alkalinity	SM 18 2320-B	15	88-108	1 mg/l
Chloride	SM 18 4500 Cl^- _B	5	92-108	1 mg/l
Fluoride	340.2/4500-F-C	30	85-115	0.044 mg/l
TSS	SM 18 2540-D	36	NA	2 mg/l
$TRCl_2$	SM 18 4500 Cl-B	9	NA	0.1 mg/l
Sulfate	SM 4500-SO_4^{2-}-E	30	75-125	1.7 mg/l
Turbidity	SM 18 2130-B	9	NA	0.2 mg/l
TKN	EPA1 351.2	18	86-119	0.05 mg/l
NH_4-N	SM 18 4500 –NH_3 H	20	86-113	0.005 mg/l
NO_{23}-N	EPA1 353.2	15	81-116	0.005 mg/l
TP	EPA1 365.4	13	80-111	0.05 mg/l
PO_4-P	SM 18 4500-P F	15	87-115	0.005 mg/l
Copper	Chelation/Extraction, 220.2	20	60-140	0.74 µg/l
Iron	6010(3010)	20	75-125	18 µg/l
Ra 226	EPA2 903.1	15.4	72-122	0.3 p Ci/l
Ra 228	EPA 600/4-75-008	13.9	79-122	1.0 p Ci/l
Gross Alpha	EPA2 900	27.0	68-132	0.5 p Ci/l

Table 2. Sediment Quality data quality objectives.

Analyte	Analytical Method	P	A	MDL
Cadmium	SW - 846 6010(3050)	20	75-125	0.087 mg/kg
Arsenic	SW - 846 6010(3050)	20	75-125	0.45 mg/kg
Barium	SW - 846 6010(3050)	20	75-125	0.16 mg/kg
Chromium	SW - 846 6010(3050)	20	75-125	0.17 mg/kg
Silver	SW - 846 6010(3050)	20	75-125	0.19 mg/kg
Nickel	SW - 846 6010(3050)	20	75-125	0.43 mg/kg
Lead	SW - 846 6010(3050)	20	75-125	0.42 mg/kg
Selenium	SW - 846 6010(3050)	20	75-125	0.43 mg/kg
Copper	SW - 846 6010(3050)	20	75-125	0.72 mg/kg
Iron	SW - 846 6010(3050)	20	75-125	4.5 mg/kg
H_2S	SW - 846 9030	50	50-150	2.0 mg/kg
TOC	SW - 846 9060	40	60-140	150 mg/kg
Particle Size	ASTM D-4464-8, C-1070-86	20	90-110	1 u

SW-846	Test Methods for Evaluating Solid waste Physical/Chemical Methods, EPA SW-846
SM18	Standard Methods for Examination of Water and Waste water, American Public Health Association, American Water Works Association, Water Pollution Control Federation, 18th Edition, 1992
EPA1	Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, 1979, revised March 1983
ASTM	"Annual Book of ASTM Standards" Volume 4.08, Soil and Rock, American Society for Testing and Materials, 1991
EPA2	EPA 600/4-80-032 Prescribed Procedures for Measurement of Radioactivity in Drinking Water

The determination of gross alpha in the presence of high dissolved solids (seawater) necessitates the use of a small sample volume with a consequent elevation in method detection limit (See, **Appendix C**). The radiological laboratory implemented a change in analytical method in July 2001, which resulted in detection limits elevated beyond the Class III criteria for marine waters for the samples with high dissolved solids. Since then, some of those samples from the September 2001 and January 2002 sampling were re-analyzed by the original method using archived sample fractions. Archived samples were not available for the July 2001 sampling. Results of the re-analysis reported in **Appendix Tables 24** and **27** revealed that the values are in accordance with the other sampling events for the respective stations. These re-analyzed values, although subject to alternate preservation or generated past allowed holding times, were used in generating the following figures.

V. RESULTS

In situ and water quality data for both pre- and post-restoration sampling efforts appear in **Appendix Tables 1** through **30**. Sediment grain size data are in **Appendix Tables 32** and **34**. Sediment metals data are in **Appendix Tables 31, 33** and **35** . These tables were compiled from data reports from the various laboratories. (Analytical reports are included as an **Appendix C** to this report). Sediment metal data from the pre-restoration sampling was reported on a wet weight basis and was adjusted to a dry weight basis before incorporation into **Appendix Table 31**. Both Hog and Palma Sola Creeks are tidal and displayed salinity gradients. Gradients were more pronounced at the Hog Creek site. The individual samplings were not tidally filtered. **Figure 2** illustrates the salinities (laboratory) for the pre- and post-restoration samplings of the stations on the two creeks. To account for varying saline influence at a given geographic location, analytical data were examined both as a function of station and as a function of salinity. The following figures illustrate the concentrations of pre- and post-restoration analytes by station and as a function of salinity. When a reported value for an analyte was below the detection limit, ½ of reported MDL value was used in preparing these figures. The sediment metal, TOC, sulfide and grain size data were examined both as bulk concentrations and normalized to the percent fine fraction since metals are typically associated with the finer fractions.

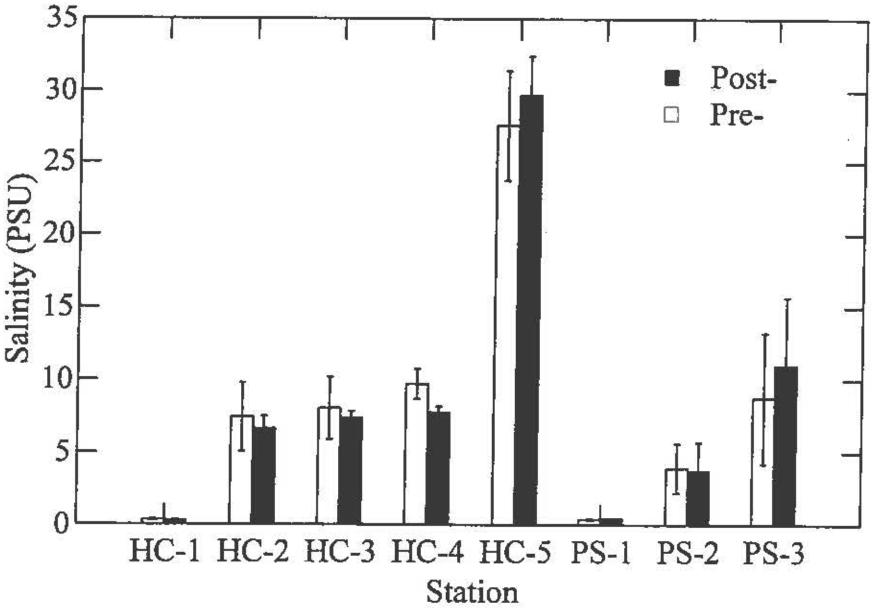

Figure 2. Mean salinities (laboratory) for Pre- and Post-restoration by station. Vertical bars indicate ± standard error of the mean.

VI. DISCUSSION

In situ measurements to determine station locations and measure water quality were performed approximately 20 cm below the surface. Analytical sample containers were filled using either an appropriately cleaned intermediate container or the sample container itself, by submerging the container to the same depth. At Stations PS-2, PS-3, and HC-4, the process of submerging the container or the *in situ* instrumentation would visibly disrupt the stratified layers of water, which at PS-2 and PS-3 ranged from 1 PSU at the surface to 30 PSU at depth. Even simultaneous filling of containers generated very different salinity values under these conditions. In order to eliminate this problem, on July 10, 2001 sampling, at stations PS-2 and PS-3 instrument measurements were made and samples were collected from well-mixed station water in clean buckets. The field and laboratory salinity data for this sampling are in **Appendix Table 19**. During other samplings, where an intermediate bucket had not been used there was a varying degree of difference between field and lab salinity values. The field and laboratory salinity data of the attached tables illustrate the range of salinity data possible at a given station. At all of the stations except PS-1 and HC-1 there was some degree of salinity stratification during all samplings. As evidenced by the lab and field measured salinities, stratification at PS-2 was particularly marked.

During the sampling events, flows in Hog Creek were always higher than those of Palma Sola Creek. There was no water present at HC-1 at some samplings. Even when water is present at HC-1, there was no detectable surface flow from HC-1 to HC-2, indicating that flows in Hog Creek were mainly from the discharge at HC-2. It appeared that the water quality at HC-1 had little influence on the water quality beyond station HC-2 of the creek. No storm events were sampled when the influence of HC-1 waters might have been greater.

The pre- and post–restoration flows for Hog Creek remained about the same. Flows at HC-2 were higher during dry weather samplings than during those of the wet weather. Salinity at HC-1 was consistently low; the salinity of the reverse osmosis discharge to Hog Creek was 3-11 PSU and displayed a slight increasing gradient between HC-2 and HC-4. Once in Sarasota Bay, Hog Creek discharges were subject to increased dilution and Station HC-5 evidenced a dramatic increase in salinity. Pre- and post-restoration salinity gradients in Hog Creek were comparable and would be expected to be larger if flows from HC-1 had been greater. It appears that, based on the tidal and flow conditions sampled, restoration has not increased the variety or range of low salinity habitat available, but has increased the overall area of low salinity habitat.

Salinity in Palma Sola Creek ranged between 0.5 and 23 PSU, but stratification made these measurements extremely variable. Tidally unfiltered gradients were comparable between pre- and post-restoration samplings indicating that a general climatic and flow conditions were comparable over the course of the study. Gradients as illustrated for Palma Sola stations, however, can be misleading since PS-2 was established based on salinity rather than on geographic location. (During some samplings, combined with the high flow and the low tide, the station PS-2 (~10 PSU), was located downstream of station PS-3.)

Dissolved oxygen (DO; **Figure 3**) displayed extreme maxima and minima at Station HC-1. Minima below marine Class III instantaneous criteria of 4.0 mg/l were also frequently noted at the Palma Sola stations. The central Hog Creek stations were typically between 5.0 and 7.0 mg/l, and declined with distance downstream. Both HC-5 and PS-3 recorded concentrations of DO higher than the upstream stations, perhaps in response to decreased canopy cover and/or increased turbulence and mixing.

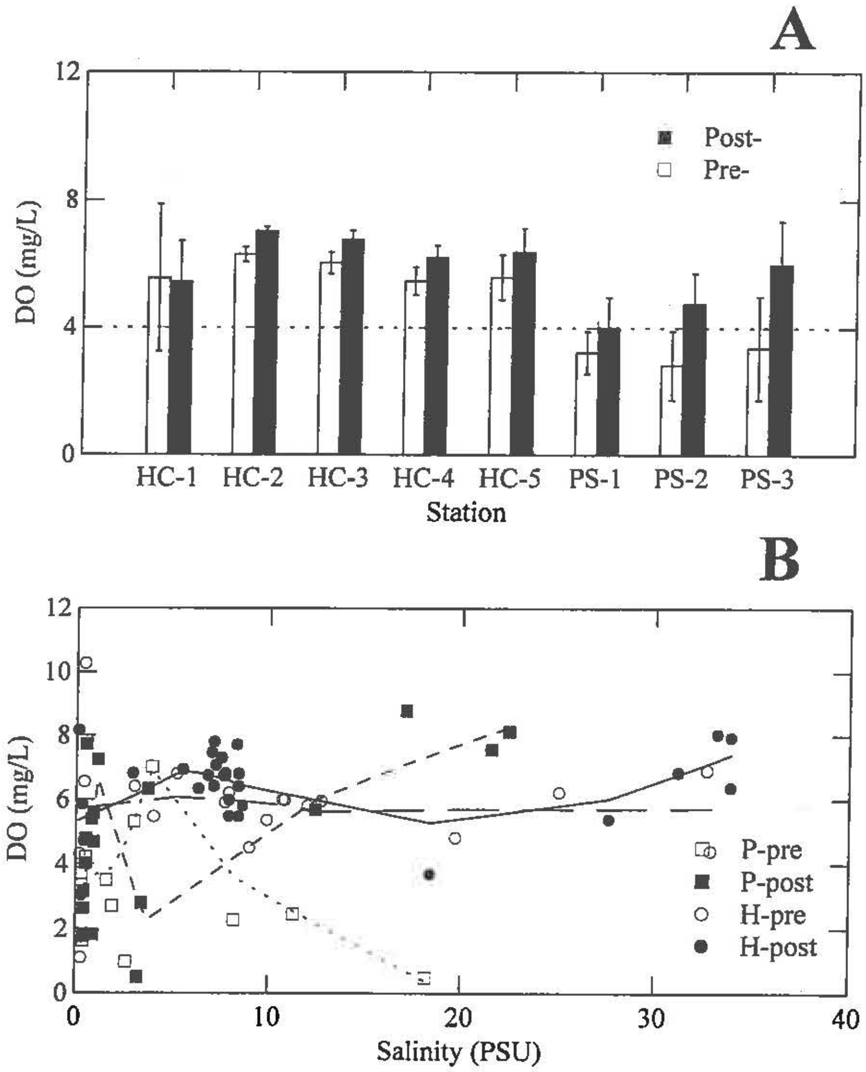

Figure 3. A (Top) Mean dissolved oxygen concentration for pre- and post-restoration by station (Class III marine instantaneous criteria = 4.0 mg/L). B (Bottom) Dissolved oxygen concentration as a function of salinity; LOWESS (Locally Weighted Scatterplot Smooth) lines: solid- Hog-post; large dash-Hog-pre; medium dash- Palma Sola-post; fine dash - Palma Sola-pre.

Hog Creek stations HC-2, HC-3, and HC-4 showed substantively higher concentrations of gross alpha radioactivity (**Figure 4**) and ^{226}Ra (radium) with slightly higher levels of ^{228}Ra (**Figure 5**). A number of the HC-2 and HC-3 samples (both pre- and post-restoration) exceeded marine Class III criteria of 15 pCi/L for gross alpha. All HC-2 and HC-3 samples (both pre- and post-restoration) exceeded the marine Class III criteria of 5 pCi/L for ^{226}Ra plus ^{228}Ra (**Figure 6**). Palma Sola stations were uniformly low for all radiological parameters, at concentrations comparable with HC-1 and HC-5. Post-restoration concentrations for gross alpha radiation at HC-2 and HC-3 were only slightly lower than those from pre-restoration samples. As HC-2 is almost exclusively the reject reverse osmosis water , it is possible that feed water, plant operations, or percentage of reject have altered somewhat.

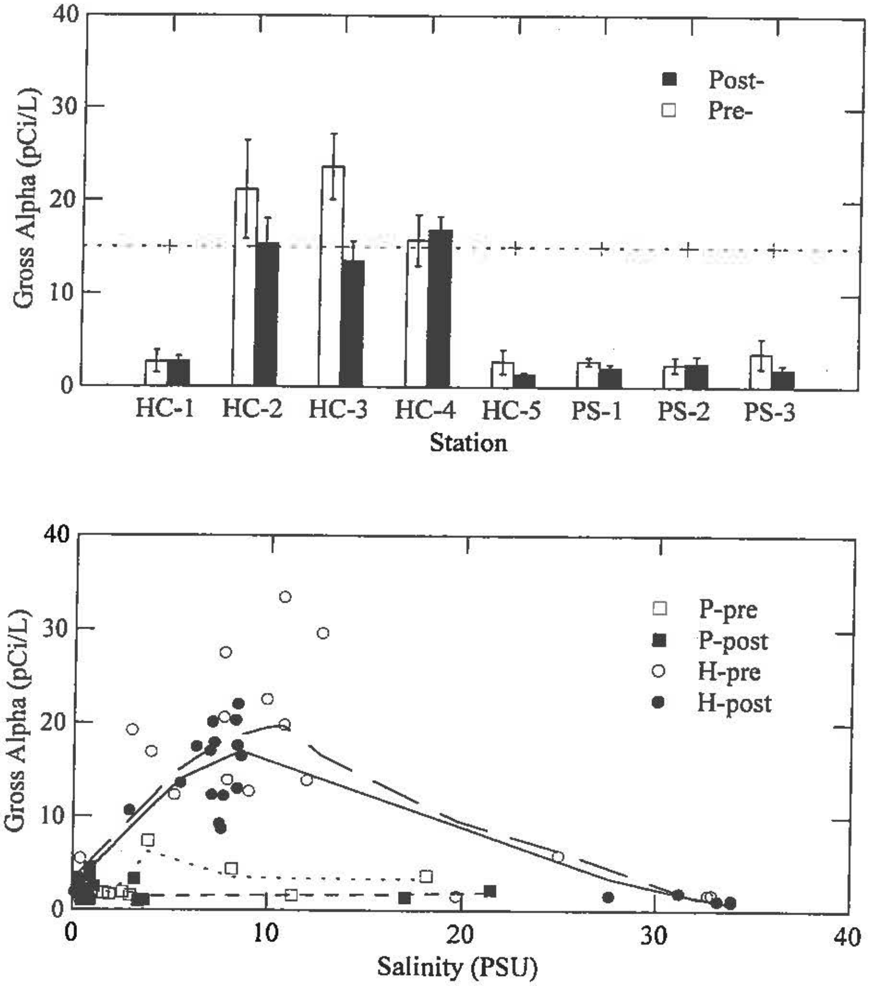

Figure 4. A. Mean gross alpha concentration for pre- and post-restoration by station (Class III marine criteria = 15 pCi/L). B. Gross alpha concentration as a function of salinity - symbol lines are as in Figure 3.

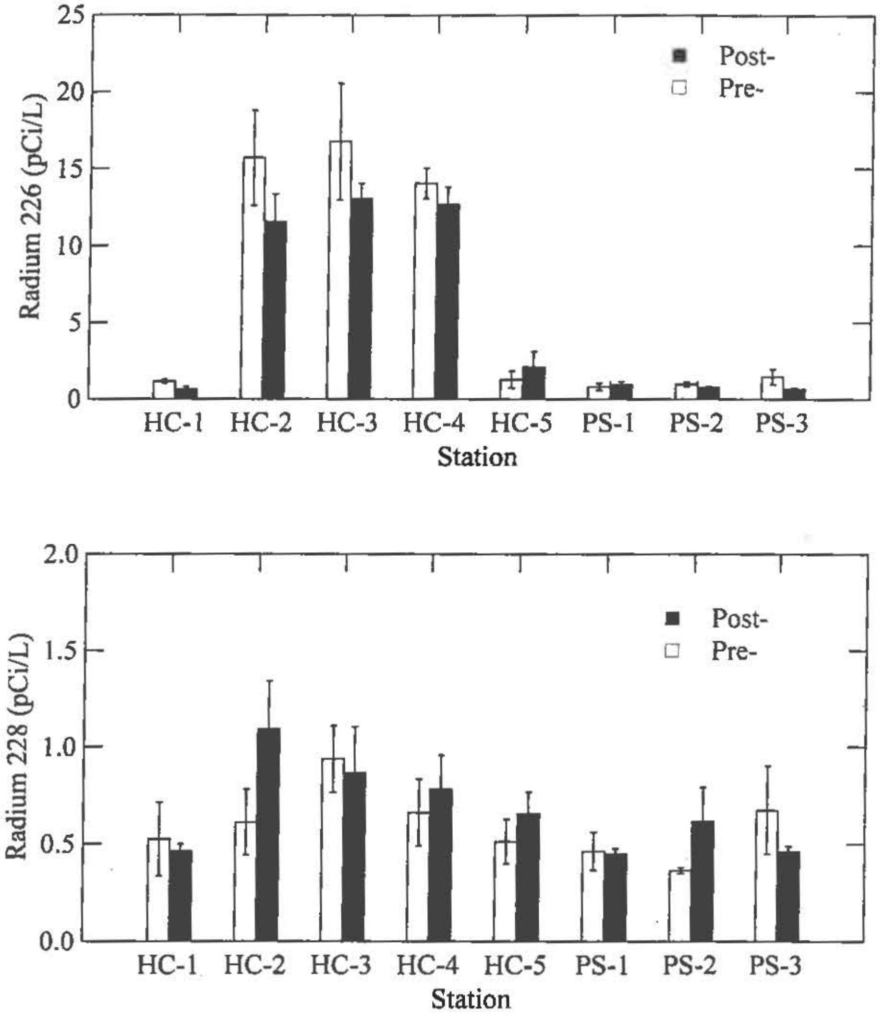

Figure 5. A. Mean radium 226 concentration , and B. mean radium 228 concentration for pre- and post-restoration by station.

Relationships of gross alpha and ^{226}Ra plus ^{228}Ra as a function of salinity also appear in **Figures 4** (above) and **6** (below). Individual data points are shown together with a locally weighted scatterplot smooth (LOWESS) curve indicating the general tendency of the data. The curves illustrate both the differences between Hog and Palma Sola Creeks, as well as indicating little change between pre- and post-restoration conditions for either gross alpha or the combined radium species.

Pre-restoration conditions in Hog Creek did record the highest concentrations of both analytes. (It is unknown how much seasonal or inter-annual variation in quality of reject water is typical.) Concentrations of both gross alpha and ^{226}Ra plus ^{228}Ra at HC-5 did converge to the level of the most saline Palma Sola station.

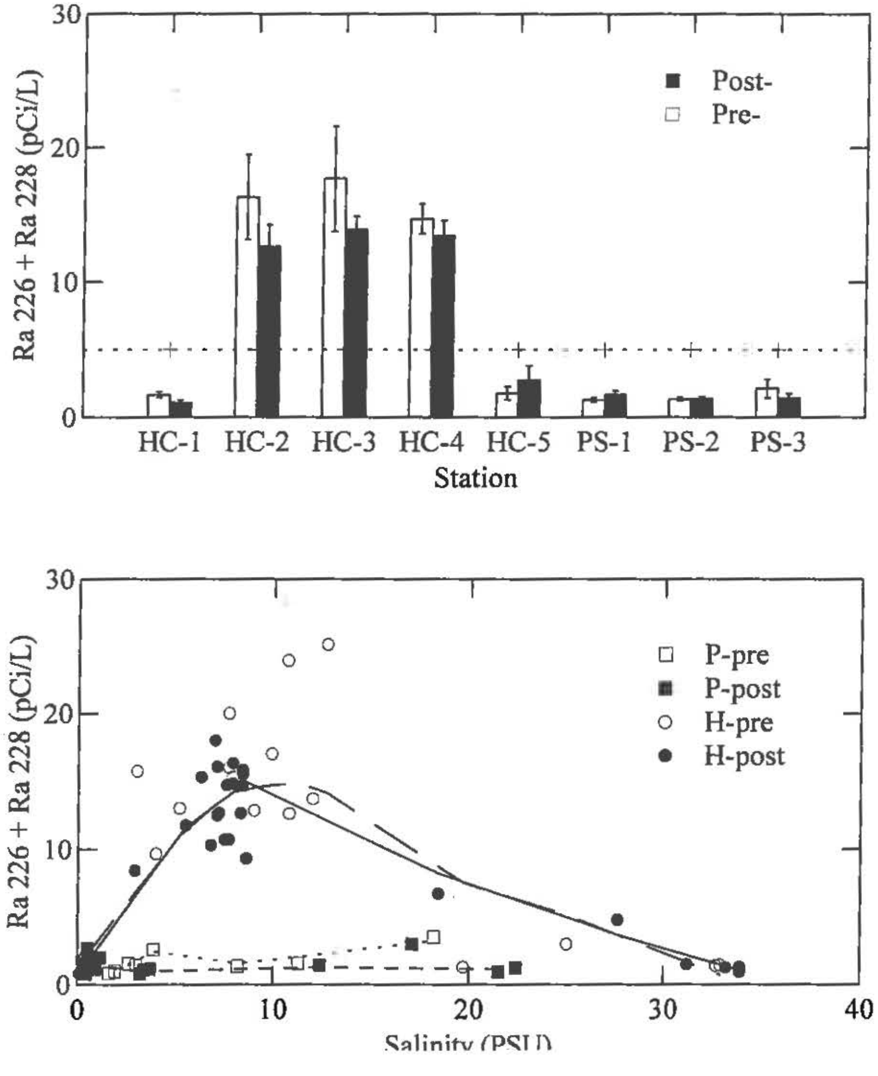

Figure 6. A. Mean radium 226 plus radium 228 concentration for pre- and post-restoration by station (Class III marine criteria = 5 pCi/L). B. Radium 226 plus radium 228 concentration as a function of salinity - symbol lines are as in Figure 3.

Ammonia-nitrogen concentrations (NH_4-N; **Figure 7**) in Palma Sola were relatively uniform with respect to salinity. Before restoration, the Hog Creek stations downstream of the plant discharge (HC-2 to HC-3) had higher concentrations of ammonia-nitrogen than either the Palma Sola Creek stations or post-restoration values at the same stations. Changes in plant operation of feed water quality appear likely. Post-restoration values in Hog Creek HC-2 and HC-3 were comparable to Palma Sola creek, where there was little change over the sampling period. LOWESS measures of general tendencies ammonia as a function of salinity were lower for post-restoration Hog Creek than during either period for Palma Sola. Increased residence time due the larger mixing pool of Hog Creek may allow additional opportunities for biotic consumption of ammonium species. Ammonia-nitrogen concentrations at HC-1 were highly variable, and concentrations in Sarasota Bay (HC-5) the lowest observed.

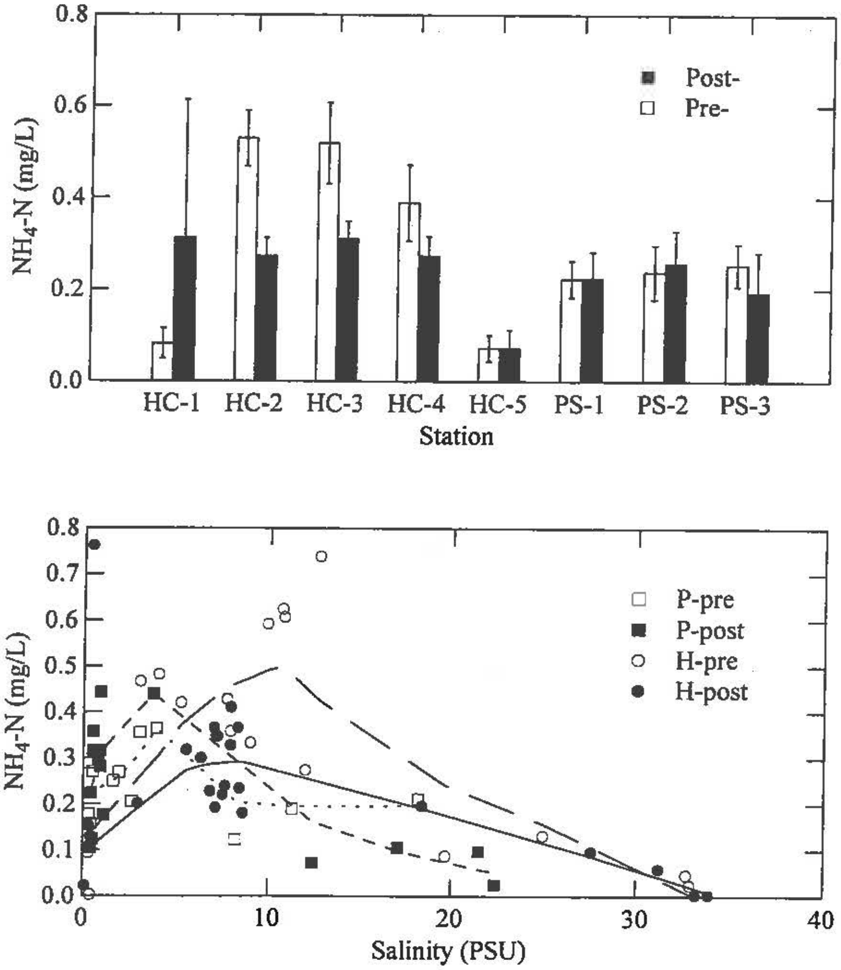

Figure 7. A. Mean ammonia -nitrogen concentration for pre- and post-restoration by station. B. Ammonia -nitrogen concentration as a function of salinity - symbol lines are as in Figure 3.

In contrast, nitrate nitrite-nitrogen (NO_{23}-N; **Figure 8 - top**) was always higher at Palma Sola Creek stations than between HC-2 to HC-5. (Station HC-1 evidenced an unusually high concentration of NO_{23}-N on one occasion that may be related to residential influences such as lawn fertilization. **Figure 8 - bottom**, is plotted without this outlier value.) The higher NO_{23}-N concentrations at Palma Sola may be the result of drainage from the Palma Sola golf course, which is irrigated with treated effluent. A increase in NO_{23}-N was noted at stations HC-2 to HC-4 between pre- and post-restoration. Both Palma Sola and Hog Creek samples converge to similar low values of NO_{23}-N at salinities of about 20 PSU and above. The salinity related gradients of NO_{23}-N are more pronounced for the Palma Sola stations.

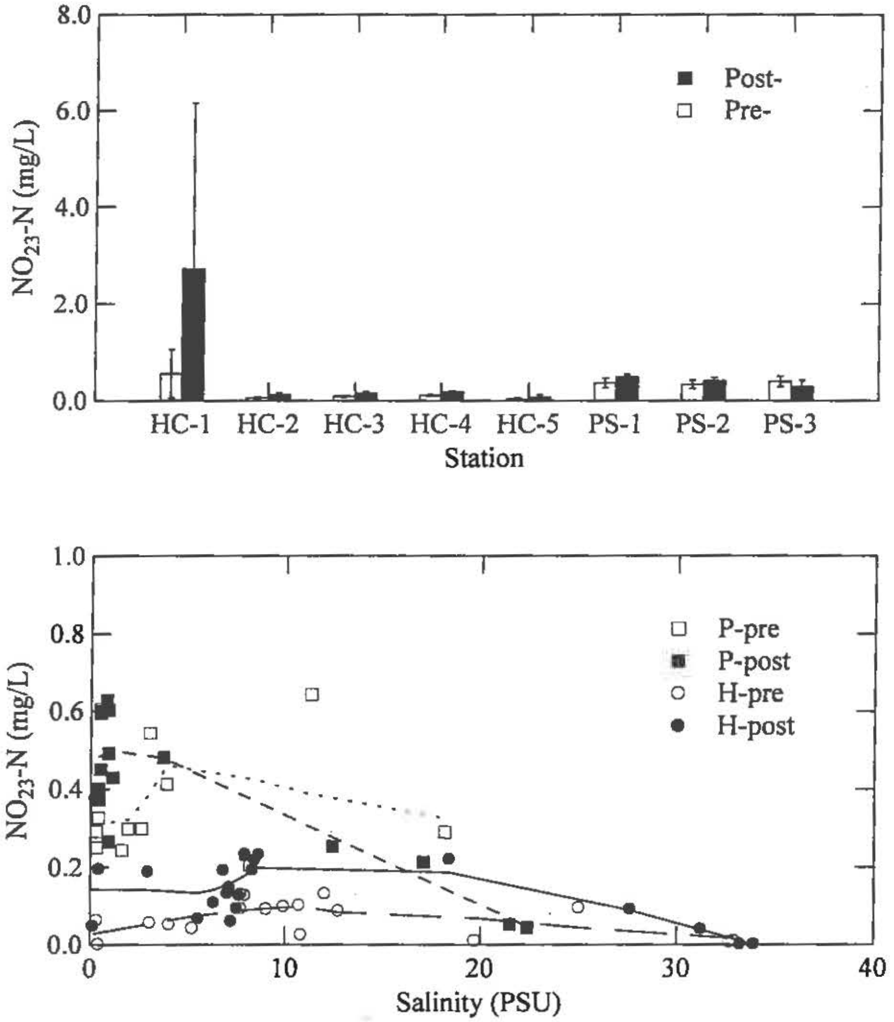

Figure 8. A. Mean nitrate nitrite-nitrogen concentration for pre- and post-restoration by station. B. Nitrate nitrite-nitrogen concentration as a function of salinity - symbol lines are as in Figure 3.

Total Kjeldahl Nitrogen (TKN; **Figure 9**) was also elevated at the Palma Sola stations and displayed little salinity dependence at either Hog or Palma Sola Creeks. A slight decrease in TKN was noted at the central stations of Hog Creek following restoration; decrease being higher at the upper stations.

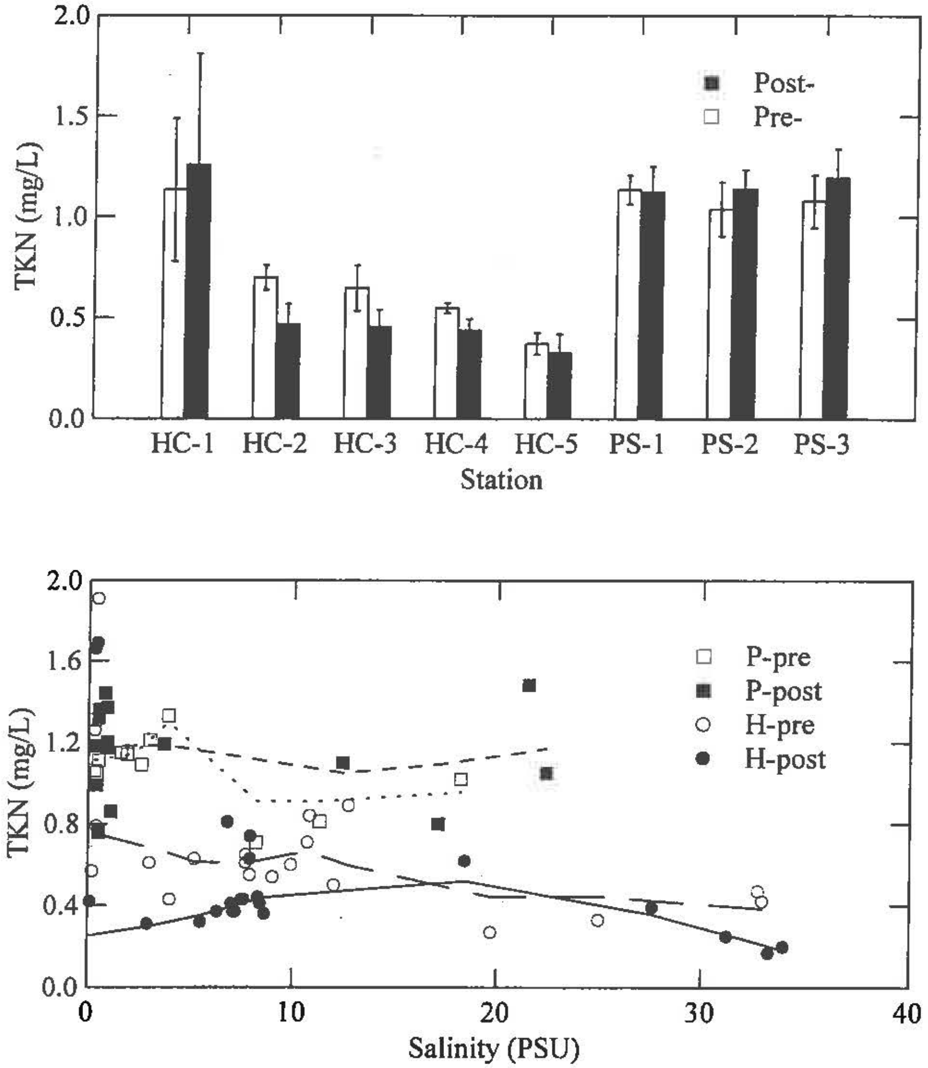

Figure 9. A. Mean total Kjeldahl nitrogen concentration for pre- and post-restoration by station. B. Total Kjeldahl nitrogen concentration as a function of salinity - symbol lines are as in Figure 3.

Before restoration, orthophosphate-phosphorus concentrations (PO_4-P; **Figure 10**) at central Hog Creek stations were lower than those at the Palma Sola creek. The higher concentrations at Palma Sola may again be a result of drainage from Palma Sola golf course. The post-restoration concentrations at central Hog stations were elevated almost three times, were most pronounced at HC-4, and all were higher than the Palma Sola concentrations. The increase was not attributable to water quality at HC-1 which remained similar for orthophosphate. As HC-2 represented the reject discharge almost exclusively, it was again likely that feed water quality or plant operations have changed. There was little change between pre- and post-restoration time periods for the Palma Sola stations. Increased levels of PO_4-P with distance downstream indicate that the restoration area (both before and after restoration) contribute PO_4-P to the water column. Dilution again reduces PO_4-P at HC-5 to low levels and relationships of PO_4-P with salinity converge for both Palma Sola and Hog Creeks.

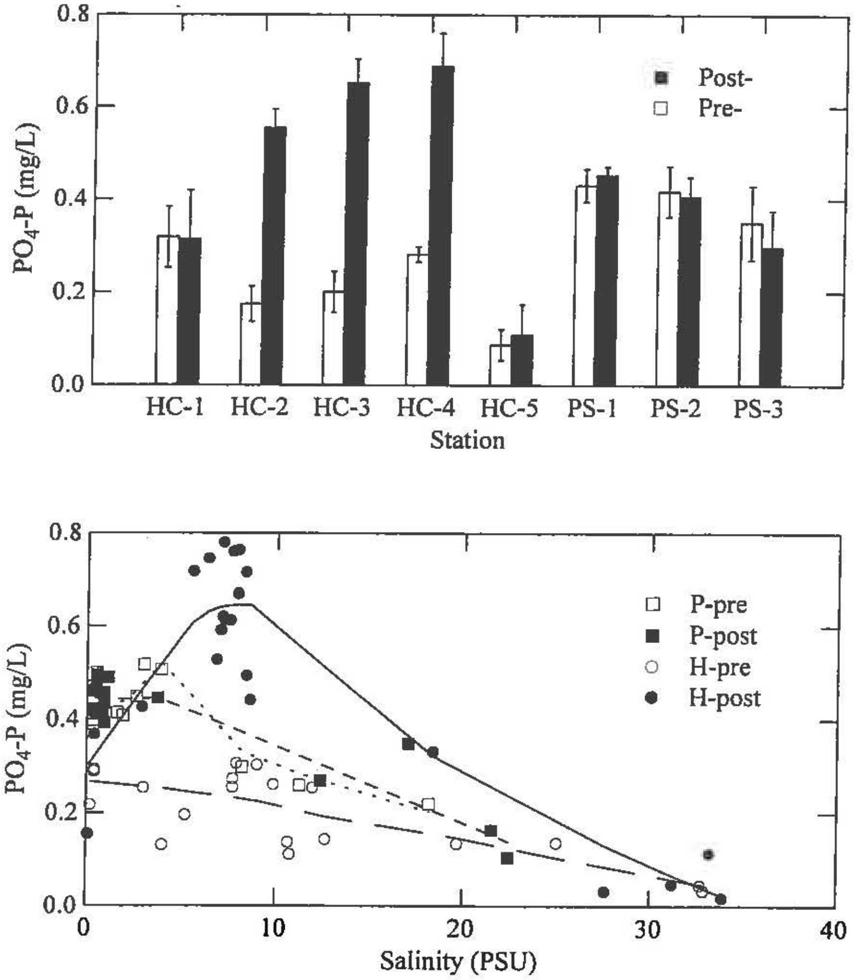

Figure 10. A. Mean orthophosphate-phosphorus concentration for pre- and post-restoration by station. B. Orthophosphate-phosphorus concentration as a function of salinity - symbol lines are as in Figure 3.

The total phosphorus concentrations however, of the central stations of Hog Creek (HC-2, HC-3 and HC-4) were all similar to one another and much higher than those of the HC-1, HC-5 or the Palma Sola Creek stations (**Figure 11**). The post-restoration concentrations at Hog Creek are slightly lower, the decrease is especially noted at HC-2 and HC-3, while the Palma Sola stations showed little change over time. The Palma Sola stations exhibited little salinity dependence, while the higher salinities at HC-5 apparently resulted in more dilution of total phosphorus and a resulting salinity dependence. Again total phosphorus concentrations of the two creeks converge at higher salinities. Ratios of total nitrogen to total phosphorus (TN:TP; **Figure 12**) show little change from pre- to post-

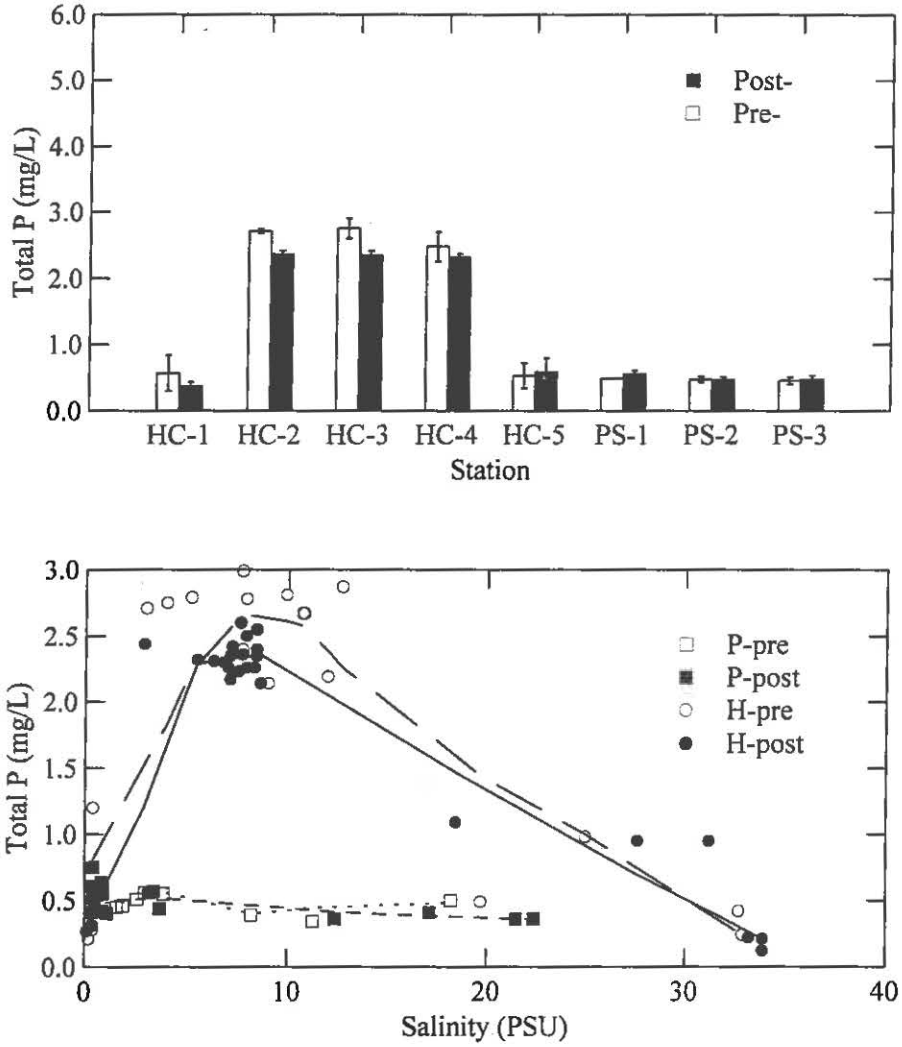

Figure 11. A. Mean total phosphorus concentration for pre- and post-restoration by station. B. Total phosphorus concentration as a function of salinity - symbol lines are as in Figure 3.

restoration time periods in either creek. Almost all values are below 7.2 mg:mg, indicating a nitrogen limited system. Due to the elevated phosphorus concentrations in Hog Creek, TN:TP ratios were even lower there, except at HC-1 where high nitrate-nitrite-nitrogen levels increased the ratios.

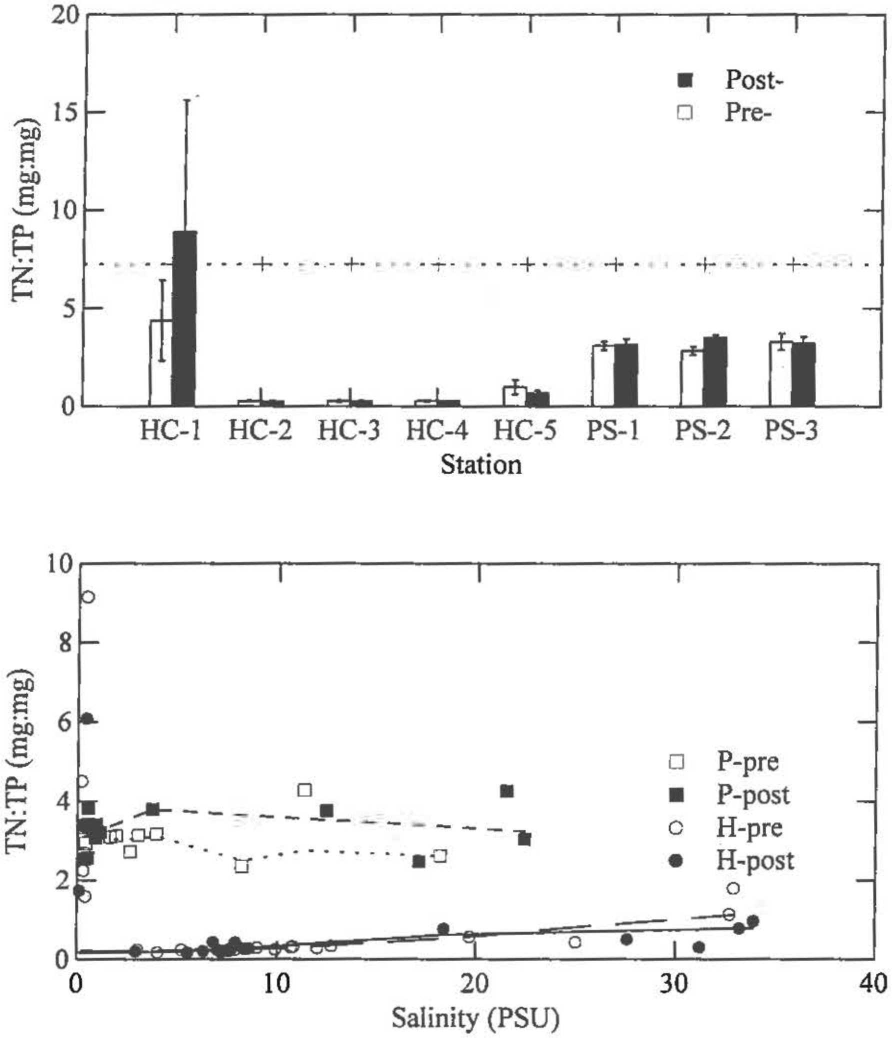

Figure 12. A. Mean total nitrogen : total phosphorus for pre- and post-restoration by station. B. Total nitrogen : total phosphorus as a function of salinity - symbol lines are as in Figure 3.

Sulfates (SO_4), with higher concentrations in seawater, exhibit reverse gradients when compared to nutrient data and should exhibit nearly linear increases with salinity. While sulfate concentrations (**Figure 13**) at high and low salinities are comparable for Hog and Palma Sola Creeks, and for both pre- and post-restoration, the central Hog Creek stations have sulfate concentrations elevated above that expected for the observed salinities. Stations HC-2, HC-3 and HC-4 were higher than the equivalent Palma Sola Creek stations. Concentrations at HC-5 are near the oceanic average values of 2700 mg/L and where one would expect based on a linear extrapolation of the Palma Sola SO_4:salinity relationship. Differences between pre- and post-restoration for both creeks were generally not noteworthy.

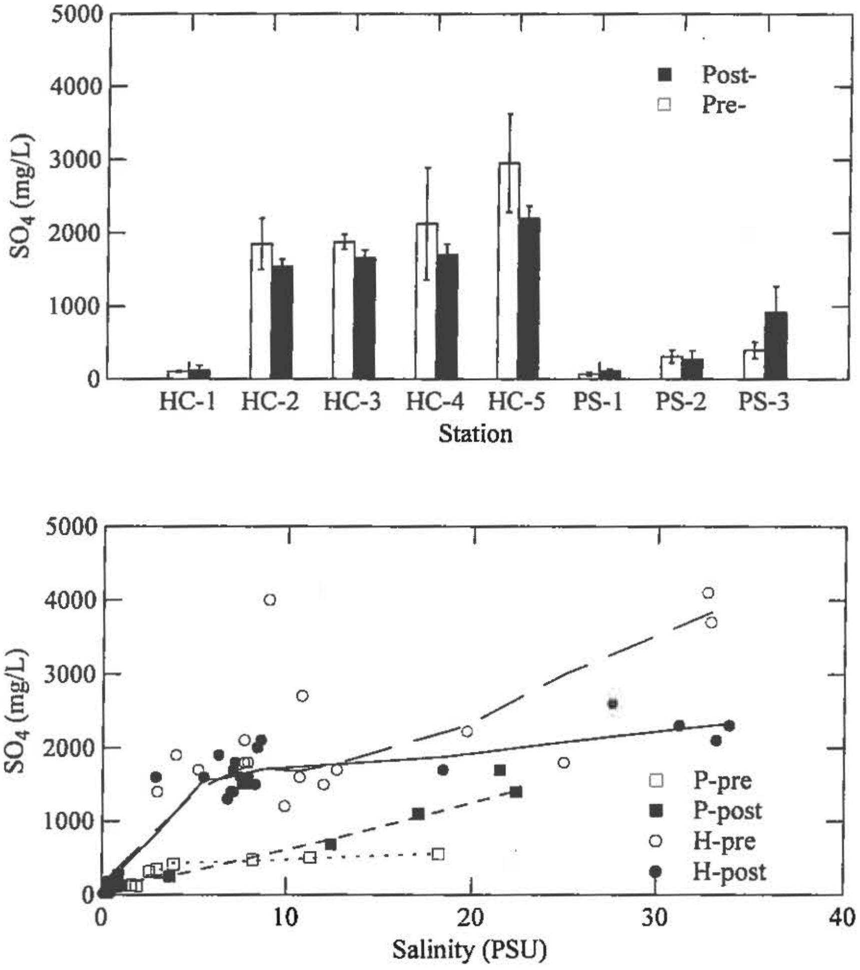

Figure 13. A. Mean sulfate concentration for pre- and post-restoration by station. B. Sulfate concentration as a function of salinity - symbol lines are as in Figure 3.

As a result of the elevated SO_4 concentrations, the chloride:sulfate rations ($Cl:SO_4$) of the central Hog Creek stations were smaller than for the comparable salinities at the Palma Sola stations (**Figure 14**). Again pre- to post-restoration differences were generally not noteworthy. The ratios at PS-1 were larger than at HC-1 and were attributable to elevated chloride concentrations that are characteristic of treated domestic wastewater and to the overall low concentration of ions at these two stations. A number of the pre-restoration samples from Palma Sola Creek were complicated by the intense statification at this site. Sample fractions were such that chloride and laboratory salinity were analyzed from one container, and sulfate from another. Discrepancies in water masses samples between the two containers resulted in higher than normal $Cl:SO_4$ ratios for Palma Sola Creek. Later samples where an intermediate container was used, have similar ratios of $Cl:SO_4$ for both PS-3 and HC-5 and both near the oceanic mean of 7.2.

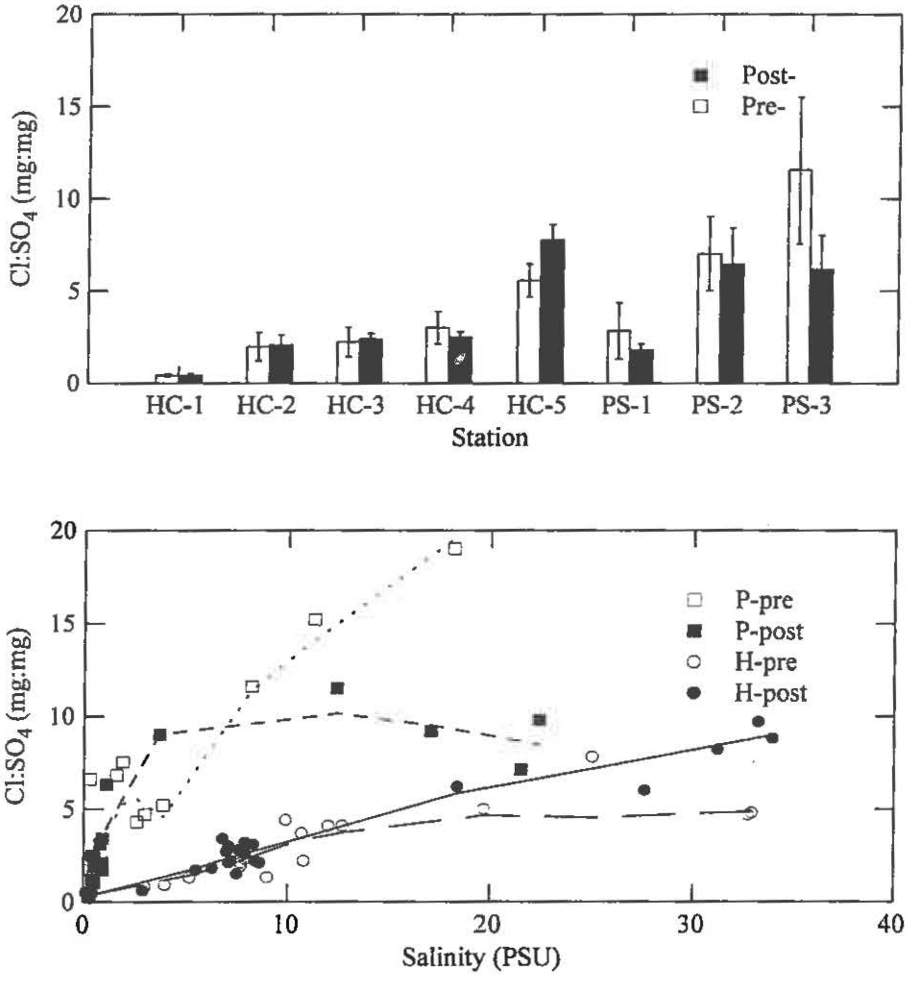

Figure 14. A. Mean chloride : sulfate for pre- and post-restoration by station. B. Chloride : sulfate as a function of salinity - symbol lines are as in Figure 3.

Fluoride concentrations (**Figure 15**) were remarkably stable over the study period at all sites. The central Hog Creek stations were elevated due to the reject water and were higher than those of Palma Sola Creek, but all were lower than the Class III marine criteria of 5 mg/L. The concentrations declined with an increase in salinity at Hog Creek and increased with increasing salinity in Palma Sola Creek. Both creek systems converge to similar values at higher salinities.

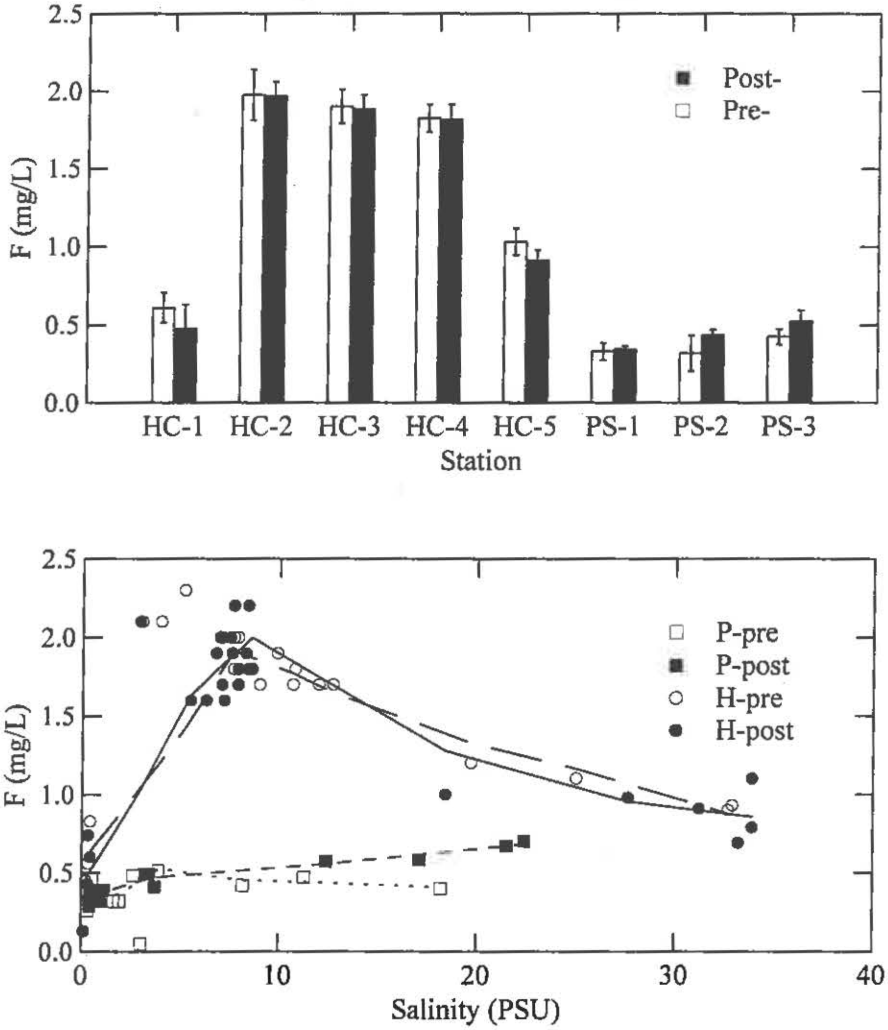

Figure 15. A. Mean fluoride concentration for pre- and post-restoration by station. B. Fluoride concentration as a function of salinity - symbol lines are as in Figure 3.

Alkalinity (**Figure 16**) was depressed at the central Hog Creek stations, below both HC-1 and all the Palma Sola stations. Post-restoration values at HC-2 to HC-4 were lower than pre-restoration values implying a change in plant operation and little attenuation within the creek itself. Values of alkalinity from both creek systems converged at higher salinities.

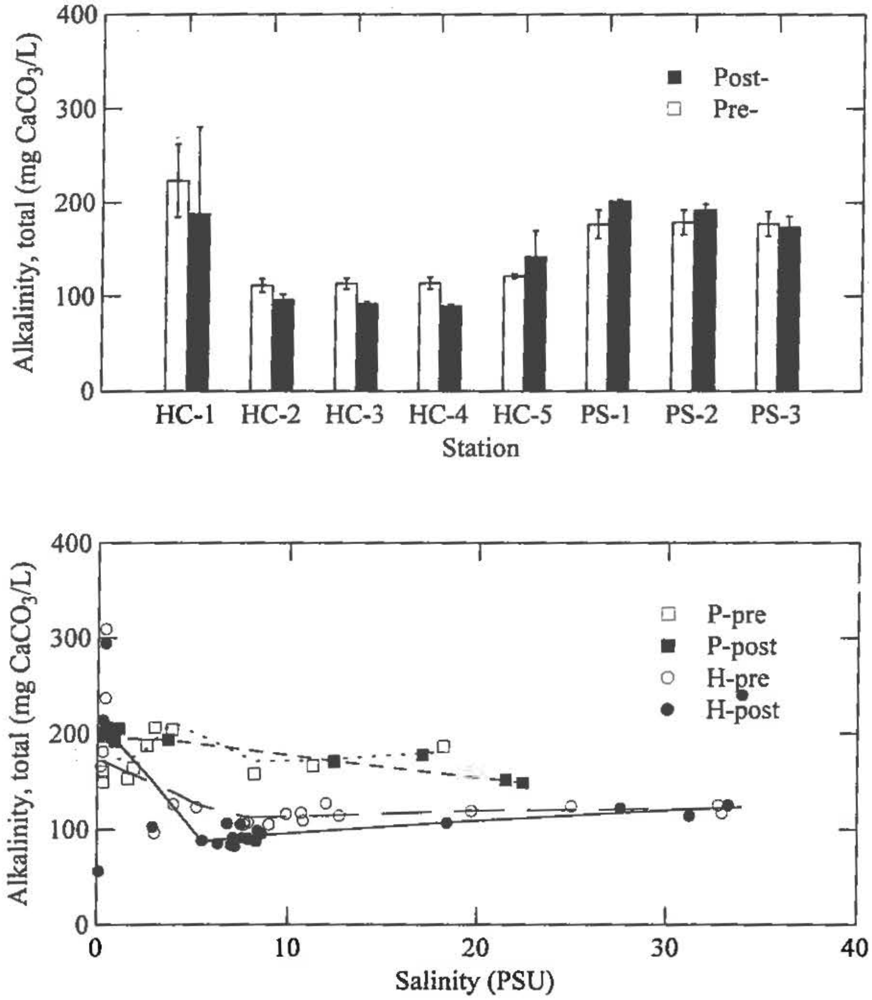

Figure 16. A. Mean total alkalinity concentration for pre- and post-restoration by station. B. Total alkalinity concentration as a function of salinity - symbol lines are as in Figure 3.

All of the stations, had concentrations exceeding the Class III marine criteria of 2.9 mg/L for copper (Cu; **Figure 17**). There was little salinity dependence for either creek and salinity relationships were generally comparable between systems at the higher salinity values. Palma Sola Creek, Stations PS-1 and PS-2 had particularly elevated copper concentrations during the pre-restoration period. Copper is again a common contaminant in treated domestic wastewater.

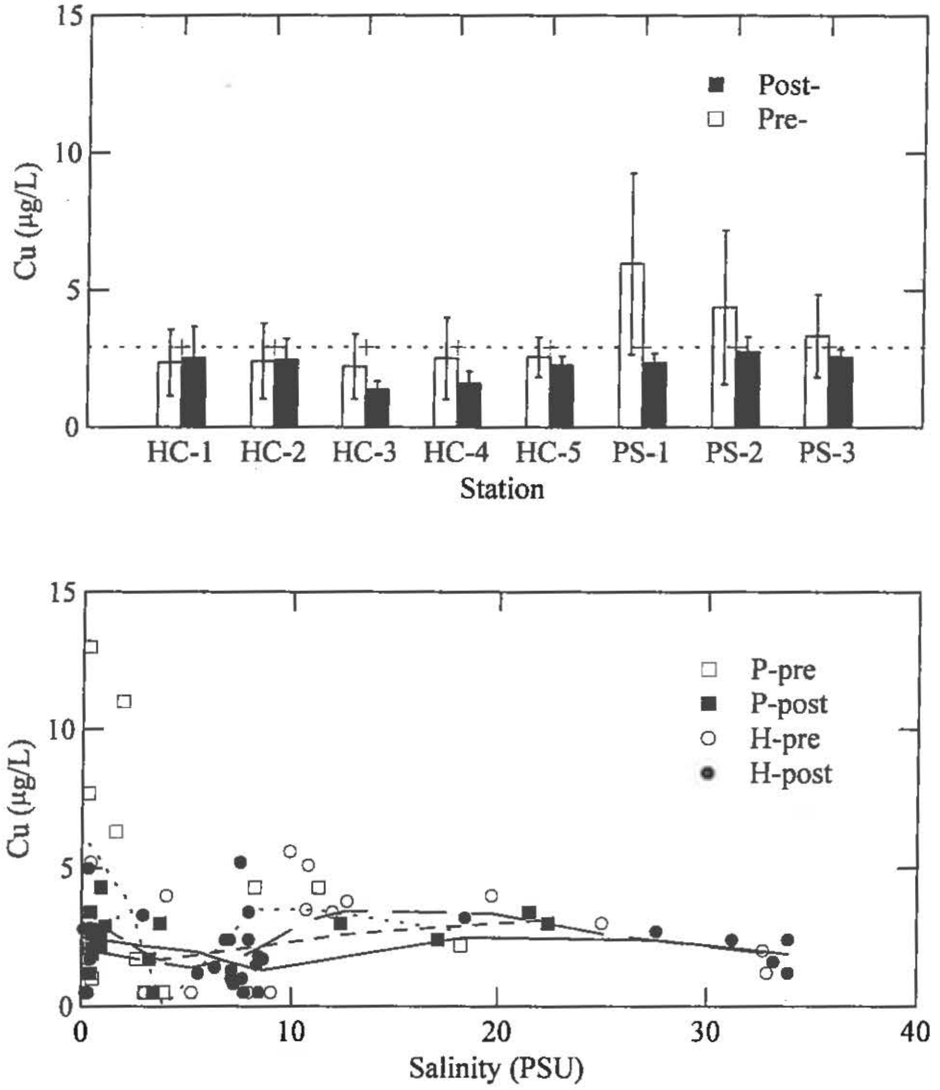

Figure 17. A. Mean copper concentration for pre- and post-restoration by station (Class III marine criteria = 2.9 µg/L). B. Copper concentration as a function of salinity - symbol lines are as in Figure 3.

Iron concentrations (Fe; **Figure 18**) generally declined between pre- and post-restoration periods, particularly for the Hog Creek stations. Declines again appear related to plant operations. Interestingly, levels increased with increasing salinity and based on the Fe:salinity relationships, there was little difference between Hog and Palma Sola Creeks. Iron levels were depressed at HC-5 during a number of the post-restoration samplings and may reflect uptake by phytoplankton. Many samples were above the Class III marine criteria of 0.3 mg/L.

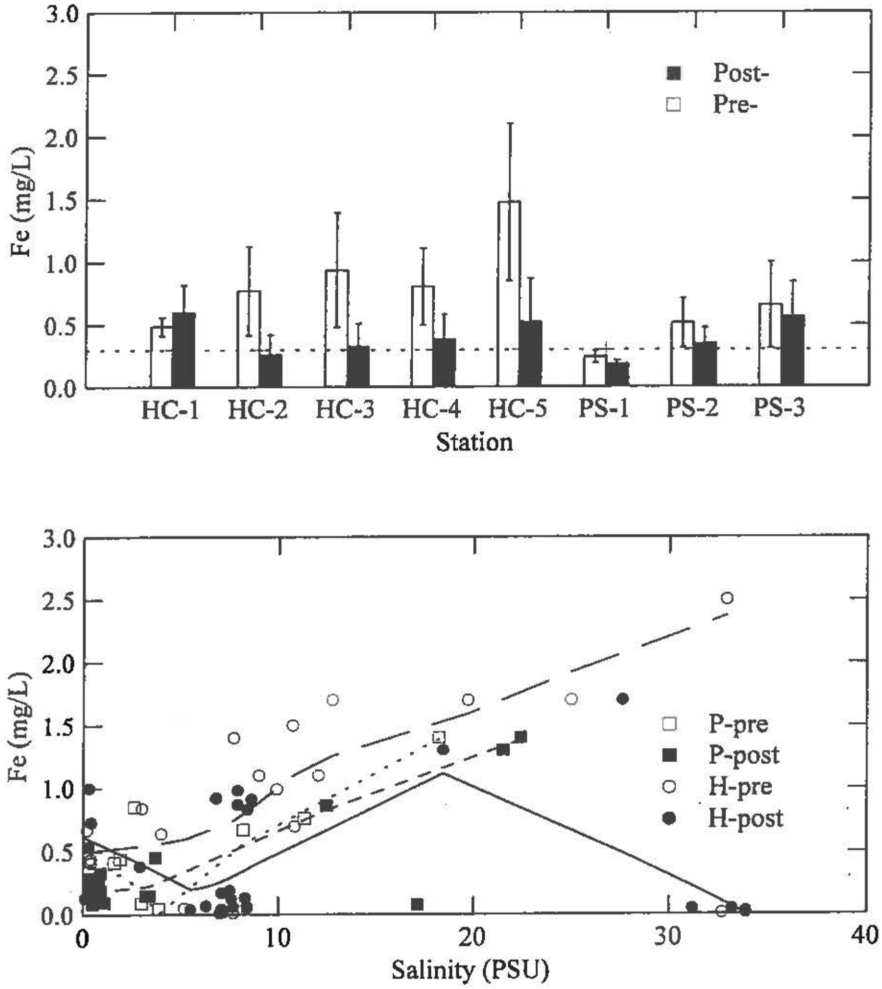

Figure 18. A. Mean iron concentration for pre- and post-restoration by station (Class III marine criteria = 0.3 mg/L). B. Iron concentration as a function of salinity - symbol lines are as in Figure 3.

As expected, turbidity and total suspended solids (TSS) were correlated, with small differences between creeks or between time periods. Individual stations demonstrated few changes between time periods and were limited to an increase at Stations HC-4 for both parameters following restoration. The location of this station indicates that the elevation could just as easily be from increased wave climate on the sampling date rather than from Hog Creek influences. Total sulfide and total residual chlorine concentrations in both creeks were low or below detection limits throughout the sampling.

Statistical tests of significant differences employed Kruskal-Wallis non-parameteric tests at 0.05 probability levels, evaluating whether changes in the central measure of rank had occurred between groups. Stations were pooled to evaluate the entire system. Pre- to post-restoration comparisons of Hog Creek evaluated stations HC-2 through HC-4 on the assumption that no alterations had been performed at HC-1 and that dilution with Sarasota Bay waters would overwhelm any changes attributable to restoration. This also provided a more comparable range in salinity between the two systems, minimizing differences due to different salinity regimes. Comparisons of post-restoration conditions between Hog Creek and Palma Sola also employed all Palma Sola stations and HC-2 to HC-4.

Pre- to post-restoration changes for the Hog Creek system as a whole and as observed and discussed above were as follows. Significant changes were slight decreases in salinity, declines in ammonium-nitrogen, total Kjeldahl nitrogen, total phosphorus, alkalinity, and iron , increases in dissolved oxygen, pH, nitrate-nitrite-nitrogen, orthophosphorus, and total suspended solids. Some of the changes, based on the change observed at Station HC-2, appear to reflect changes in plant operation rather than effects of the increased mixing area. Restoration and climatic variations between sampling periods has not significantly affected the system values of temperature, radiological parameters, turbidity, fluoride, chloride, sulfate, chloride:sulfate ratio, total residual chlorine, total hydrogen sulfide, despite apparent changes on the basis of individual stations.

Following restoration, Hog Creek stations were significantly different from the Palma Sola sites as follows; higher for gross alpha, and ^{226}radium and $^{226+228}$Radium, dissolved oxygen, total phosphorus, orthophosphorus, sulfate, and fluoride. Total residual chlorine values, while significantly higher are at or below detection limits for most analyses. Significantly lower values were obtained in Hog Creek for nitrate-nitrite-nitrogen, total Kjeldahl nitrogen, alkalinity, and copper. Comparable values in both systems were obtained for salinity, pH, temperature, total suspended solids, turbidity, total sulfide, ammonium nitrogen, iron, and CL:SO4 ratio,

Pre- restoration sediments were predominantly sandy (**Figure 19**); percent sand was highest under the high energy conditions of HC-2 and HC-3. Based on sand content, HC-4 experienced a reduction in energy, with a larger fraction of silts and clays at HC-5. Palma Sola sediments were also predominantly sandy, with a larger fraction of fines where the channel opened (PS-3). While high flows were not observed in Palma Sola Creek during any sampling, the coarse grain size indicates either occasional high flows or a lack of fines contributed to the system.

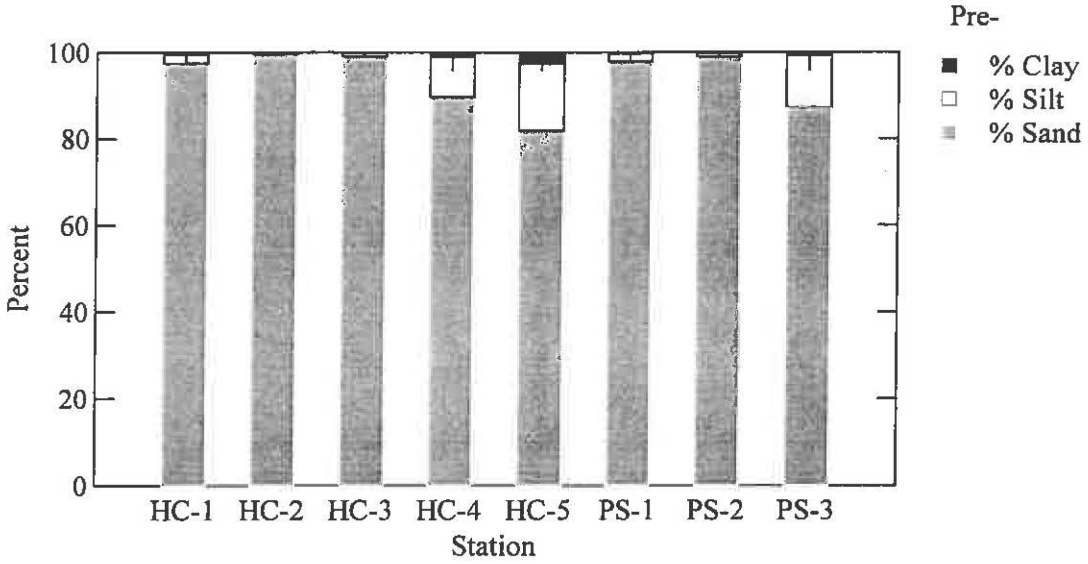

Figure 19. Percent particle size distribution - pre-restoration by station.

Following restoration (**Figure 20**), sediments at a number of stations had increased in the proportion of fine grain sized material. Changes in both creeks may be related either to construction activities and/or the relatively dry conditions experienced during the post-restoration time period. Enlargement of the mixing pool on Hog Creek created a lower velocity environment that would permit fine sediments to settle and accumulate, especially at HC-2 and HC-3. Increases in fines at HC-1, where restoration construction activities should be minimal, indicated that either watershed activities or system heterogeneity resulted in varying fines. In an area that should have been the most stable, HC-5, percent silt and clay fraction combined almost doubled. It is possible that construction or watershed activities contributed a thin veneer of fine sediment to the region.

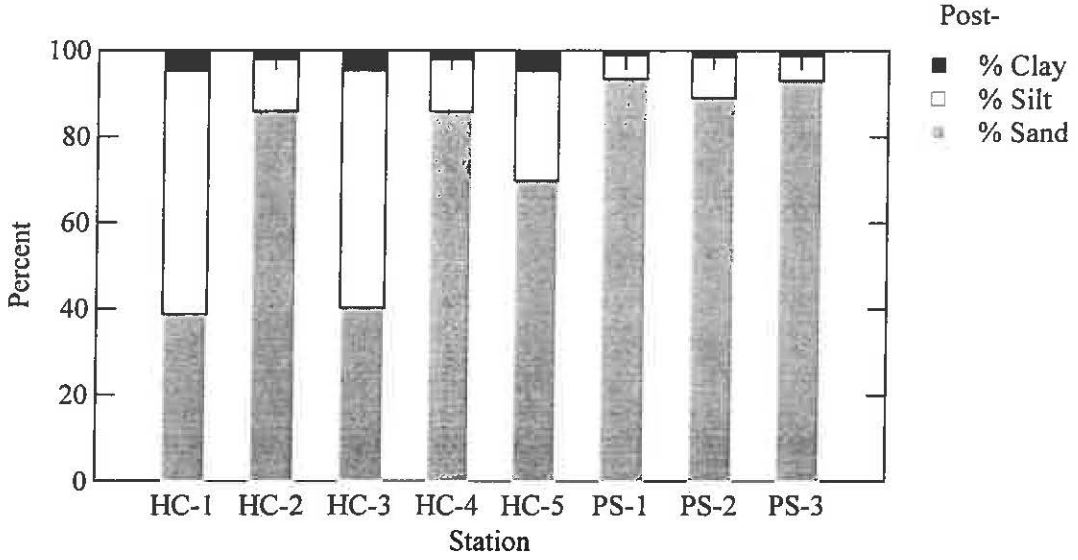

Figure 20. Percent particle size distribution - post-restoration by station.

At some stations (HC-1, HC-2, and HC-5), the increase in fines was accompanied by an increase in percent organics (**Figure 21**). Changes in organics at these three stations were greater than the increases observed in Palma Sola Creek. Similarly, total organic carbon (TOC; **Figure 22**) also increased at several stations, with increases at HC-2 and HC-4 greater than that observed in Palma Sola Creek. In particular, the high post-restoration TOC value at HC-4 indicates that some of the organic material present was of a relatively coarse size fraction and non-homogenously distributed. A plot of percent organics (**Figure 23**) as a function of percent silt-clay size fraction indicates that pre-restoration Palma Sola stations were roughly comparable to post-restoration values. Pre-restoration Hog Creek stations were relatively higher in percent organics than the Palma Sola stations of similar grain size distributions. Following restoration, the Hog Creek stations increased the percentage of fines without increasing the organic content, particularly for Station HC-3. The high organics at post-restoration HC-1 appears to be similar in ratio to the increase in fines observed. Changes in HC-1, therefore were attributed to sampling a heterogeneous environment, while changes at the lower Hog Creek stations were attributed to an increase in mineral fines in the sediments. This postulate is consistent with the exposure of a different, finer sediment during the excavation of the mixing pool.

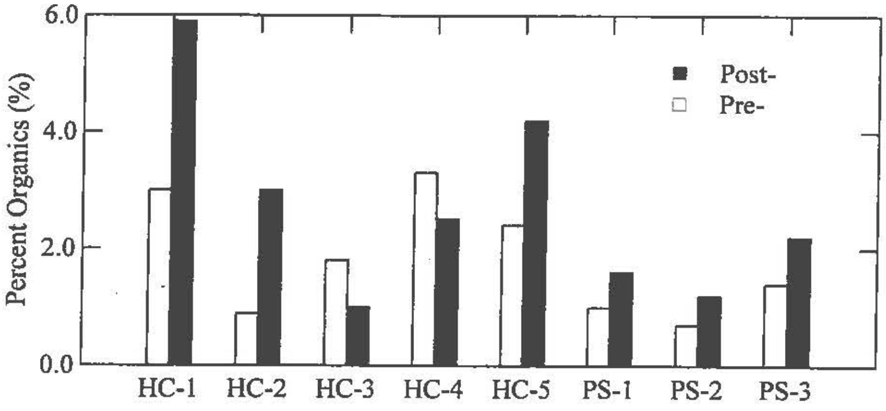

Figure 21. Percent organic content for pre- and post-restoration by station.

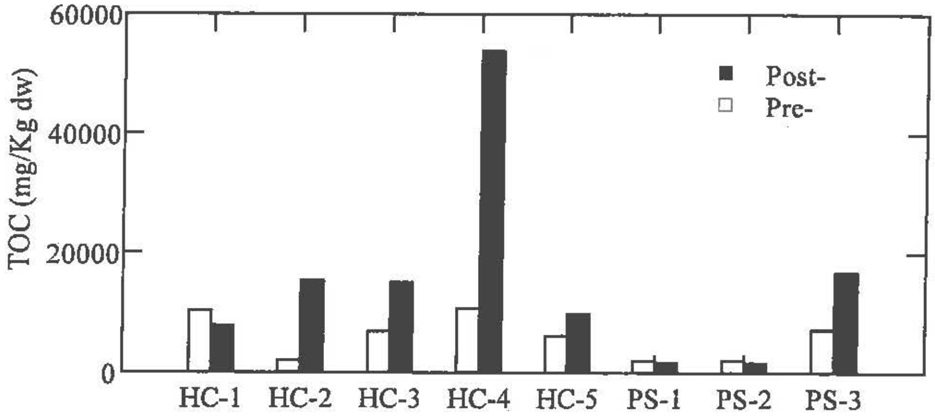

Figure 22. Total organic carbon content for pre- and post-restoration by station

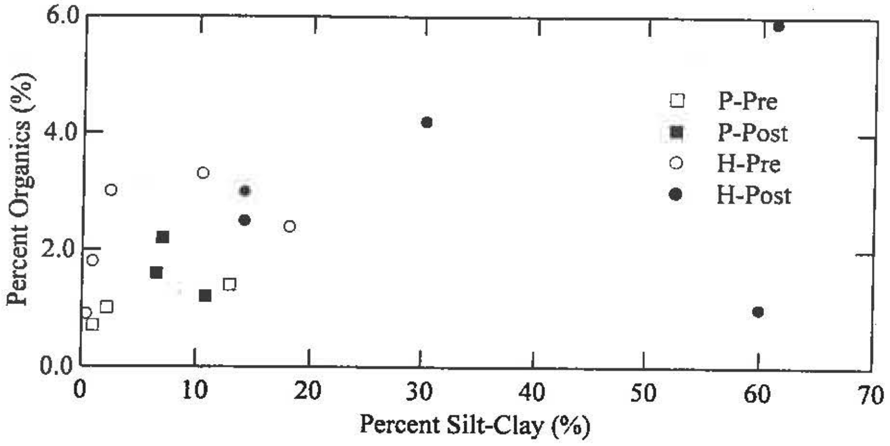

Figure 23. Percent organic content as a function of percent silt and clay for pre- and post-restoration.

The percentage of fines in a sample is closely linked to the energy of the benthic environment, and fines are often very heterogeneous even within constricted areas. As trace metals in sediments are generally preferentially associated with fine particles, the challenge becomes to interpret the bulk metal concentrations and to separate changes in metals concentrations from changes observed merely from differing proportions of fine grain sized material. Accordingly, sediment data illustrated below appears both as bulk concentrations, and normalized by the percentage of silt and clay in the sample. As grain size information was not part of the sampling program during the final post-restoration sampling, normalized data are limited to a single pre- and a single post-restoration observation per station.

For arsenic, lead, and copper, one station in Hog Creek would have a single elevated concentration indicating heterogeneous distribution. The elevated concentrations, however, were at different stations (HC-3 and HC-4) and during different time periods. In order to view the remaining stations, these elevated values were not illustrated in **Figure 24** through **33**.

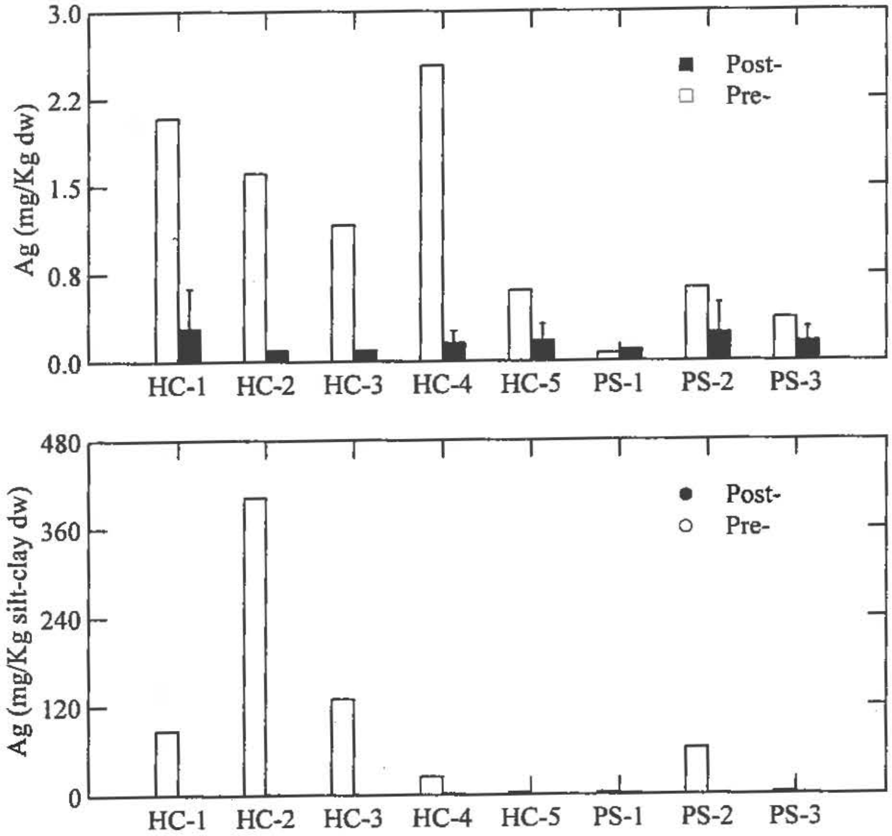

Figure 24. A. Bulk silver concentration for pre- and post-restoration by station. B. Silver content normalized by percent silt and clay for pre- and post-restoration by station.

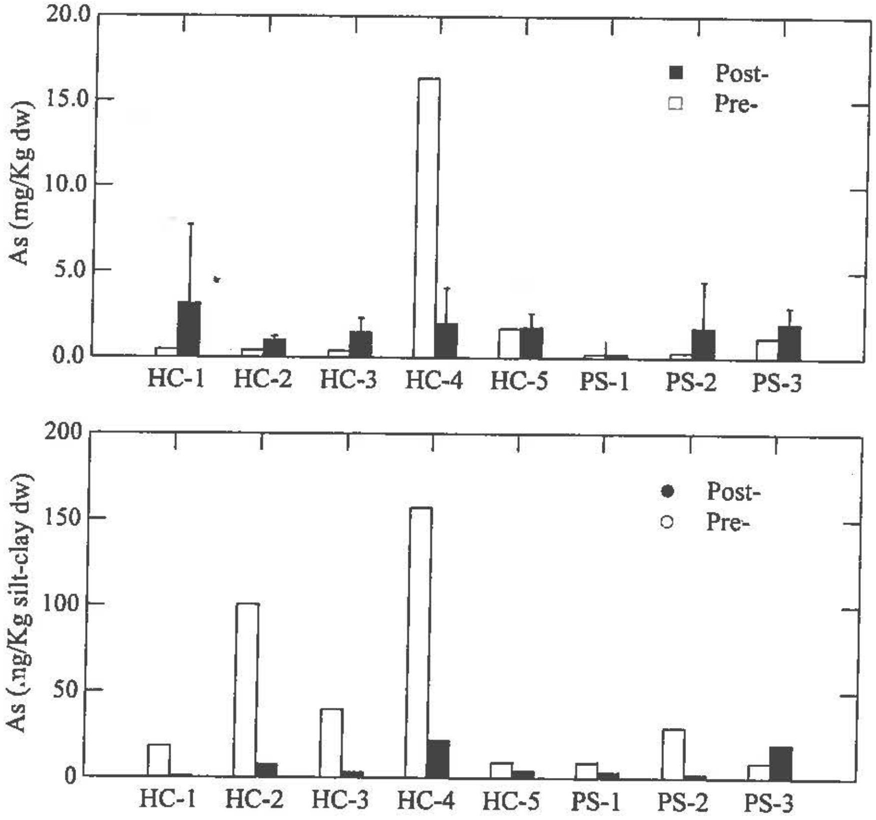

Figure 25. A. Bulk arsenic concentration for pre- and post-restoration by station. B. Arsenic content normalized by percent silt and clay for pre- and post-restoration by station.

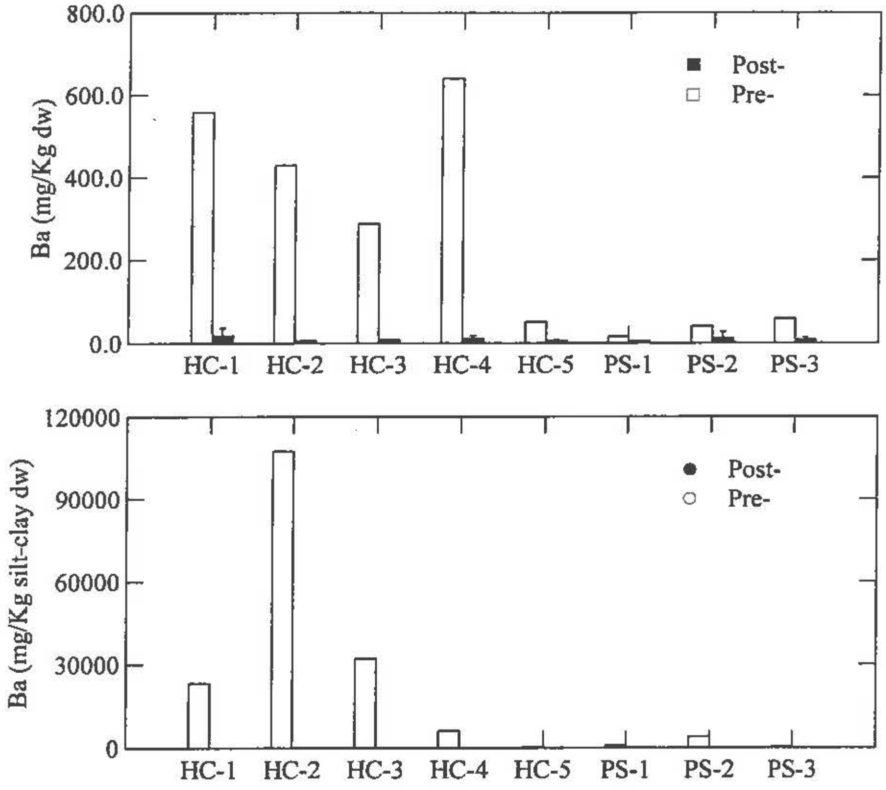

Figure 26. A. Bulk barium concentration for pre- and post-restoration by station. B. Barium content normalized by percent silt and clay for pre- and post-restoration by station.

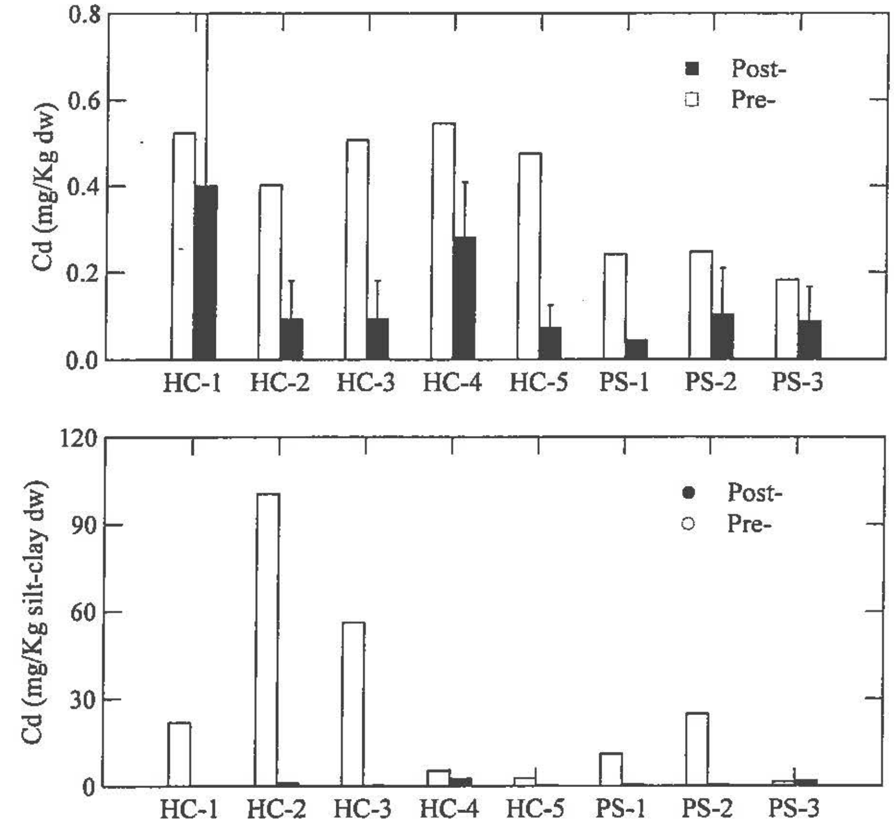

Figure 27. A. Bulk cadmium concentration for pre- and post-restoration by station. B. Cadmium content normalized by percent silt and clay for pre- and post-restoration by station.

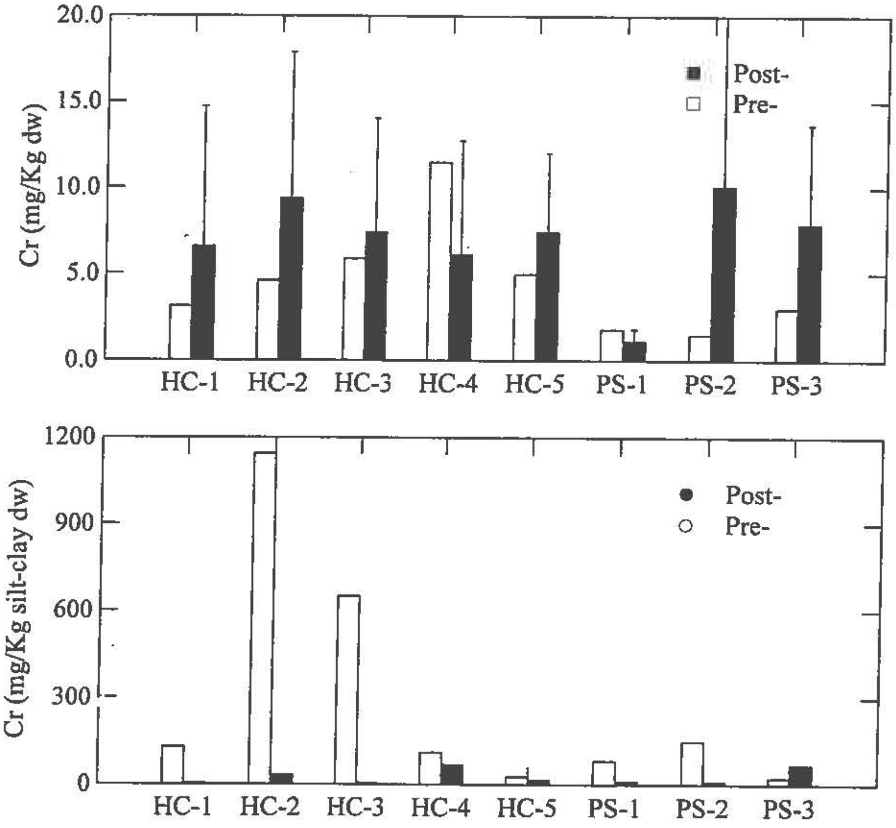

Figure 28. A. Bulk chromium concentration for pre- and post-restoration by station. B. Chromium content normalized by percent silt and clay for pre- and post-restoration by station.

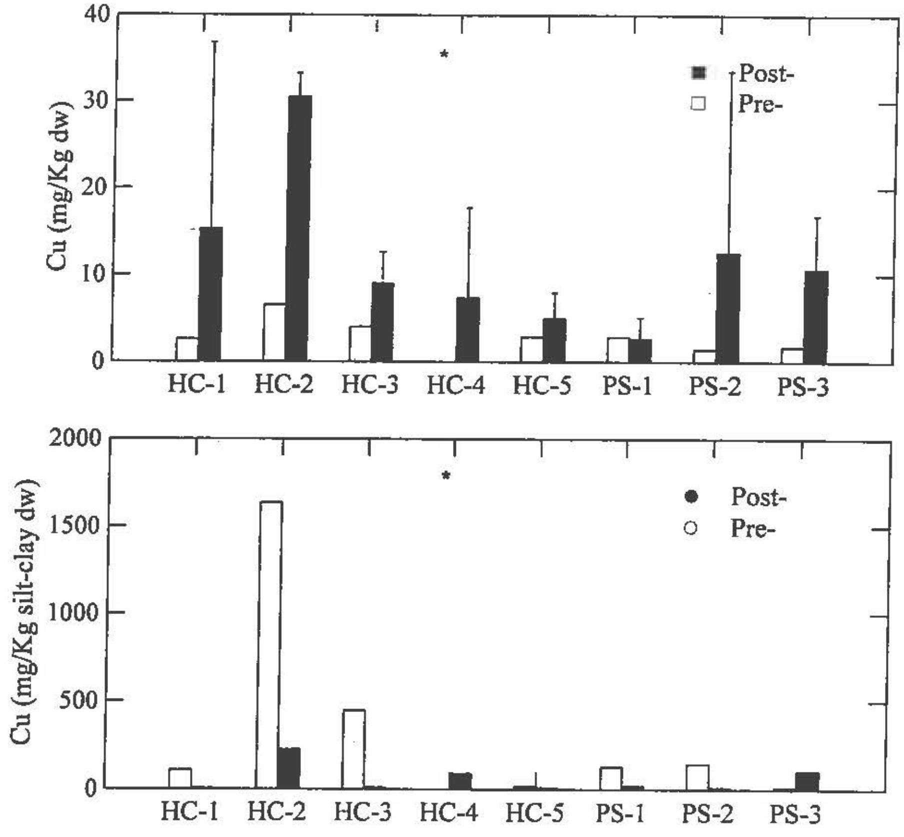

Figure 29. A. Bulk copper concentration for pre- and post-restoration by station. *- indicates an outlier value not incorporated in the plot. B. Copper content normalized by percent silt and clay for pre- and post-restoration by station. *- indicates an outlier value not incorporated in the plot.

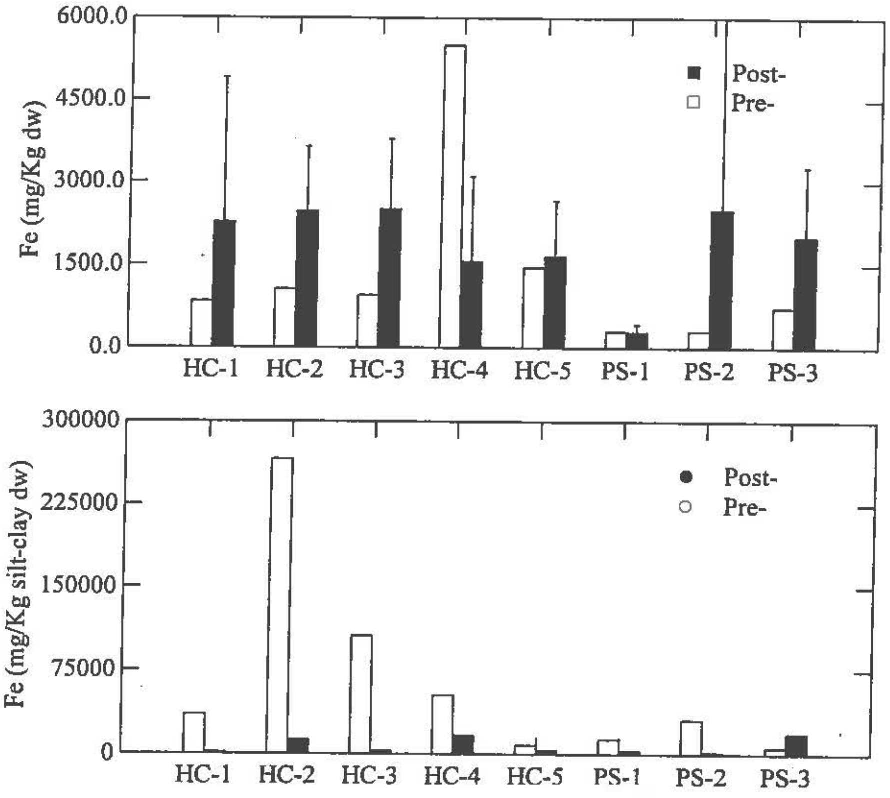

Figure 30. A. Bulk iron concentration for pre- and post-restoration by station. B. Iron content normalized by percent silt and clay for pre- and post-restoration by station.

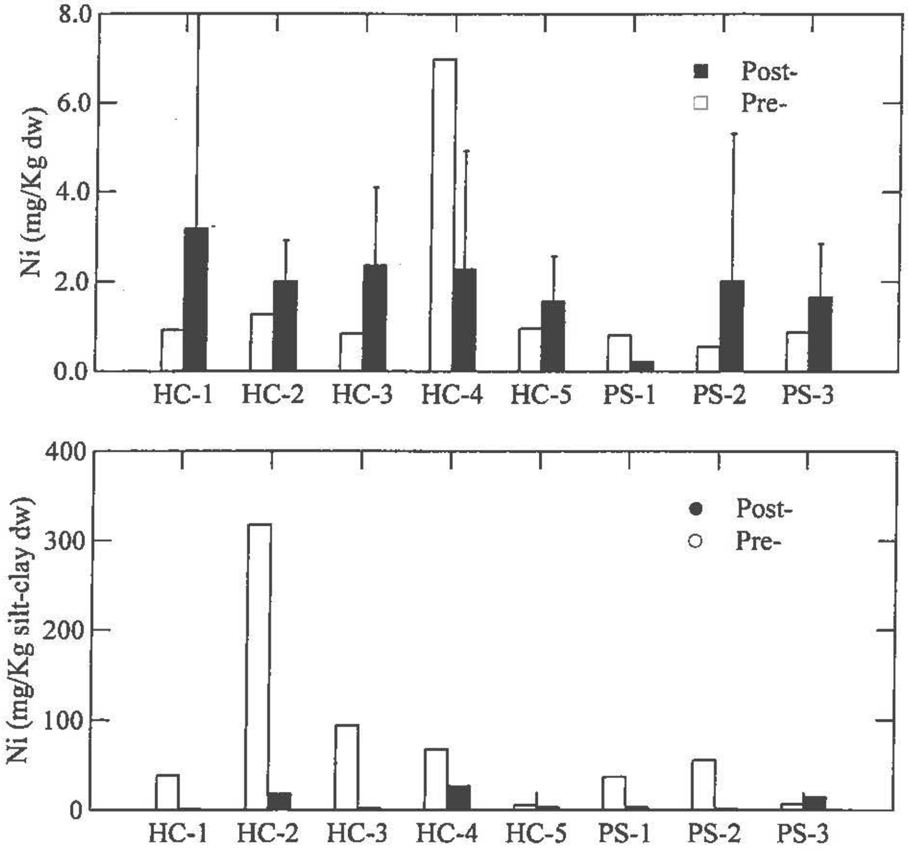

Figure 31. A. Bulk nickel concentration for pre- and post-restoration by station. B. Nickel content normalized by percent silt and clay for pre- and post-restoration by station.

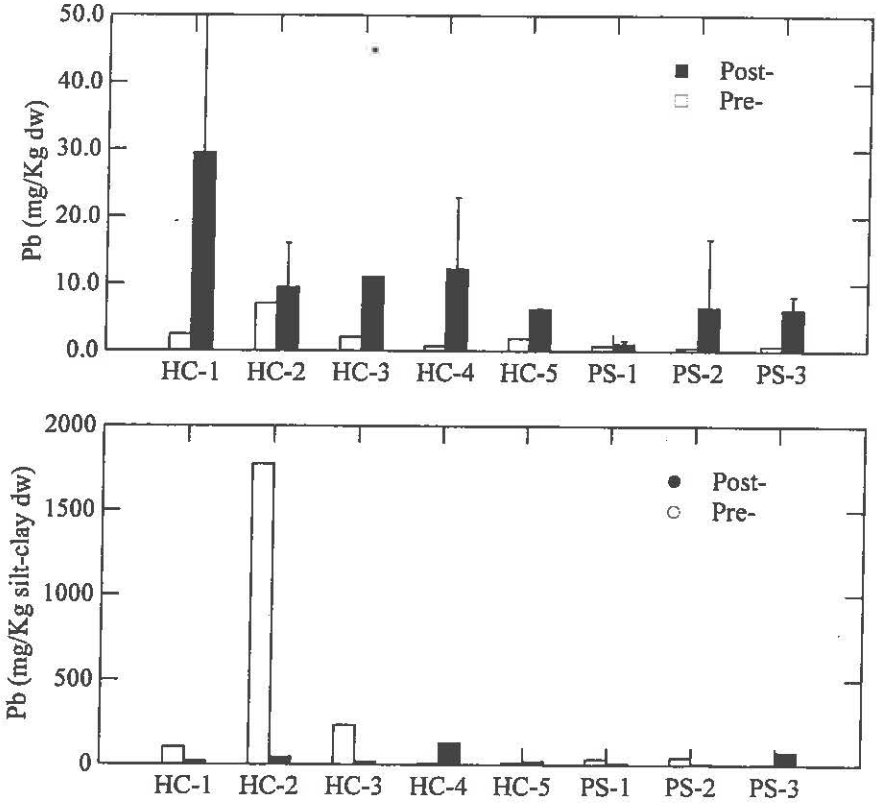

Figure 32. A. Bulk lead concentration for pre- and post-restoration by station. *- indicates an outlier value not incorporated in the plot. B. Lead content normalized by percent silt and clay for pre- and post-restoration by station.

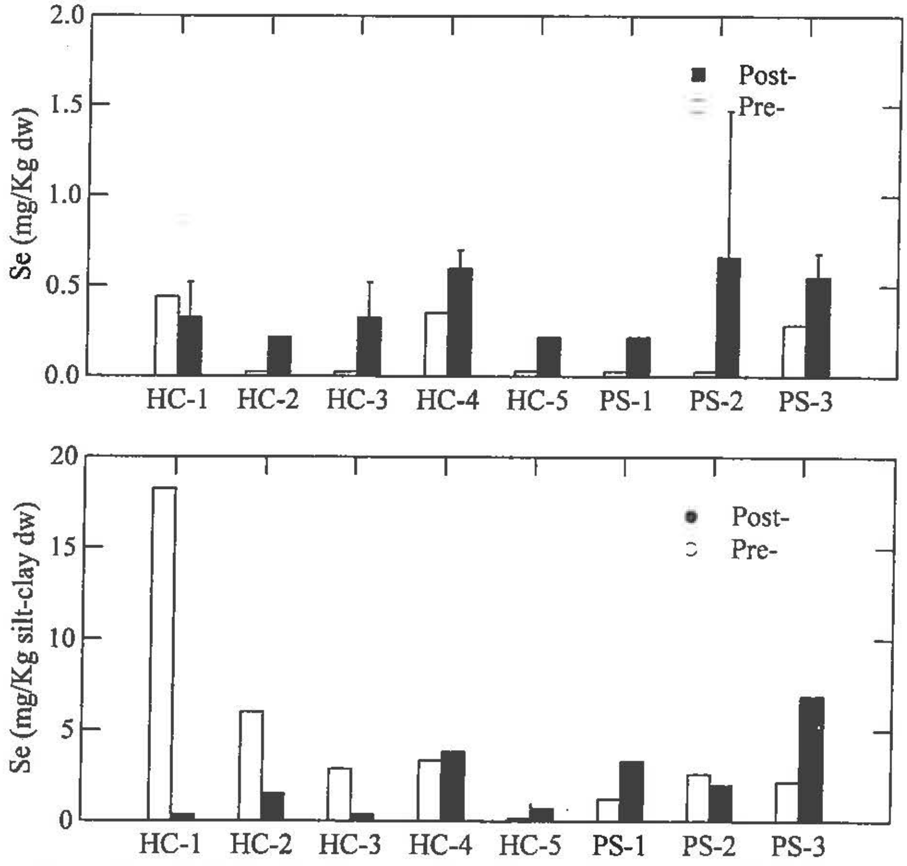

Figure 33. A. Bulk selenium concentration for pre- and post-restoration by station. B. Selenium content normalized by percent silt and clay for pre- and post-restoration by station.

For barium, silver, cadmium, and to a lesser extent chromium, bulk metal concentrations were higher for pre-restoration sediments from Hog Creek than either the post-restoration values or the sediments of Palma Sola Creek. For iron, copper, arsenic, nickel, and lead, the post-restoration bulk concentrations in both Hog and Palma Sola Creeks were greater than the pre-restoration values. To examine the influence from changing fine material, bulk concentrations were normalized by silt clay for the sampling in which that parameter was available.

In the pre-restoration samples, all Hog Creek stations were typically greater in normalized metals concentrations than the Palma Sola sediments. Station HC-2 contained the highest concentration of all metals with the exception of arsenic (maximum at HC-4) and selenium (maximum at HC-1). Following restoration, Hog Creek sediments appeared quite similar in metal content to Palma Sola Creek sediments, especially considering the degree of discrepancy observed prior to restoration. The change is consistent with removal of sediments contaminated with many years of urban runoff and/or plant discharge (based on the high normalized values seen at HC-2) during the excavation of the enlarged mixing pool. The freshly exposed material apparently had a higher proportion of fine material, or current velocities were reduced, allowing finer material to settle.

Sediment sulfides (H_2S; **Figure 34**) presented a comparable picture to metal concentrations. Normalized to silt-clay sized material, Station HC-3, pre-restoration, had the maximum concentration. For bulk values and concentrations normalized to either percent silt-clay or to percentage organics, post-restoration values in Hog Creek were generally lower and approached values observed in Palma Sola creek.

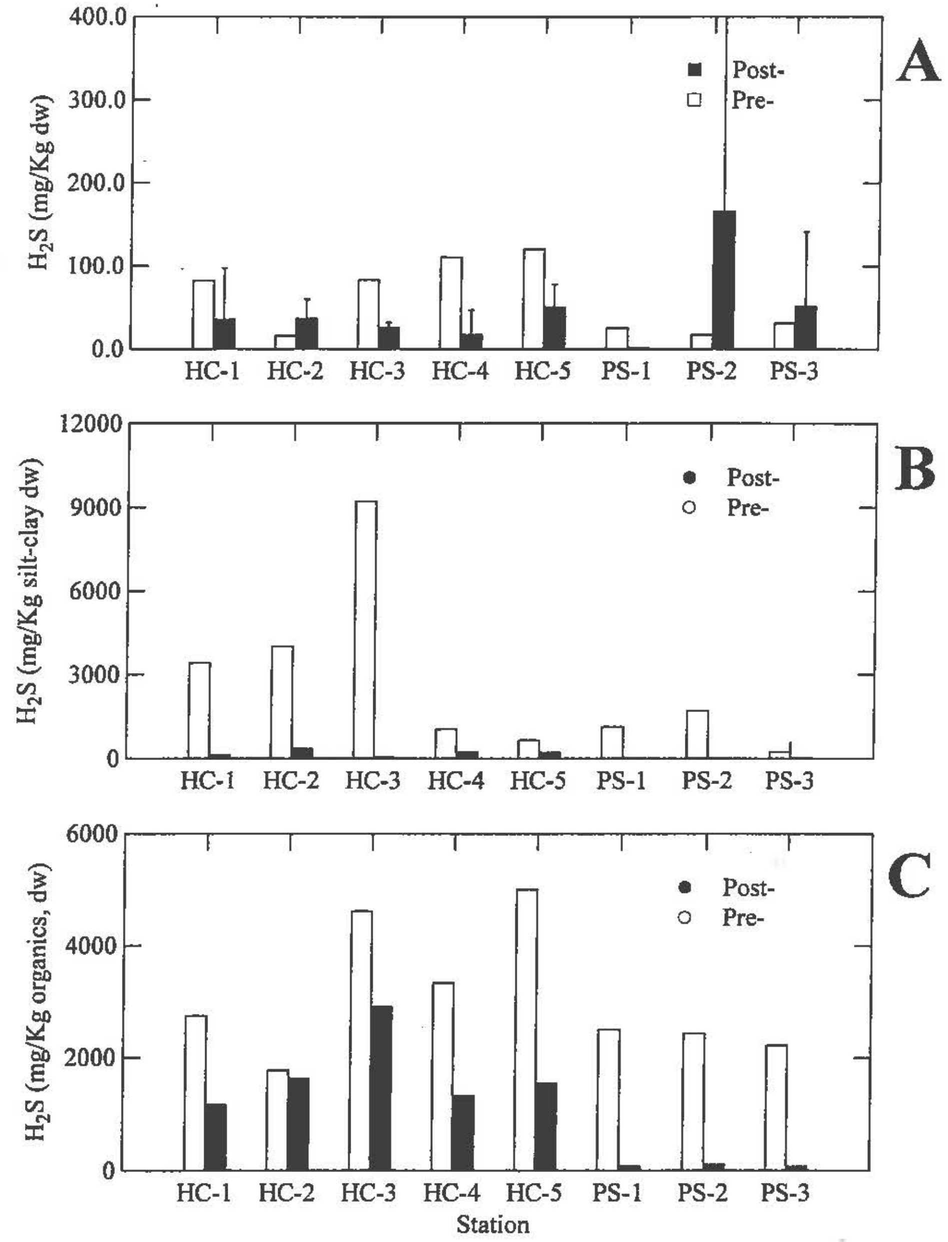

Figure 34. A. Bulk hydrogen sulfide concentration for pre- and post-restoration by station. B. Hydrogen sulfide content normalized by percent silt and clay for pre- and post-restoration by station. C. Hydrogen sulfide content normalized by percent organics for pre- and post-restoration by station.

Tests of significance for sediments were limited to data normalized for grain size and included all stations in each creek system as salinity dependence was not expected. Kruskal-Wallis non-parametric comparisons (p=0.05) were again used. Evaluating Hog Creek from before and after restoration revealed the following significant changes. Increases in percent silt, clay, and decreases in percent sand justified the use of the normalized sediment data. All metals with the exception of lead and selenium decreased following restoration. Lead and selenium exhibited no significant change, as did total organic carbon, and percent organics.

In summary, many of the significant changes in the water quality of Hog Creek appear related to plant operations rather than to the restoration project. Post-restoration, a lack of significant difference in all parameters between Stations HC-2 and HC-4 indicate that the bulk of the water column entrained in the restoration area is plant discharge, although the area and linear feet of low salinity habitat is undoubtedly increased. The sediments exposed in the restoration process, have an increased proportion of fines, and as a result, have higher concentrations of some metals. However, once data are normalized for silt-clay content, restoration has generally reduced the metal content of the fine fraction, particularly at Stations HC-2.

VI. LITERATURE CITED

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