4.2 Water Quality

4.2.1 Conventional Parameters

Conventional parameters in the water and sediment quality database include those parameters that are monitored to give a general physical and chemical characterization of the water column and substrate. Parameters include water temperature, salinity, total suspended solids (analyzed in lieu of turbidity), dissolved oxygen and pH. These parameters impact the chemical and physical processes taking place in the estuary and the abundance and distribution of the Bay's living resources including finfish, shellfish and birds.

In addition to the water quality data collected by the TCEQ, the Texas Parks and Wildlife Department (TPWD) collects hydrological data in association with its fisheries independent monitoring program. TPWD hydrological parameters including dissolved oxygen, water temperature, and salinity were analyzed by the Status and Trends Project. The TCEQ and TPWD data sets were analyzed separately and at no time were they combined for analysis.

The following data contain gaps where data for a given compound may not have been collected in a sub-bay or tributary for several years in a row. Additionally, some annual averages are calculated based on only a few samples collected per area per year. To aid the reader, each trend graph is annotated with the average, minimum, and maximum sample size for each yearly average. An R^2 value is also included in each graph to aid the reader in determining statistical significance of the trend. The Status and Trends project does not consider a trend to be statically significant if $R^2 < 0.25$.

The TCEQ and TPWD use standardized sampling methodologies when collecting these characterization data. TCEQ and TPWD sampling methodologies can be reviewed in the TCEQ Surface Water Quality Monitoring Procedures Manual (TCEQ, 1999) and the Marine Resource Monitoring Operations Manual (TPWD, 2001).

Water Temperature

Water temperature data collected by the TCEQ in Galveston Bay from 1969-2001 were analyzed for the major sub-bays and tributaries. Only those samples collected at 0.3-meter depth between the hours of 5:00 and 10:00 a.m. were analyzed for this study. Water temperature is reported in degrees Celsius (°C).

The water temperature data sets for Trinity and East Bays exhibited data gaps in which there were many years where no samples were collected. Data gaps also occurred in the data for Upper and Lower Galveston Bay and West Bay, however, these data sets were much more complete.

The annual trend graph for Upper and Lower Galveston Bay is shown in Figure 4.2.1. The linear trend line for annual average water temperatures in Upper and Lower Galveston Bay exhibits no trend ($R^2 = 0.10$). Annual average water temperature in West Bay also exhibited no trend ($R^2 = 0.00$).

It is interesting to note that West Bay, in December 1983 a low value of 2°C was measured in West Bay at Carancahua Reef. As this was the only temperature reading recorded for this sub-bay in 1983, it gave the impression of a very low annual average for that year.

The Status and Trends Project obtained water temperature data collected by the TPWD in conjunction with its fisheries independent resource monitoring activities in Galveston Bay from 1977-2000. Annual average water temperatures for East Bay, Upper and Lower Galveston Bay, Trinity Bay, and West Bay were analyzed (see Appendix B). Only one sub-bay, Trinity Bay, exhibited a significantly increasing ($R^2 = 0.47$) trend (see Figure 4.2.2). Trends for the remaining sub-bays increased as well; however, R^2 values were below 0.03.

As one would expect, TCEQ data show monthly average water temperatures peaking near 30 °C in all areas of the Bay during the months of July, August and September. Alternately, the lowest water temperatures occur in December, January and February. Figure 4.2.3 and Figure 4.2.4 show monthly average water temperatures in Upper and Lower Galveston Bay and West Bay, respectively, for the period 1969-2001. Monthly average water temperatures collected by TPWD show the same trends for the four sub-bays ($R^2 > 0.70$) (see Appendix B).

Note: Each data point on the monthly average charts represents data for an individual year. Year 2001 data are identified with red triangles. Graphs for monthly average water temperatures for the other sub-bays and tributaries of Galveston Bay are found in Appendix B.

Figure 4.2.1. Annual Average Water Temperatures in Upper and Lower Galveston Bay as Sampled by the TCEQ

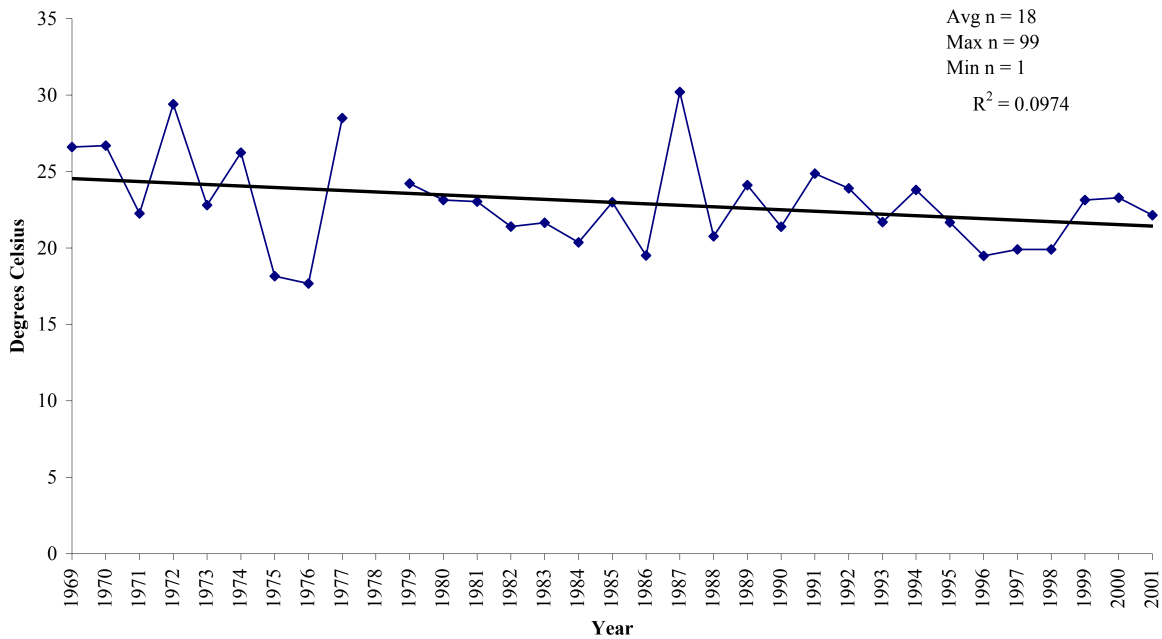


Figure 4.2.2. Annual Average Water Temperatures in Trinity Bay as Sampled by the TPWD

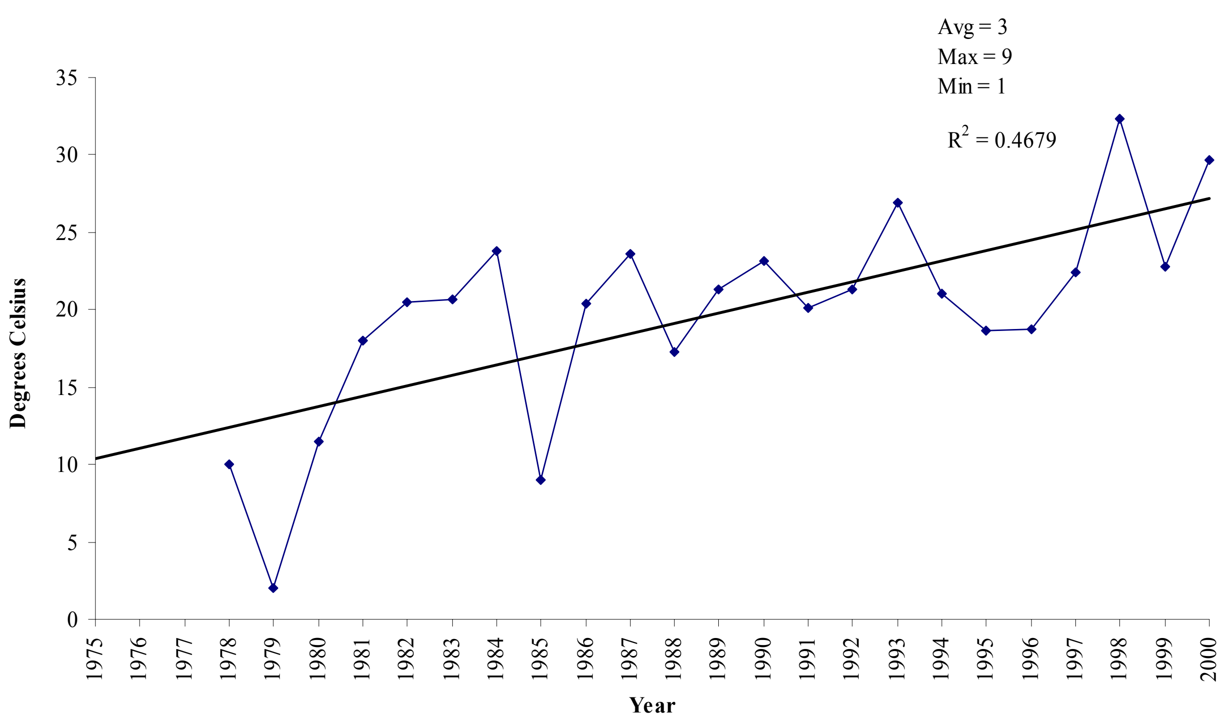


Figure 4.2.3. Monthly Average Water Temperature in Upper and Lower Galveston Bay, 1969 to 2001

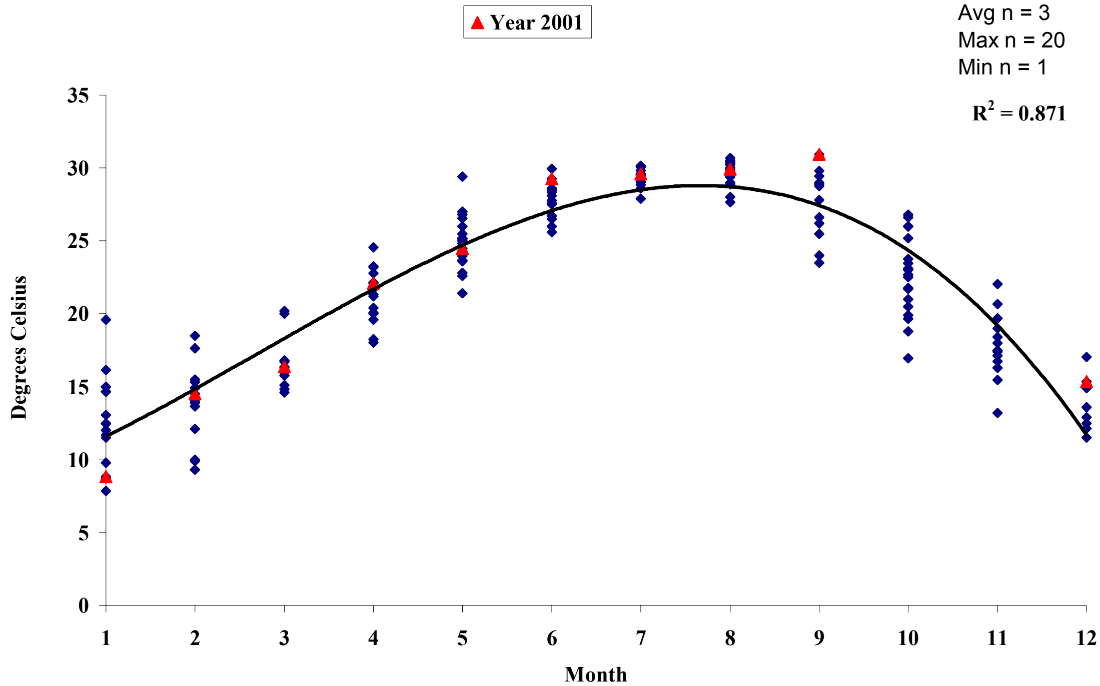
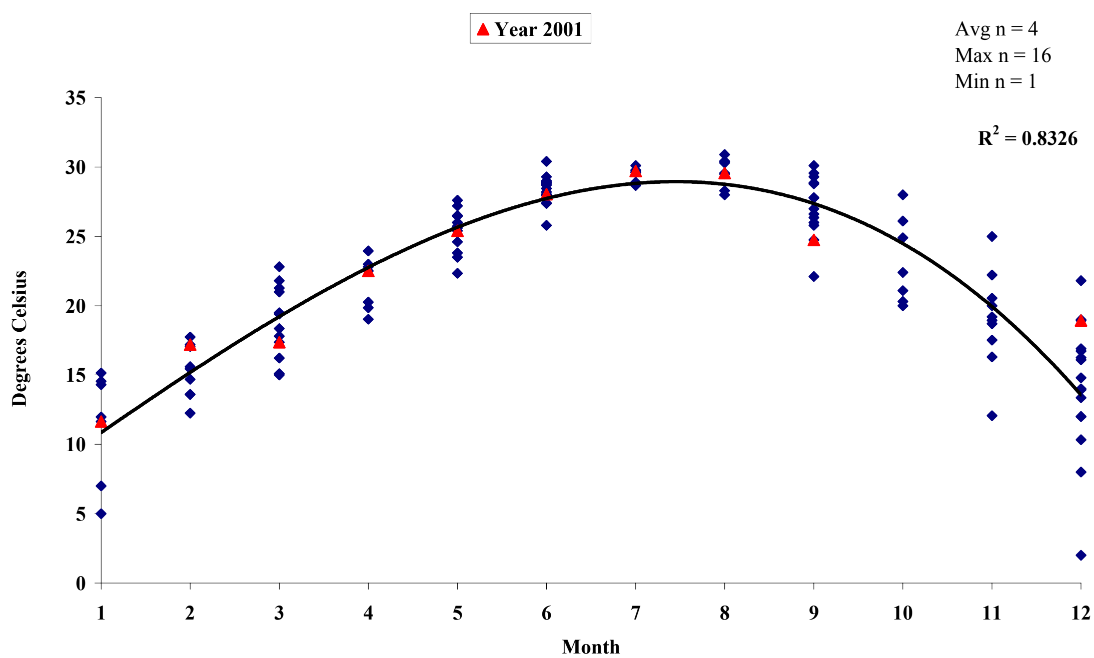


Figure 4.2.4. Monthly Average Water Temperature in West Bay, 1969 to 2001



pH

pH data collected by the TCEQ in Galveston Bay from 1969-2001 were analyzed for the major sub-bays and tributaries in the Galveston Bay system. Samples collected at all depths and times were analyzed. While a few samples were measured by the TCEQ in 1969 and 1970, the majority of the pH record begins in 1972. pH is reported in pH standard units.

As seen in Figure 4.2.5, annual average pH in water in Upper and Lower Galveston Bay lies near 8.0 standard units. Linear trend lines for pH are stable to slightly declining across all sub-bays and tributaries in the Galveston Bay system (see Appendix B).

Generally, pH exhibits low variability in coastal environments due to the high buffering capacity of seawater. While variability is low overall, East Bay (Figure 4.2.6) and Trinity Bay exhibit the greatest variability in pH relative to the other sub-bays.

Trends in monthly average pH in water typically range from 7.0 - 9.0. Several areas have monthly average pH values as high as 10.0 or as low as 6.0. Even so, trend lines are relatively stable across all sub-bays and tributaries as seen in the graphs for the Houston Ship Channel and West Bay (Figures 4.2.7 and 4.2.8).

Note: Each data point on the monthly average charts represents data for an individual year. Year 2001 data are identified with red triangles. Graphs for monthly average pH in water for other sub-bays and tributaries of Galveston Bay are found in Appendix B.

Figure 4.2.5. Annual Average pH in Water in Upper and Lower Galveston Bay

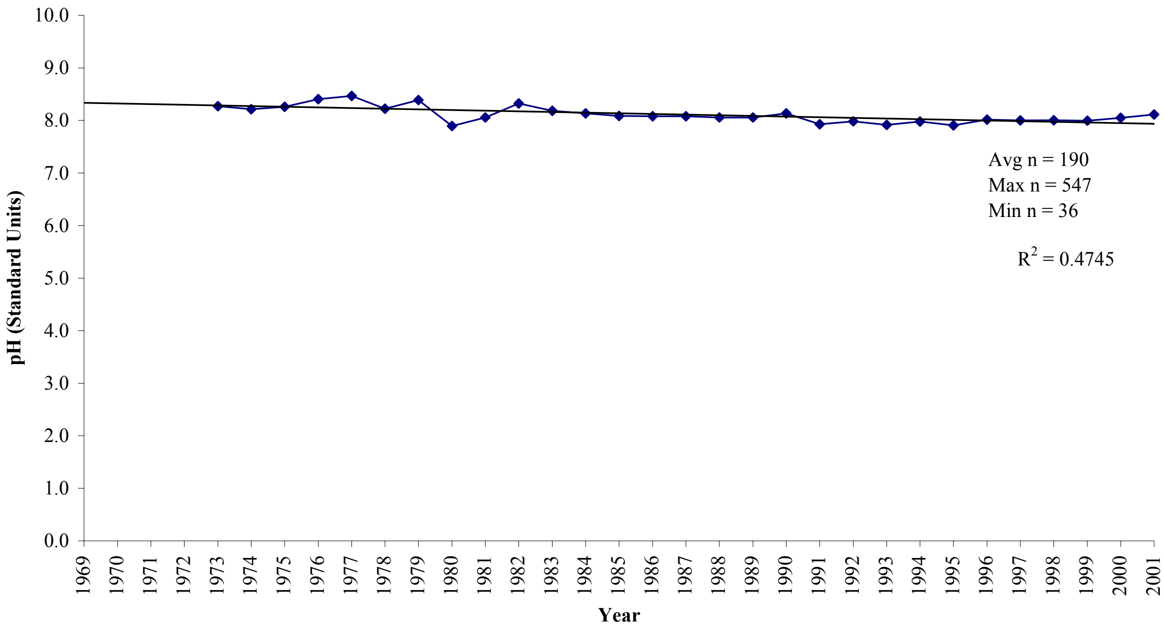


Figure 4.2.6. Annual Average pH in Water in East Bay

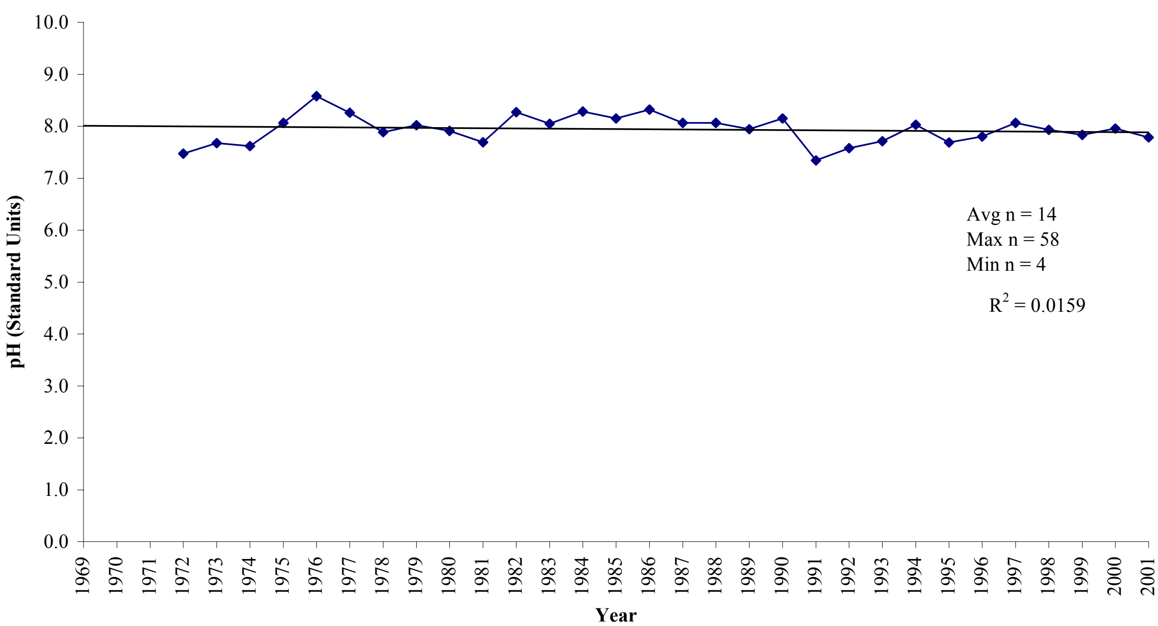


Figure 4.2.7. Monthly Average pH in Water in the Houston Ship Channel, 1972 to 2001

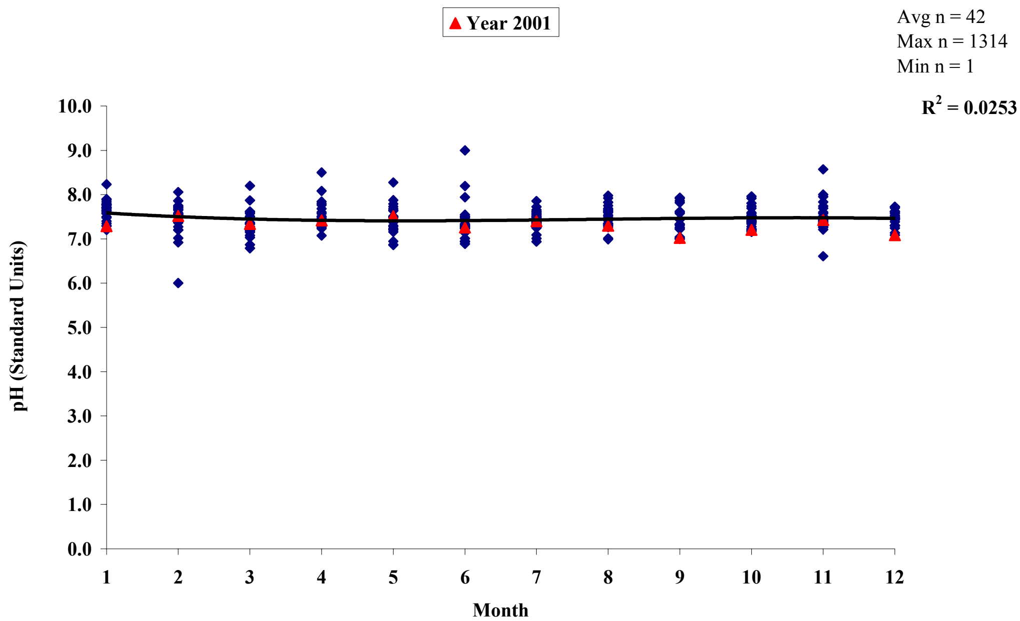
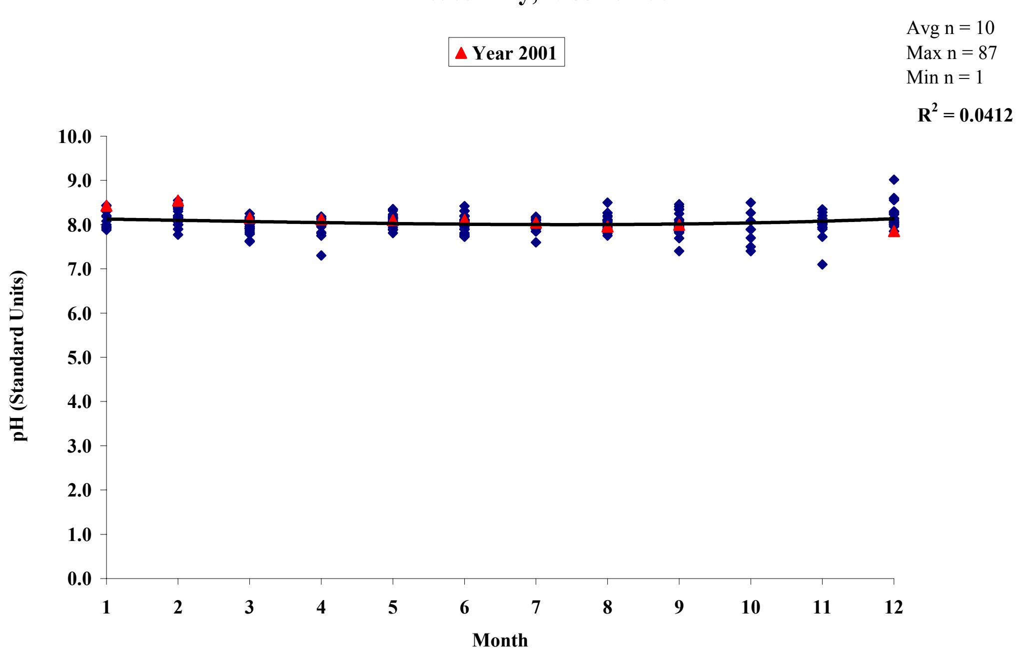


Figure 4.2.8. Monthly Average pH in Water in West Bay, 1973 to 2001



Salinity
Salinity has been monitored in the Galveston Bay system by the TCEQ since 1973. A number of the samples were collected in the 1970's. However, of the 5,492 salinity measurements (collected at 0.3 meters depth), the bulk of the data were collected from 1980 to the present. It must be noted that only those samples collected at 0.3-meter depth were analyzed. Salinity stratification occurs in the sub-bays and tributaries of Galveston Bay. Limiting samples to those collected at 0.3 meters allowed for analysis of a uniform data set. Salinity is reported in parts per thousand (ppt). According to the TCEQ, salinity data can also be derived from the data on conductivity. However, conductivity was not analyzed by the Status and Trends project.

With the exception of West Bay, salinities exhibit declining trends over the period of record for all Galveston Bay sub-bays and tributaries analyzed by this project. The linear trend line for Upper and Lower Galveston Bay lies between 15 and 20 parts per thousand (ppt) for the period of record, 1973-2001 (see Appendix B). The trend line is slightly decreasing, but is not significant with an $R^2 = 0.05$.

As seen in Appendix B, areas of Galveston Bay exhibiting relatively low salinities include Trinity Bay, the San Jacinto River, the Houston Ship Channel, Clear Creek and Clear Lake, Cedar Bayou, and Dickinson Bayou and Dickinson Bay. As seen in Appendix B, portions of the Galveston Bay system exhibiting higher salinities include East Bay, Upper and Lower Galveston Bay, Chocolate Bayou, the Texas City Ship Channel and West Bay.

West Bay sees the highest salinities of any sub-bay or tributary in the Galveston Bay system (see Figure 4.2.9) due to the influence of both more saline Gulf waters and the presence of the Texas City Dike. The linear trend line for West Bay lies at approximately 24 ppt and exhibits a nearly stable trend over the period of record, 1973-2001.

The Status and Trends Project obtained salinity data collected by the TPWD in conjunction with its fisheries independent resource monitoring activities in Galveston Bay from 1977-2000. Annual average salinities for East Bay, Upper and Lower Galveston Bay, Trinity Bay, and West Bay were analyzed (see Appendix B). Only one sub-bay, East Bay, exhibited an increasing ($R^2 = 0.29$) trend (see Figure 4.2.10). Data for the remaining sub-bays showed no trends in salinity concentrations.

Monthly average salinities exhibit a similar trend across all sub-bays and tributaries of Galveston Bay (see Figures 4.2.11 and 4.2.12 and Appendix B). Typically, the lowest salinities occur in the months of March, April and May when the spring freshet occurs. The highest salinities of the year occur in the drier months of August, September and October. Again West Bay (Figure 4.2.12) sees the highest salinities with several summer averages approaching 45 ppt. Monthly average salinity collected by TPWD show trends similar to the TCEQ data for the four sub-bays, however, $R^2 < 0.25$ (see Appendix B).

Note: Each data point on the monthly average charts represents data for an individual year. Year 2001 data are identified with red triangles.

Figure 4.2.9. Annual Average Salinity in Water in West Bay as Sampled by the TCEQ

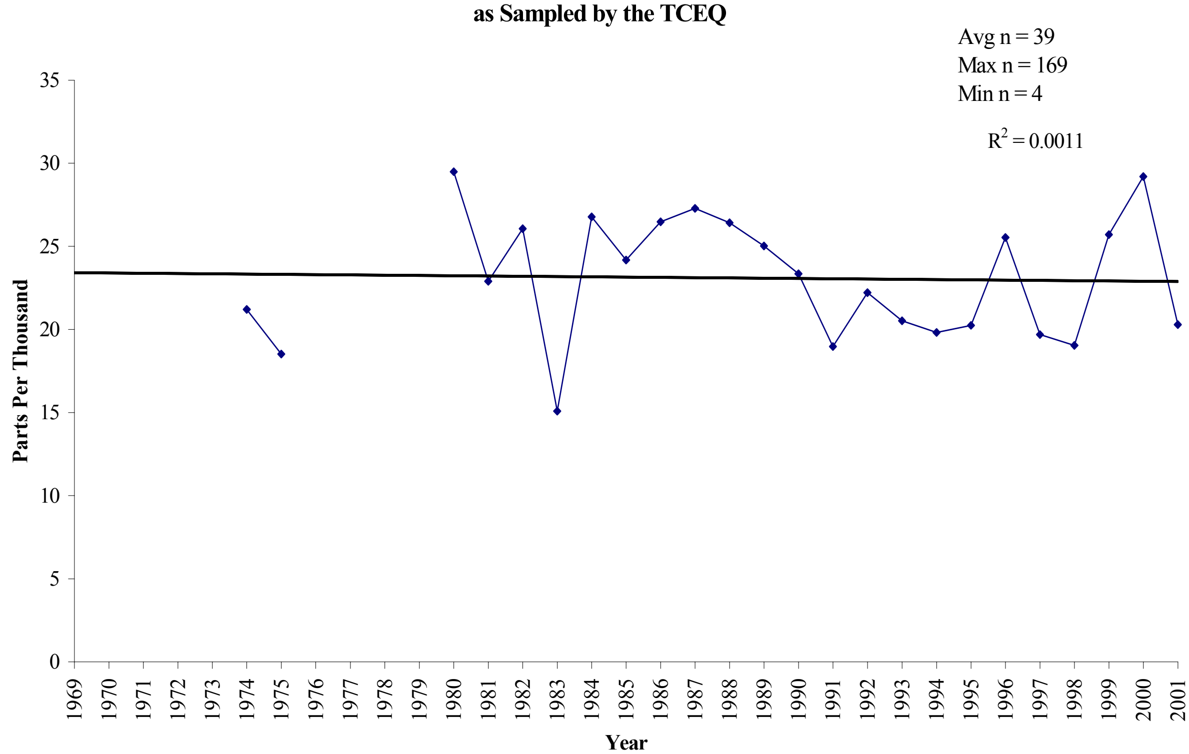
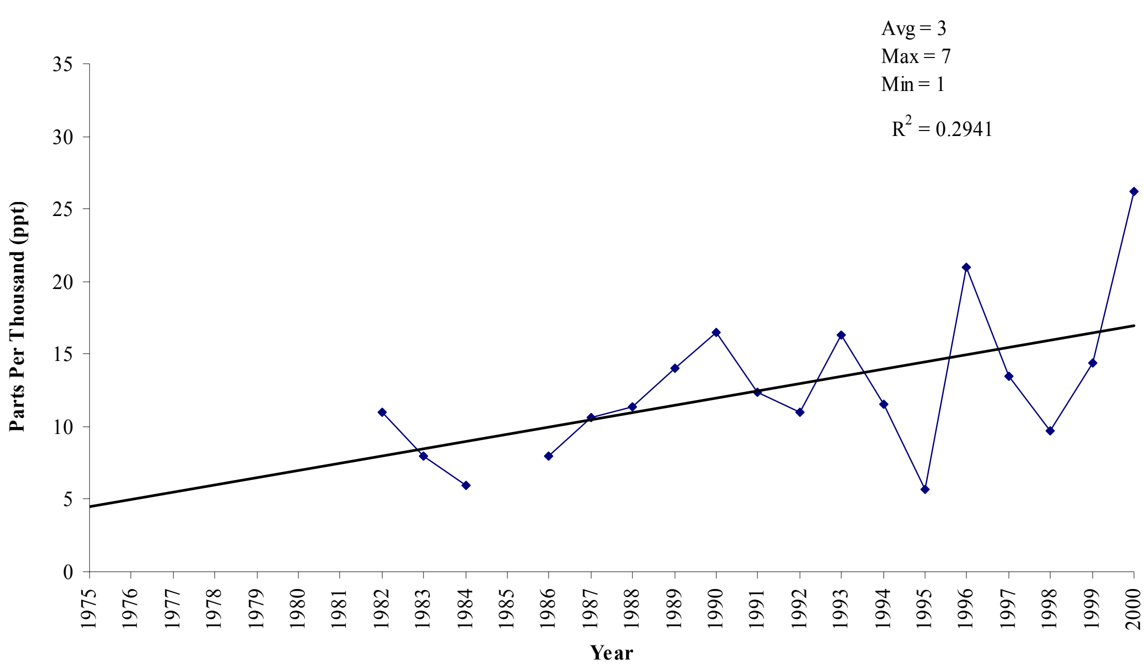


Figure 4.2.10. Annual Average Salinity in Water in East Bay as Sampled by the TPWD



Figur 4.2.11. Monthly Average Salinity in Water in Upper and Lower Galveston Bay, 1973 to 2001

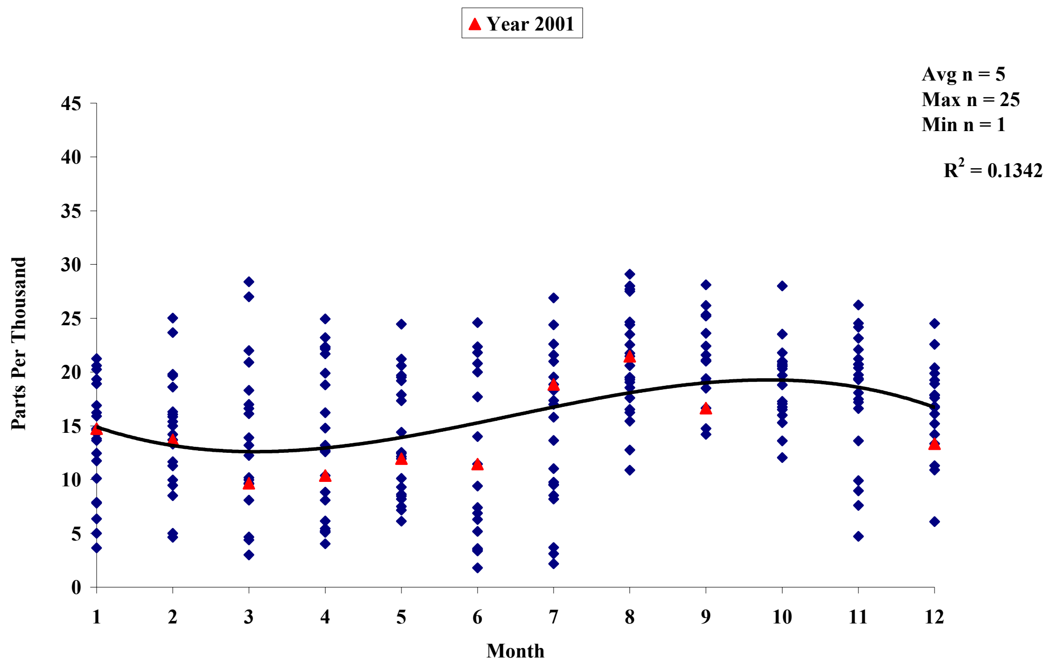
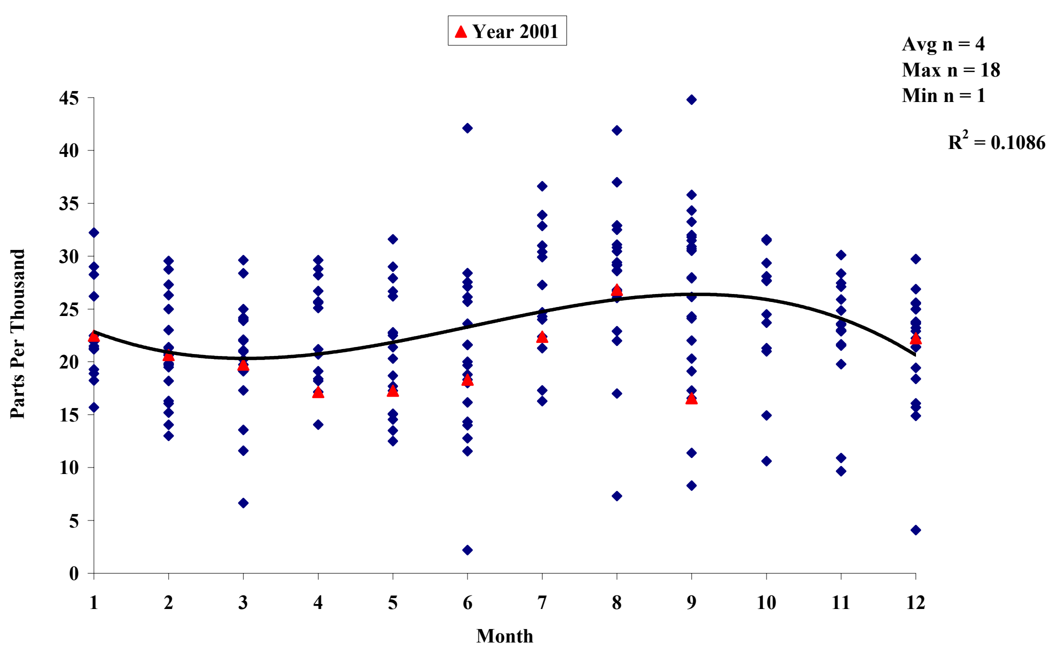


Figure 4.2.12. Monthly Average Salinity in Water in West Bay, 1974 to 2001



Total Suspended Solids

Total suspended solids (TSS) are a measure of suspended sediment in the water column. TSS has been monitored in the Galveston Bay system by the TCEQ since 1969. In terms of time period, it is one of the most complete water quality data sets for the Galveston Bay estuary and is a good candidate for trend analysis. To ensure a uniform analysis and to lessen the effects of perturbation of sediments near the Bay bottom, data analyses were limited to TSS samples collected at a depth of 0.3 meters. TSS is reported as total non-filterable residue in mg/L.

TSS exhibited declining trends in annual average concentrations across all sub-bays and tributaries (see Appendix B) of the Galveston Bay system with the exception of Upper and Lower Galveston Bay and Cedar Bayou. The stable trend line for Upper and Lower Galveston Bay remained at near 30 mg/L through the period of record with the highest value occurring in 1996 at a concentration of 98 mg/L (Figure 4.2.13). Cedar Bayou was the only area of Galveston Bay to exhibit an increasing trend in TSS concentrations. However, the relatively short period of record for TSS in Cedar Bayou (1987-2001) should be noted.

As seen below in Figure 4.2.14, annual average TSS in East Bay exhibited a declining trend ($R^2 = 0.43$) that ranged from approximately 130 mg/L in 1969 to 10 mg/L in 2001. The highest annual average TSS concentration in East Bay occurred in 1979 with a value of 230.5 mg/L. Annual average values have continually declined since with a slight increase in values occurring since 1995.

The trend lines for TSS in Trinity Bay and West Bay show decreasing annual average concentrations over the period of record (see Appendix B). TSS concentrations in Trinity Bay were highest in the years 1970, 1972 and 1974 with the highest annual average concentration of 171.5 mg/L occurring in 1974. Concentrations have remained below 50 mg/L since then.

Seasonal trends for TSS were difficult to discern due to an extremely high TSS value of 1,188 mg/L recorded in East Bay in 1979. To compensate for this high value, monthly average TSS concentrations were analyzed on a logarithmic scale. Trends in monthly average TSS concentrations for sub-bays and tributaries (see Appendix B) are typically slight ($R^2 < 0.14$) with increasing concentrations occurring in the spring and declining concentrations occurring in late summer and early fall as seen in the trend for Trinity Bay (Figure 4.2.15). The exceptions are East Bay (no trend), West Bay (peak concentrations in May, June and July; low concentrations in December and January) (Figure 4.2.16), and the Texas City Ship Channel for which the TSS concentrations peak in August and September.

As seen in the status map for the year 2000 (Figure 4.2.17), the highest TSS concentrations occurred in Cedar Bayou, Clear Creek and Clear Lake, East Bay, and Upper and Lower Galveston Bay. The lowest annual average TSS concentrations were seen in the San Jacinto River.

Note: Each data point on the monthly average charts represents data for an individual year. Year 2001 data are identified with red triangles.

Figure 4.2.13. Annual Average Total Suspended Solids in Water in Upper and Lower Galveston Bay

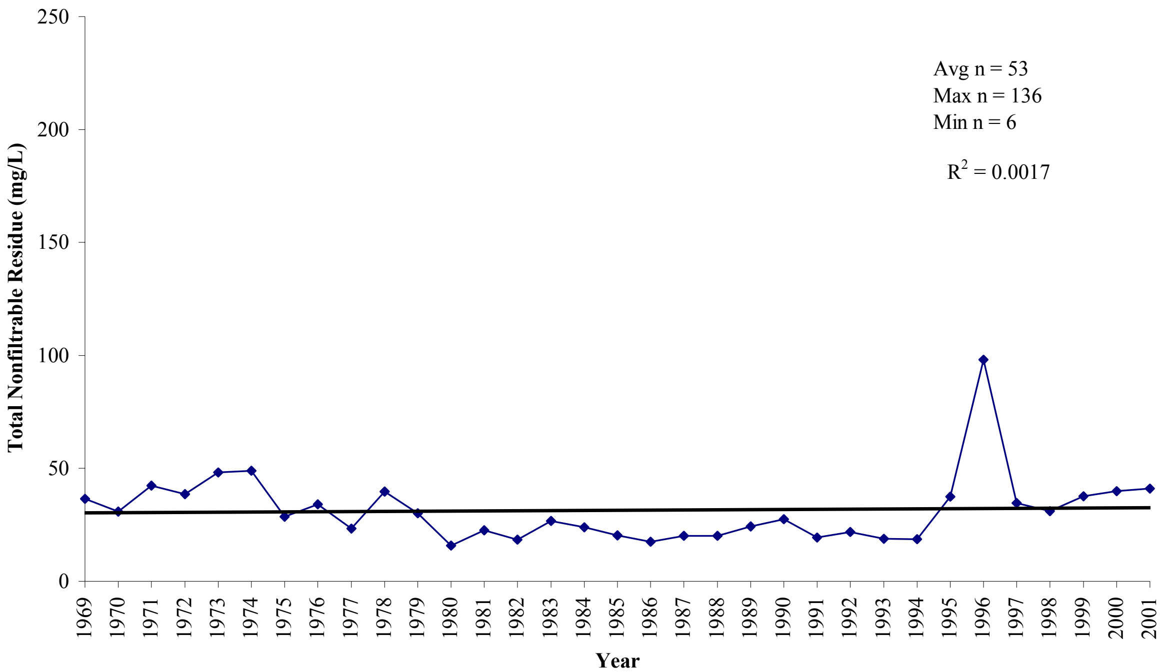


Figure 4.2.14. Annual Average Total Suspended Solids in Water in East Bay

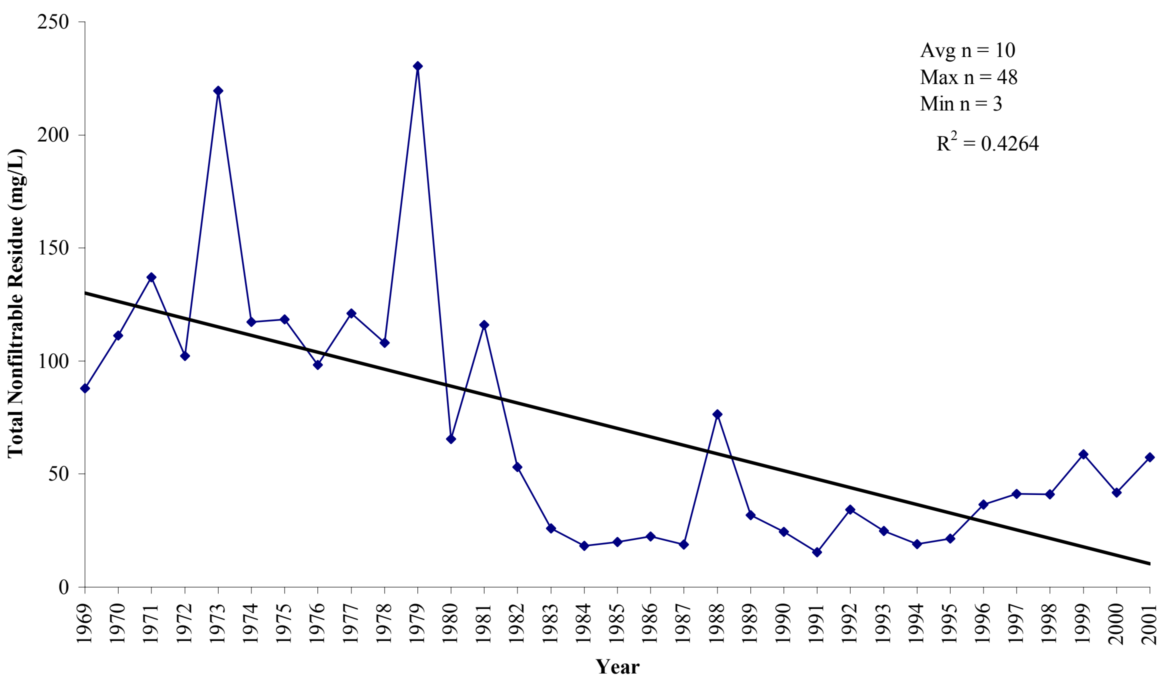


Figure 4.2.15. Monthly Average Total Suspended Solids in Water in Trinity Bay, 1969 to 2001

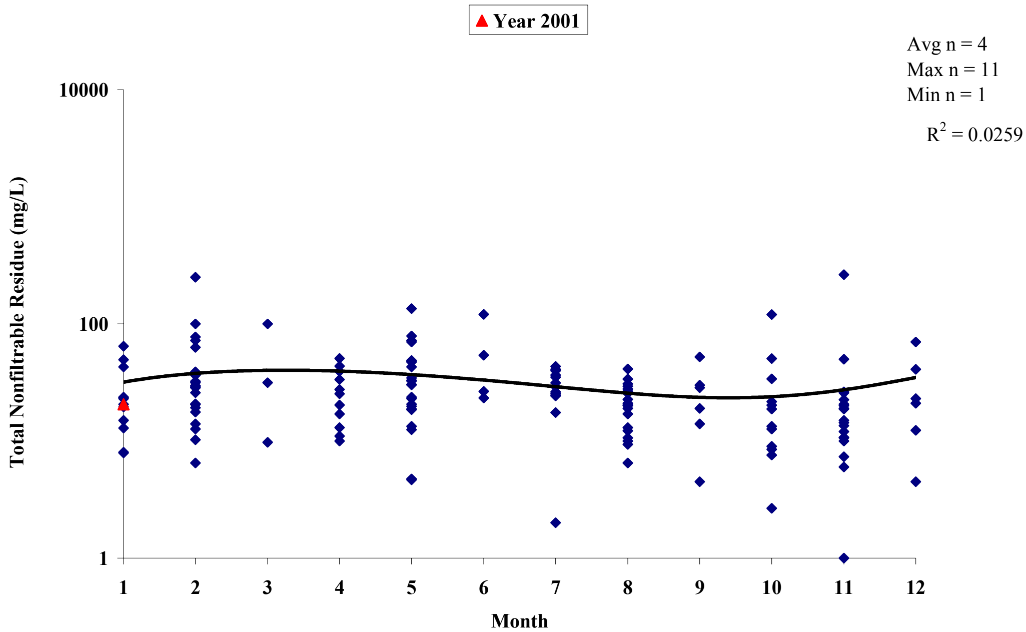


Figure 4.2.16. Monthly Average Total Suspended Solids in Water in West Bay, 1969 to 2001

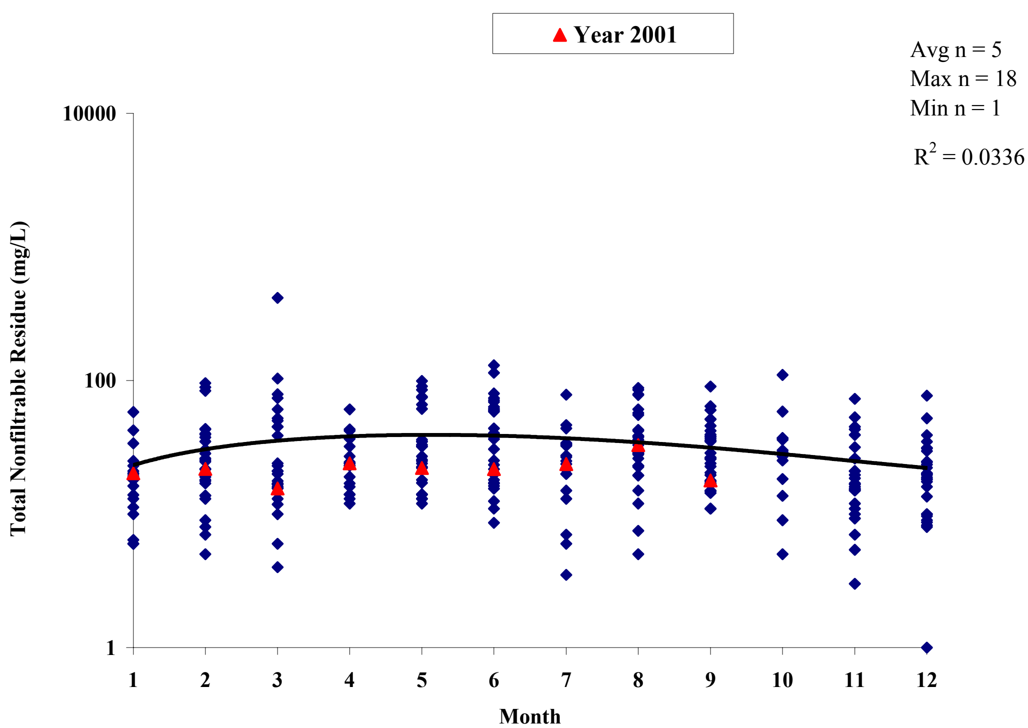
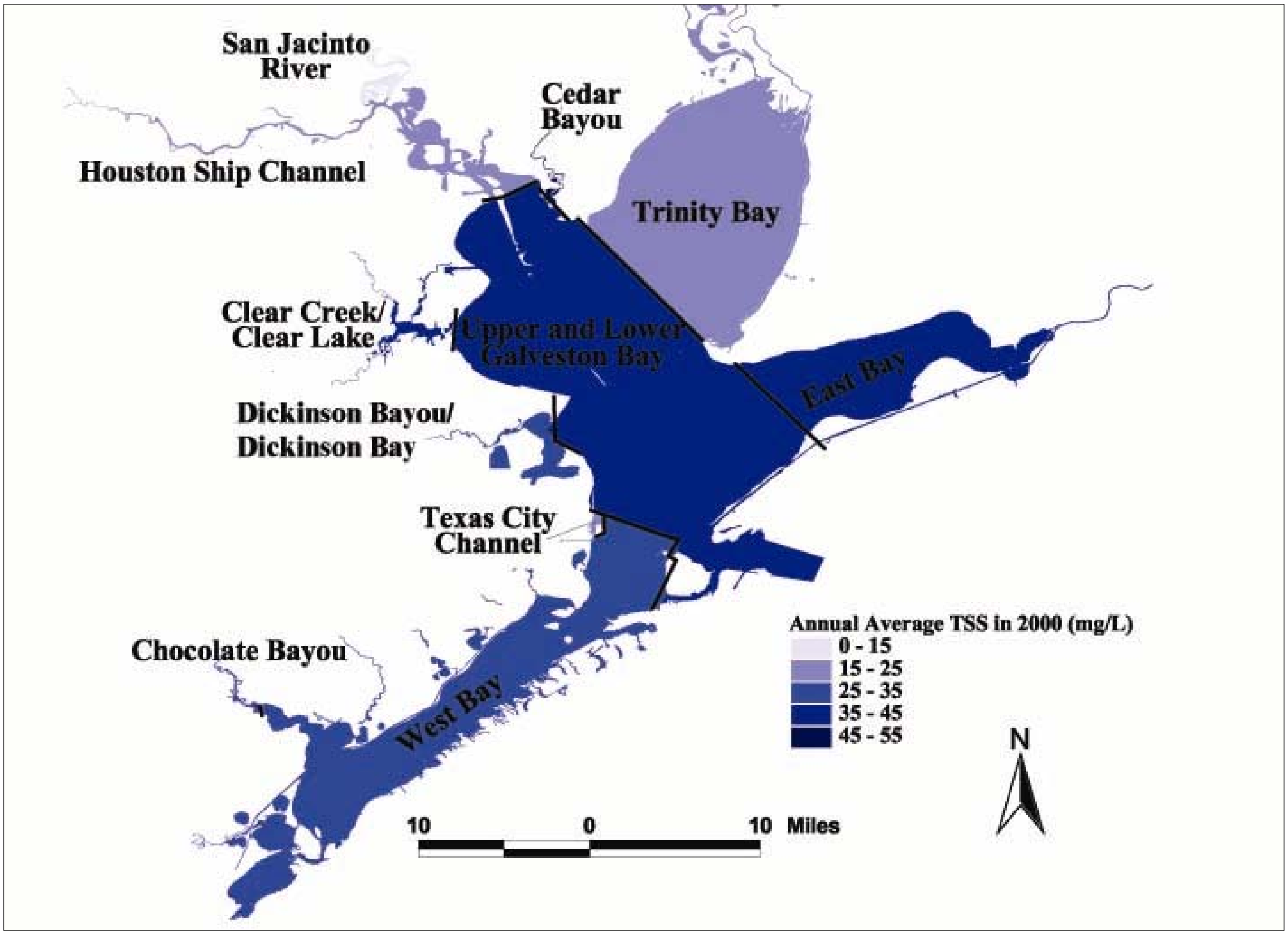


Figure 4.2.17. The status of annual average total suspended solids concentrations in waters of the Galveston Bay estuary in the year 2000.



Dissolved Oxygen
Dissolved oxygen (DO) is one of the most relied upon indicators of aquatic health. DO concentrations in Galveston Bay have been sampled by the TCEQ since 1969. In an attempt to limit the effects of photosynthesis and water temperature on DO concentrations, samples collected between the hours of 5:00 and 10:00 a.m. at a depth of 0.3 meters were analyzed. Alternatively, to observe the effects of photosynthesis and water temperature on DO concentrations, samples collected between 10:00 a.m. and 3:00 p.m. at a depth of 0.3 meters were also analyzed. DO concentrations were reported in mg/L.

The Houston Ship Channel was the only area of the Galveston Bay estuary to exhibit a statistically significant trend in DO concentrations. DO concentrations sampled between 5:00 and 10:00 a.m. exhibited an increasing trend ($R^2 = 0.19$) ranging from approximately 4.0 mg/L in 1970 to near 6.0 mg/L in 2001 (see Figure 4.2.18). The trend in DO sampled from 10:00 a.m. to 3:00 p.m. in the Houston Ship Channel showed a very strong increasing trend ($R^2 = 0.76$). As seen in Figure 4.2.19, the trend increased from near 3.0 mg/L in 1969 to near 6.0 mg/L in 2001.

DO annual average trends in all other areas of the Galveston Bay estuary were determined to not be statistically significant ($R^2 < 0.14$), therefore it would not be prudent to discuss them as true trends. The trend graphs are, however, included in Appendix B.

The Status and Trends Project obtained dissolved oxygen data collected by the TPWD in conjunction with its fisheries independent resource monitoring activities in Galveston Bay from 1977-2000. Annual average concentrations of dissolved oxygen for East Bay, Upper and Lower Galveston Bay, Trinity Bay, and West Bay were analyzed (samples were collected between 10:00 a.m. and 3:00 p.m.)(see Appendix B). Only one sub-bay, Trinity Bay, exhibited a decreasing trend ($R^2 = 0.38$) (see Appendix B). Data for the remaining sub-bays showed no trends in dissolved oxygen concentrations. Concentrations consistently remained above 5.0 mg/L and very often conditions in the sub-bays appeared to be in a state of super-saturation ([DO] > 8.0 mg/L)

Unlike the annual DO averages, monthly DO averages exhibited strong trends. Monthly average trends for DO sampled from 5:00 a.m. to 10:00 a.m. and 10:00 a.m. to 3:00 p.m. were similar in all study areas. The trend lines reach their highest points in the months of November through March. Low points on the DO monthly average curve occurred in the months of April through October (see monthly average DO for Upper and Lower Galveston Bay in Figure 4.2.20). One interesting feature of the monthly average dissolved oxygen concentrations is the amount of super-saturation ([DO]>8.0 mg/L) that occurs throughout the Bay system (see Figures 4.2.20, 4.2.21 and Appendix B). Monthly averages based on DO data collected by TPWD show trends similar to the TCEQ data for the four sub-bays (see Appendix B).

Figure 4.2.18. Annual Average Dissolved Oxygen in Water in the Houston Ship Channel (5:00am to 10:00am)

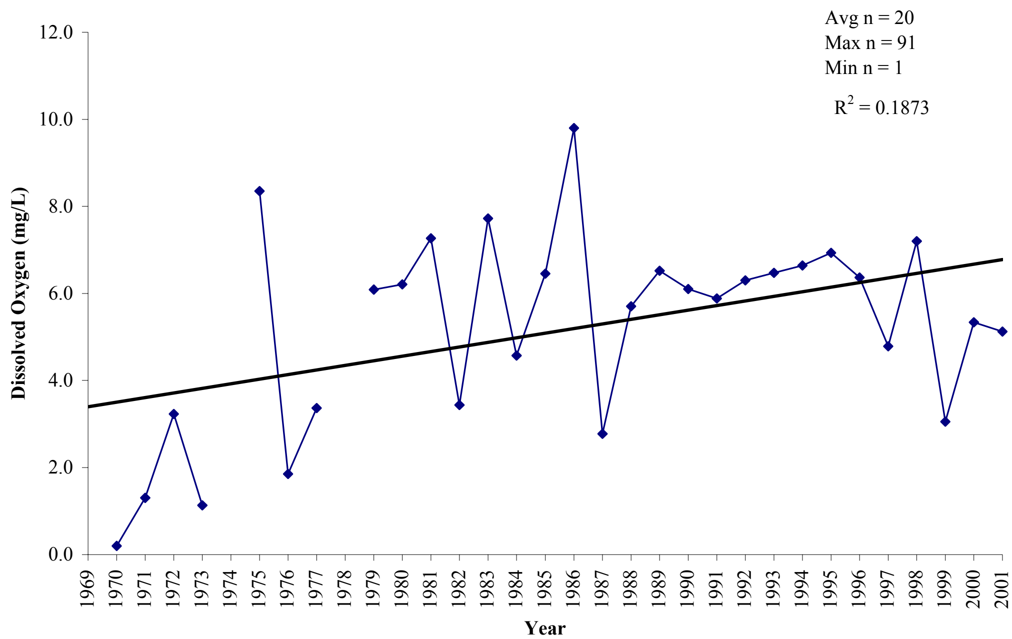


Figure 4.2.19. Annual Average Dissolved Oxygen in Water in the Houston Ship Channel (10:00 am to 3:00 pm)

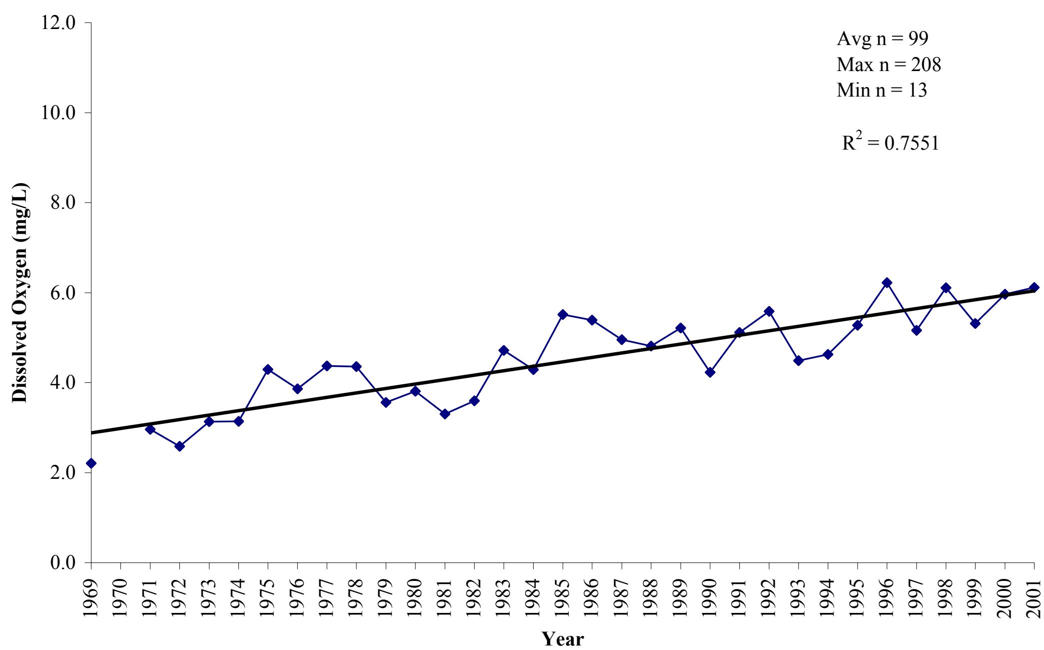


Figure 4.2.20. Monthly Average Dissolved Oxygen in Water in Upper and Lower Galveston Bay (5:00 am to 10:00 am), 1969 to 2001

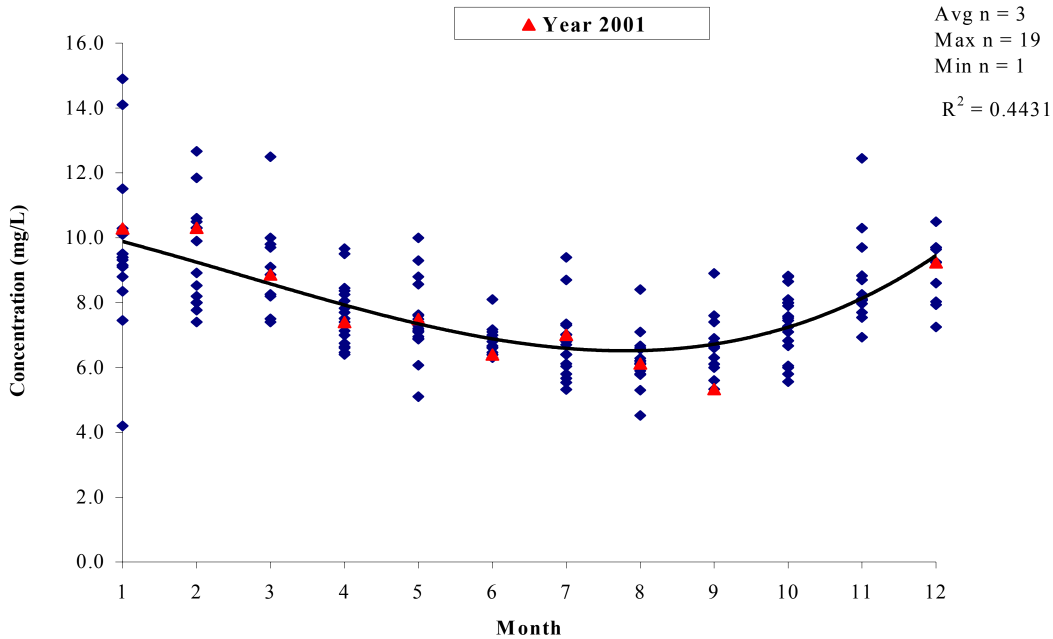
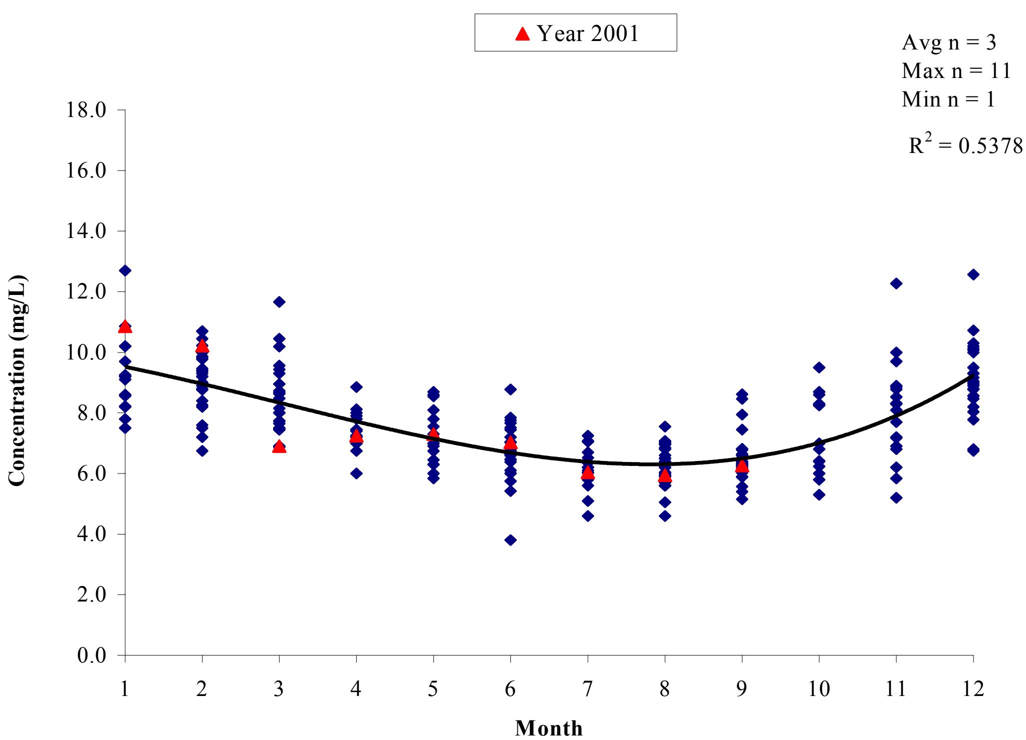


Figure 4.2.21. Monthly Average Dissolved Oxygen in Water in West Bay (10:00 am to 3:00 pm), 1969 to 2001



4.2.2 Nutrients

Data on the nutrient parameters analyzed in this study were collected by the TCEQ and acquired from their water and sediment quality database. Analyzed nutrient parameters include ammonia, total nitrate-nitrite and total phosphorus. Concentrations of these parameters are often related to non-point source runoff from the watershed and in turn affect other water quality parameters such as dissolved oxygen and chlorophyll-a (an indicator of phytoplankton abundance).

The TCEQ uses standardized sampling methodologies when collecting these data. These sampling methodologies can be reviewed in the TCEQ Surface Water Quality Monitoring Procedures Manual (TCEQ, 1999).

Nitrate-Nitrite

Nitrate and nitrite data were difficult to analyze due to a change in sampling methodologies implemented by the TCEQ. From 1969-1994 nitrate and nitrite were sampled as separate parameters. In 1980 the TCEQ began to sample nitrate and nitrite as one parameter. This combined nitrate-nitrite data exists for the period 1980-2001. To create a more complete data set for analysis of nitrate-nitrite, the total nitrate-nitrite and total nitrate parameters (TCEQ storet codes 00630 and 00620, respectively) were combined. This combined data set will be discussed below. Total nitrate-nitrite concentrations collected at all times and depths were analyzed and are reported as mg/L.

As seen in Figure 4.2.22, the highest annual average concentrations of nitrate-nitrite occurred in the Houston Ship Channel which saw an increasing trend ($R^2 = 0.55$) from approximately 0 mg/L in 1969 to near 1.75 mg/L in 2001. The only other study area to exhibit a statistically significant trend ($R^2 > 0.25$) was the San Jacinto River ($R^2 = 0.43$) which saw an increasing trend from near 0 mg/L in 1969 to 0.5 mg/L in 2001 (see Figure 4.2.23). Annual average nitrate-nitrite concentration trend graphs for the other study areas within the Galveston Bay estuary can be viewed in Appendix B.

Monthly average concentrations of nitrate-nitrate were found to have statistically significant trends in only two areas of Galveston Bay: Trinity Bay ($R^2 = 0.27$) and Cedar Bayou ($R^2 = 0.39$). Unfortunately neither area has been monitored for nitrate or nitrite since 1998. As seen in Figures 4.2.24 and 4.2.25, monthly average concentrations remain at or below 1.0 mg/L. Peak monthly average concentrations of nitrate-nitrite occurred primarily in winter and spring months when Trinity River flows were at their highest. Trend graphs for monthly average nitrate-nitrite concentrations in other areas of the Galveston Bay system can be seen in Appendix B.

Figure 4.2.22. Annual Average Total Nitrate + Nitrate-Nitrite in Water in the Houston Ship Channel

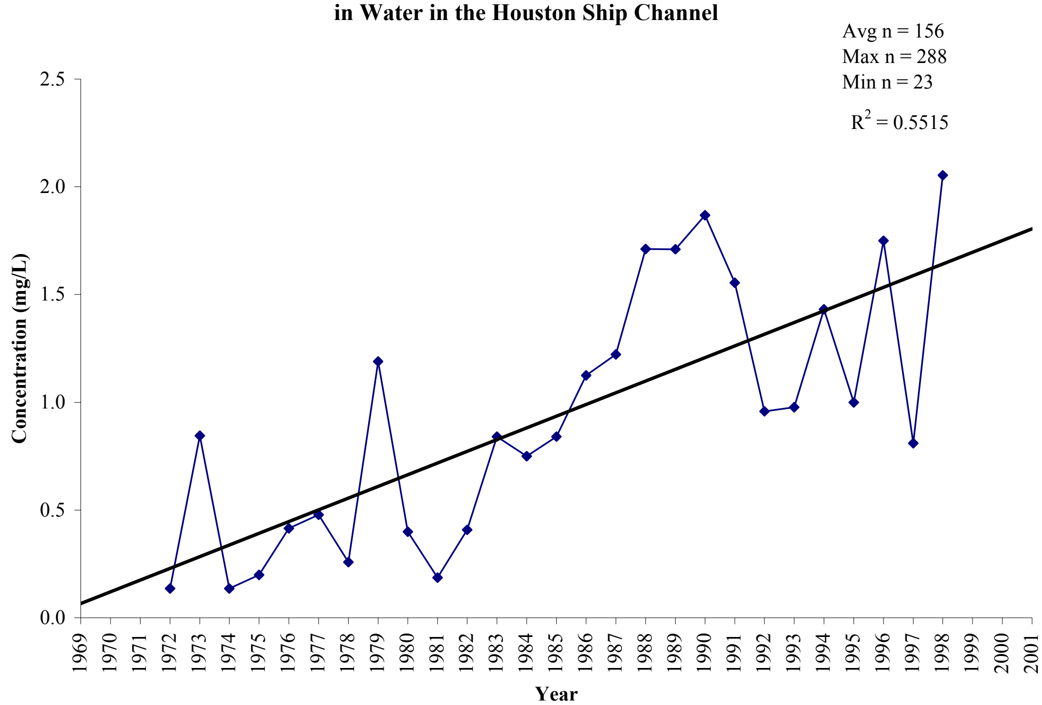


Figure 4.2.23. Annual Average Total Nitrate + Nitrate-Nitrite in Water in the San Jacinto River

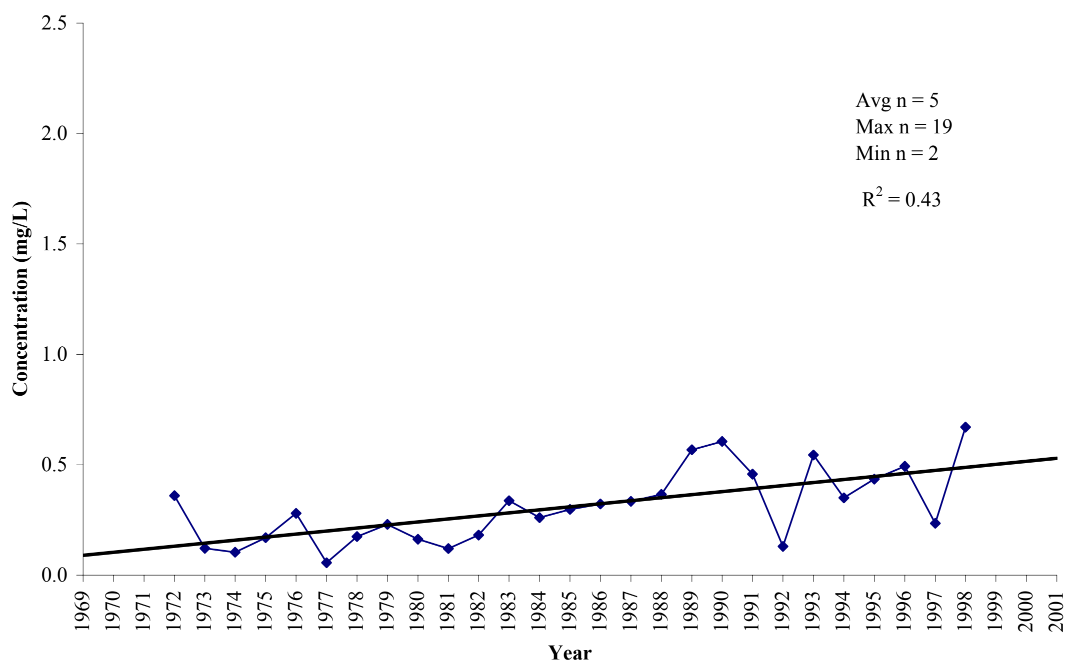


Figure 4.2.24. Monthly Average Nitrate + Nitrate-Nitrite in Water in Trinity Bay, 1969 to 1998

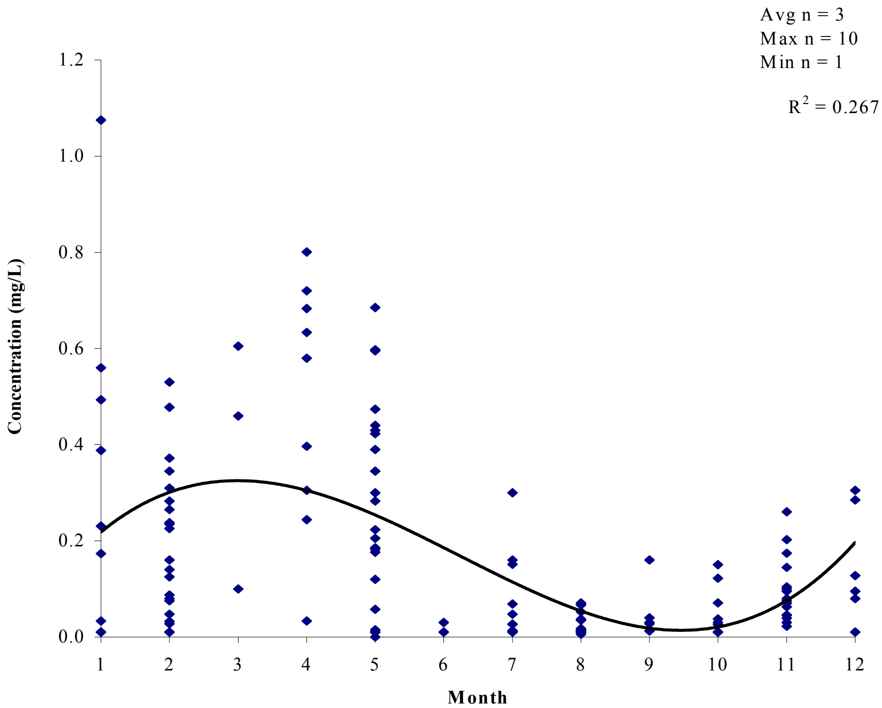
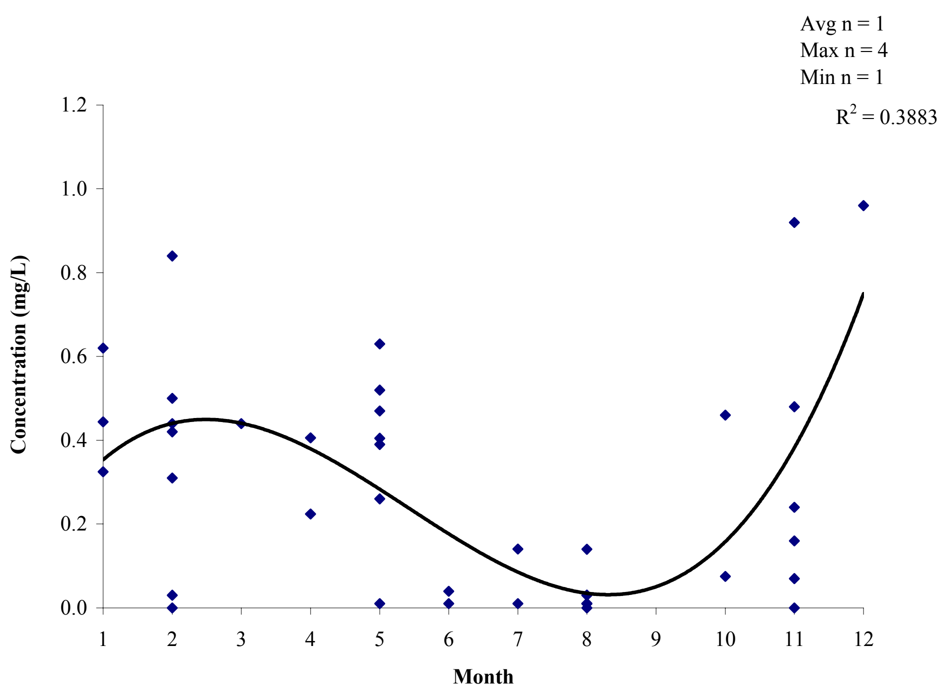


Figure 4.2.25. Monthly Average Nitrate + Nitrate-Nitrite in Water in Cedar Bayou, 1987 to 1998



Ammonia

Total ammonia concentrations in Galveston Bay have been sampled by the TCEQ since 1969. This data set is fairly complete with measurements collected in each sub-bay nearly every year for the period of record. Ammonia concentrations collected at all times and depths were analyzed and reported as mg/L.

The linear trends for annual average ammonia decline or remain stable across all areas of Galveston Bay with the most dramatic decline seen in the Houston Ship Channel (R^2 = 0.76). As seen in Figure 4.2.26, the highest annual average of nearly 3.3 mg/L occurred in 1974. The annual average concentration of ammonia in 2001 was approximately 0.5 mg/L.

Statistically significant decreasing trends ($R^2 > 0.25$) in ammonia concentration also occurred in Clear Creek and Clear Lake, East Bay, and the San Jacinto River (See Figure 4.2.27 and Appendix B). As seen in Figure 4.2.27, annual average ammonia concentrations in East Bay were at their highest levels of 1.8 mg/L in 1971 and 1.4 mg/L in 1974. A decline was seen in the 1980's with a sharper decline following in the 1990's.

There were no statistically significant trends ($R^2 > 0.25$) in monthly average ammonia concentrations in any of the eleven Galveston Bay study areas. However, the trend graphs for monthly average ammonia concentrations are included in Appendix B.

As seen in the status map for the year 2000 (Figure 4.2.28), the highest ammonia concentrations occurred in the tributaries of Galveston Bay with the Houston Ship Channel having the highest annual average concentration that year. The lowest annual average ammonia concentration was seen in Upper and Lower Galveston Bay.

Figure 4.2.26. Annual Average Total Ammonia in Water in the Houston Ship Channel

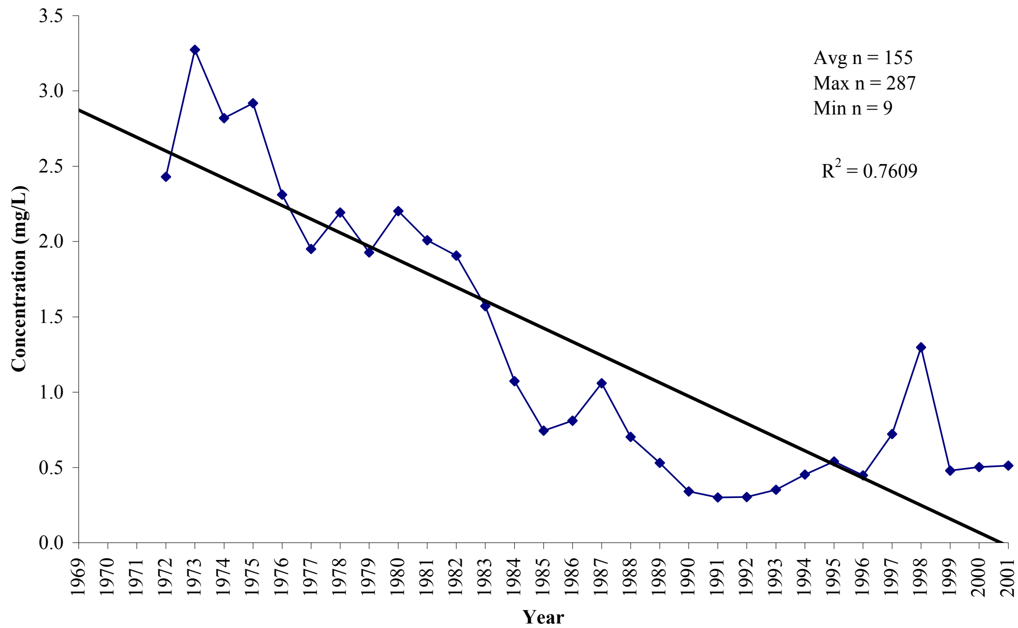


Figure 4.2.27. Annual Average Total Ammonia in Water in East Bay

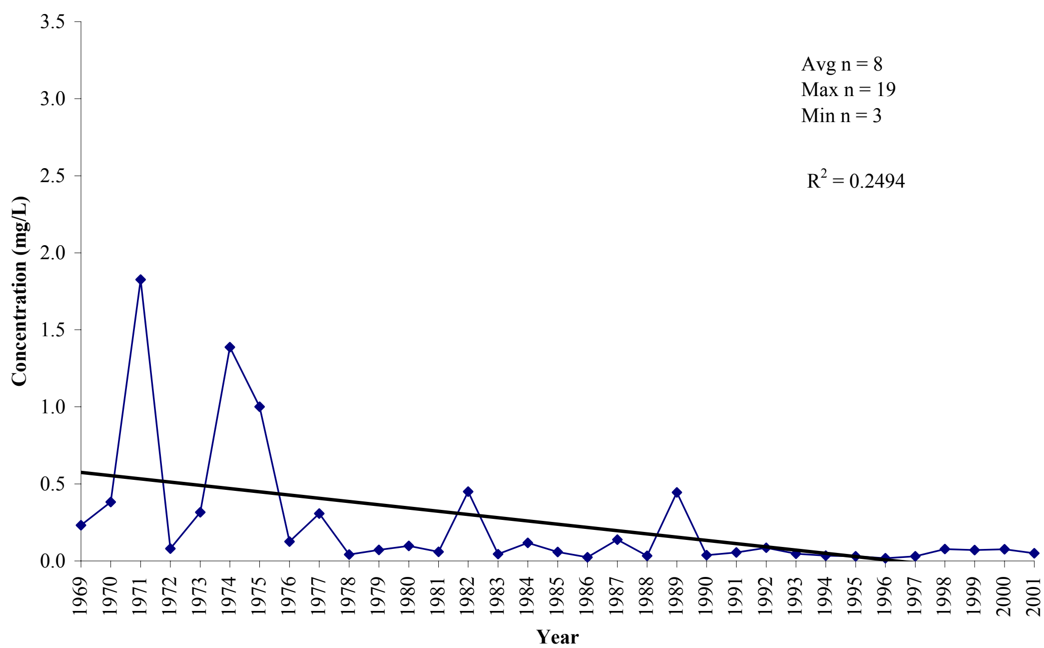
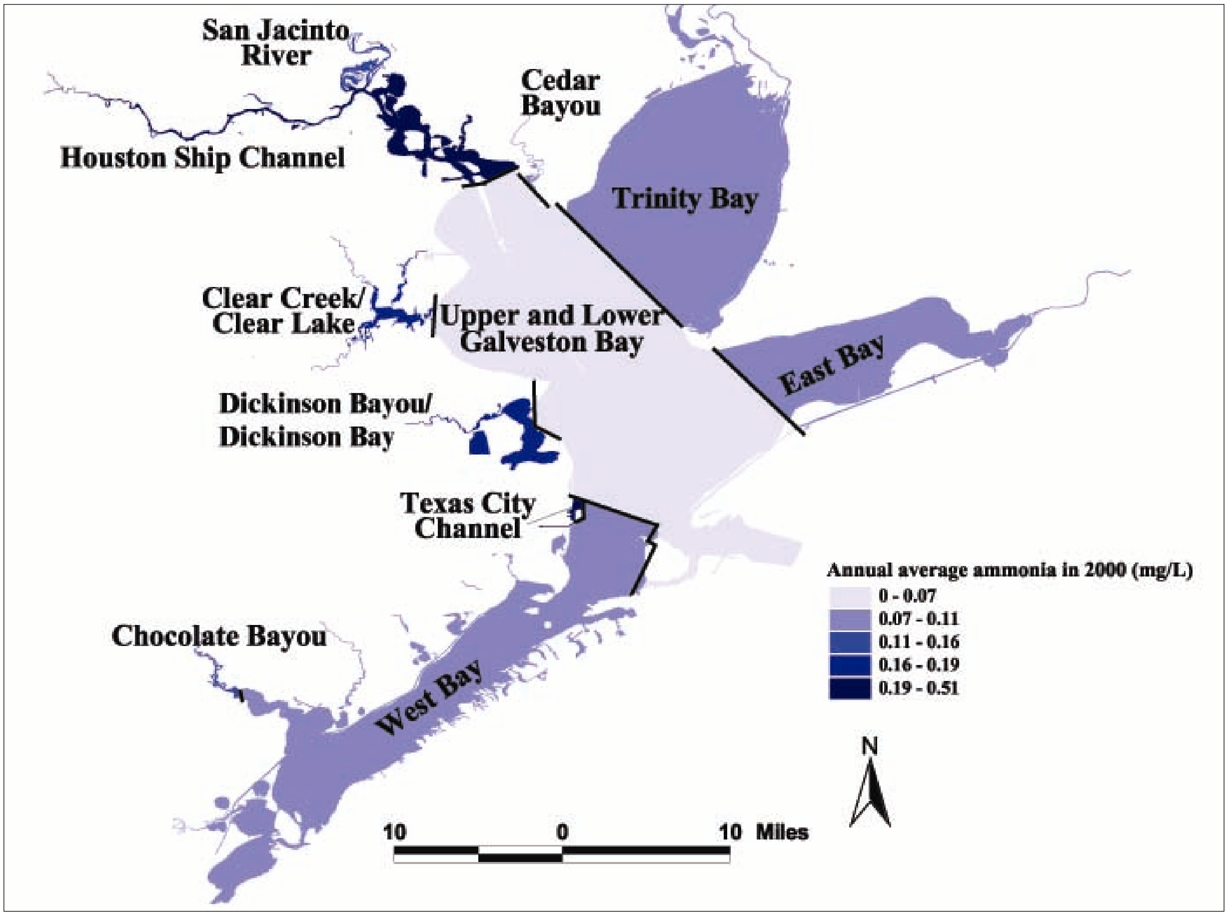


Figure 4.2.28. The status of annual average ammonia concentrations in waters of the Galveston Bay estuary in the year 2000.



Phosphorus

Total phosphorus concentrations in Galveston Bay have been sampled by the TCEQ since 1969. This data set is complete with measurements collected in every sub-bay for each year in the period of record. Phosphorus concentrations collected at all times and depths were analyzed and reported as mg/L.

Annual average phosphorus concentrations exhibited declining or stable trends in every sub-bay and tributary of Galveston Bay. Of the 11 study areas, five had statistically significant trends ($R^2 > 0.25$). Cedar Bayou ($R^2 = 0.41$), Dickinson Bayou and Dickinson Bay ($R^2 = 0.51$), East Bay ($R^2 = 0.24$), Upper and Lower Galveston Bay ($R^2 = 0.30$), and the Houston Ship Channel ($R^2 = 0.73$) all saw declining trends.

The most striking decline in phosphorus concentrations occurred in the Houston Ship Channel (see Figure 4.2.29). A peak annual average concentration of 2.2 mg/L occurred in 1974. Year 2001 saw an annual average concentration of 0.72 mg/L.

Peak annual average concentrations occurred in 1974 in each sub-bay (see Figure 4.2.29, 4.2.30 and Appendix B). Upper and Lower Galveston Bay saw its highest annual average phosphorus concentration of 1.14 mg/l in 1974. With the exception of 1973 and 1975, all other years remain at or below 0.5 mg/L (see Figure 4.2.30).

Peaks in annual average phosphorus concentrations occurred in Trinity Bay in 1974 (1.95 mg/L) and in 1979 (0.73 mg/L). Concentrations steadily declined through the 1980's and 1990's with annual averages remaining less than 0.5 mg/L

There were no statistically significant trends ($R^2 > 0.25$) in monthly average phosphorus concentrations in any of the eleven Galveston Bay study areas. However, the trend graphs for monthly average phosphorus concentrations are included in Appendix B.

As seen in the status map for the year 2000 (Figure 4.2.31), the highest total phosphorus concentrations occurred in the Houston Ship Channel, the San Jacinto River, Upper and Lower Galveston Bay, and Clear Creek and Clear Lake. The lowest annual average total phosphorus concentrations in 2000 were seen in West Bay and Dickinson Bayou and Dickinson Bay.

Figure 4.2.29. Annual Average Total Phosphorus in Water in the Houston Ship Channel

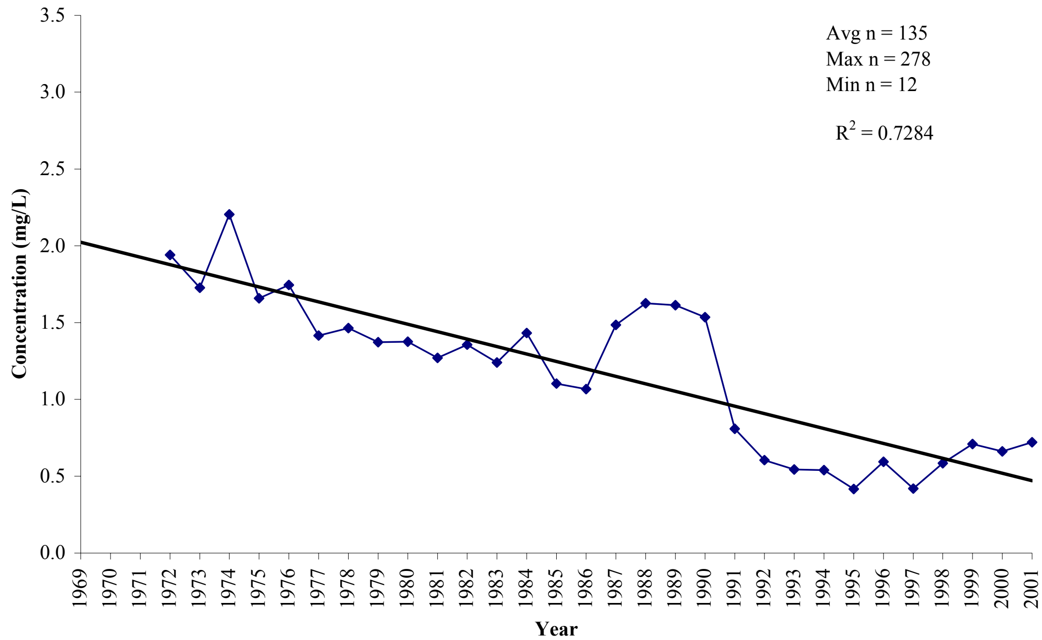


Figure 4.2.30. Annual Average Total Phosphorus in Water in Upper and Lower Galveston Bay

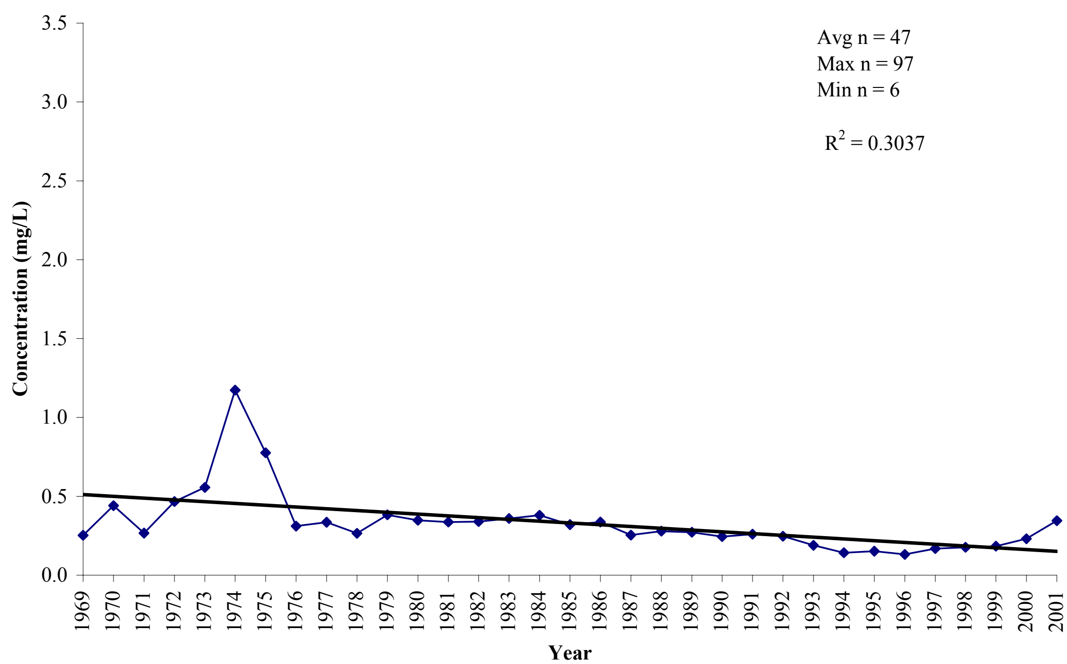
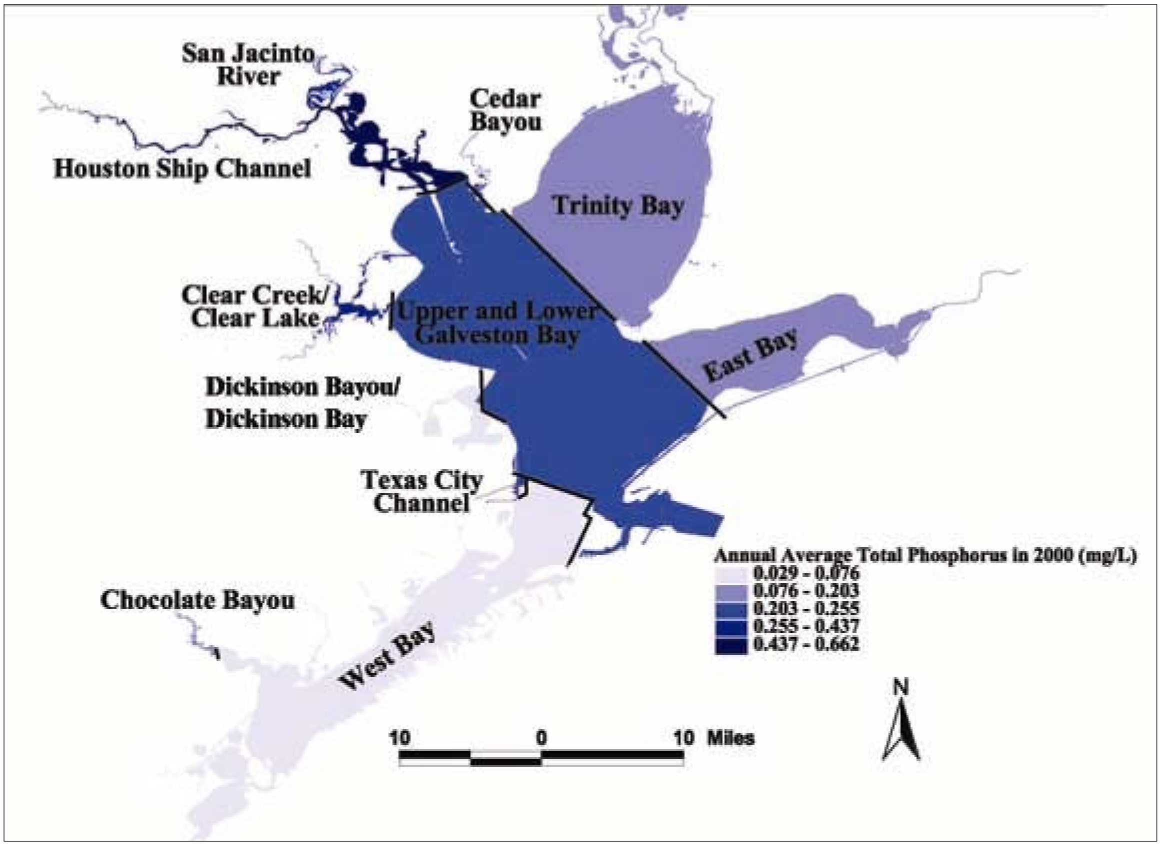


Figure 4.2.31. The status of annual average total phosphorus concentrations in waters of the Galveston Bay estuary in the year 2000.



Chlorophyll-a

Chlorophyll-a is a pigment commonly found in various species of phytoplankton and is used as an indicator of phytoplankton abundance. Chlorophyll-a concentrations in Galveston Bay have been sampled by the TCEQ since 1969. The chlorophyll-a data set is fairly complete, but contains data gaps for the years 1981-1984 across all sub-bays. Only those chlorophyll-a concentrations collected at a depth of 0.3 m were analyzed. Chlorophyll-a is reported as ug/L.

Trends in annual average concentrations of chlorophyll-a declined across all sub-bays and tributaries over the period of record. Declining trends were statistically significant ($R^2 > 0.25$) in 8 of the 11 study areas. Clear Creek and Clear Lake, Upper and Lower Galveston Bay, and Chocolate Bayou had declining trends identified as not statistically significant ($R^2 < 0.25$).

The strongest declining trends in average annual chlorophyll-a concentrations were found in the Houston Ship Channel ($R^2 = 0.64$) (see Figure 4.2.32), the San Jacinto River ($R^2 = 0.54$), and the Texas City Ship Channel ($R^2 = 0.51$).

Annual average chlorophyll-a concentrations in Trinity Bay also declined (Figure 4.2.33). High values were observed in 1972 (47.0 ug/L) and 1977 (41.2 ug/L). A low value of 1.0 ug/L was recorded in Trinity Bay in August 1983. As this was the only chlorophyll-a sample collected in Trinity Bay for that year, it gives the impression of a very low annual average. Annual averages remain below 15 ug/L for the years 1985-2000. The year 2001 then saw another peak of nearly 20 ug/L of chlorophyll-a.

Concentrations of chlorophyll-a in East Bay exhibited a decreasing trend ($R^2 = 0.37$). The highest average concentrations occurred in the early 1970's. Concentrations declined from the late 1970's through the 1990's with an increase occurring in 2001. The linear trend line for annual average chlorophyll-a West Bay decreased as well ($R^2 = 0.40$). Peaks of 20 ug/L and greater were evident in 1973 and 1978. As seen in Appendix B, average concentrations declined with smaller peaks occurring in 1996 and 2001.

The highest average concentration of chlorophyll-a was measured in Upper and Lower Galveston Bay in 2001 at a level of 81.9 ug/L. Other sub-bays and tributaries also saw increases in chlorophyll-a concentrations in 2001. They include Clear Creek and Clear Lake, Dickinson Bay and Dickinson Bayou, East Bay, Upper and Lower Galveston Bay, Trinity Bay, West Bay and the Texas City Ship Channel. However, it should be noted that the data for chlorophyll-a in 2001 includes only those samples collected in January through March of that year. It is not a true annual average.

There were no statistically significant trends ($R^2 > 0.25$) in monthly average chlorophyll-a concentrations in any of the eleven Galveston Bay study areas. However, the trend graphs for monthly average chlorophyll-a concentrations are included in Appendix B.

As seen in the status map below for the year 2000 (Figure 4.2.34), the highest chlorophyll-a concentrations occurred in Clear Creek and Clear Lake, Chocolate Bayou, and Upper and Lower Galveston Bay. The lowest annual average chlorophyll-a concentrations in 2000 were seen in West Bay and the San Jacinto River.

Figure 4.2.32. Annual Average Chlorophyll-a in Water in the Houston Ship Channel

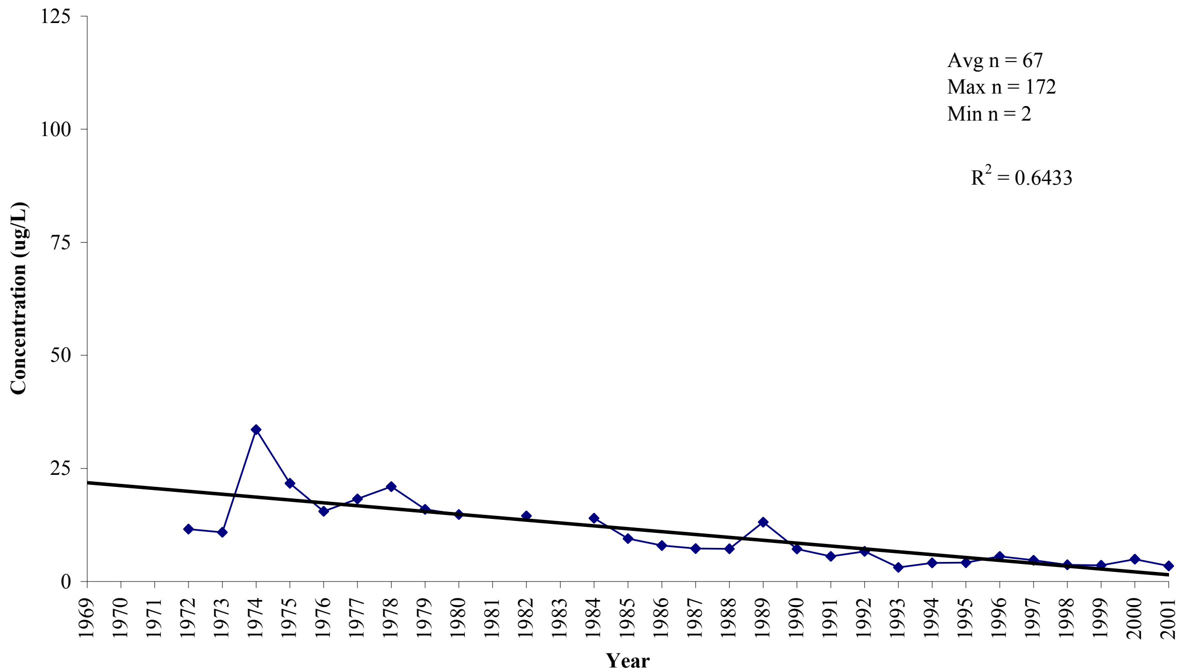


Figure 4.2.33. Annual Average Chlorophyll-a in Water in Trinity Bay

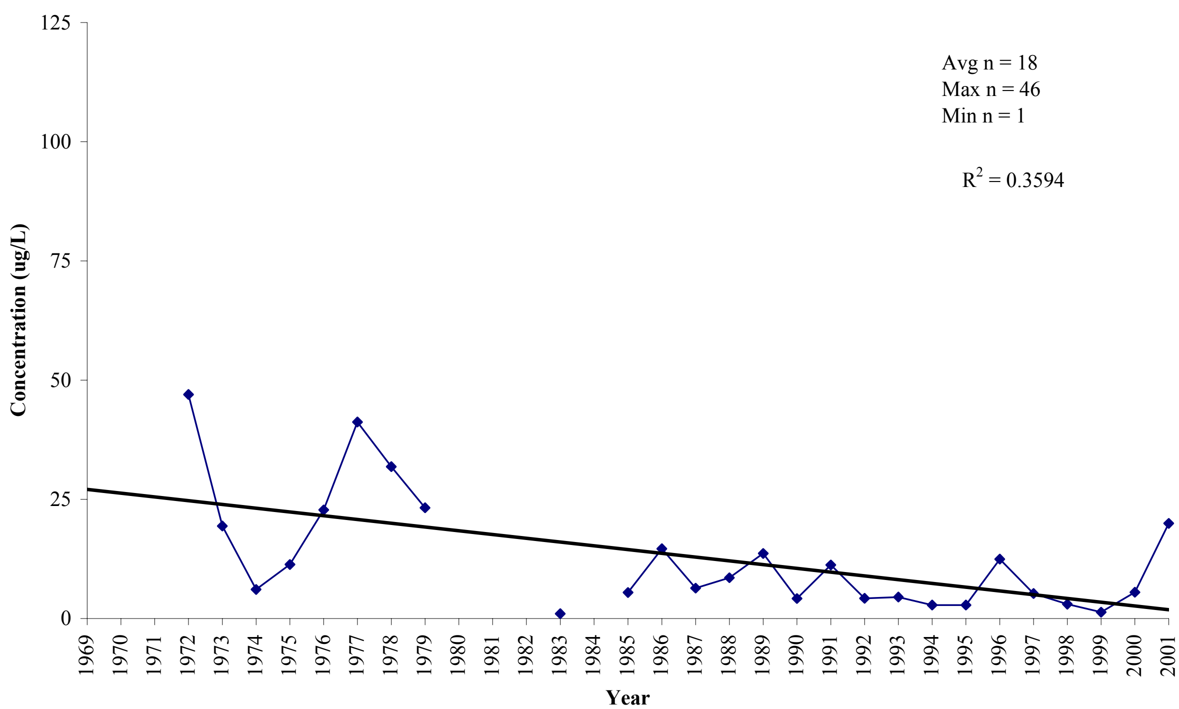
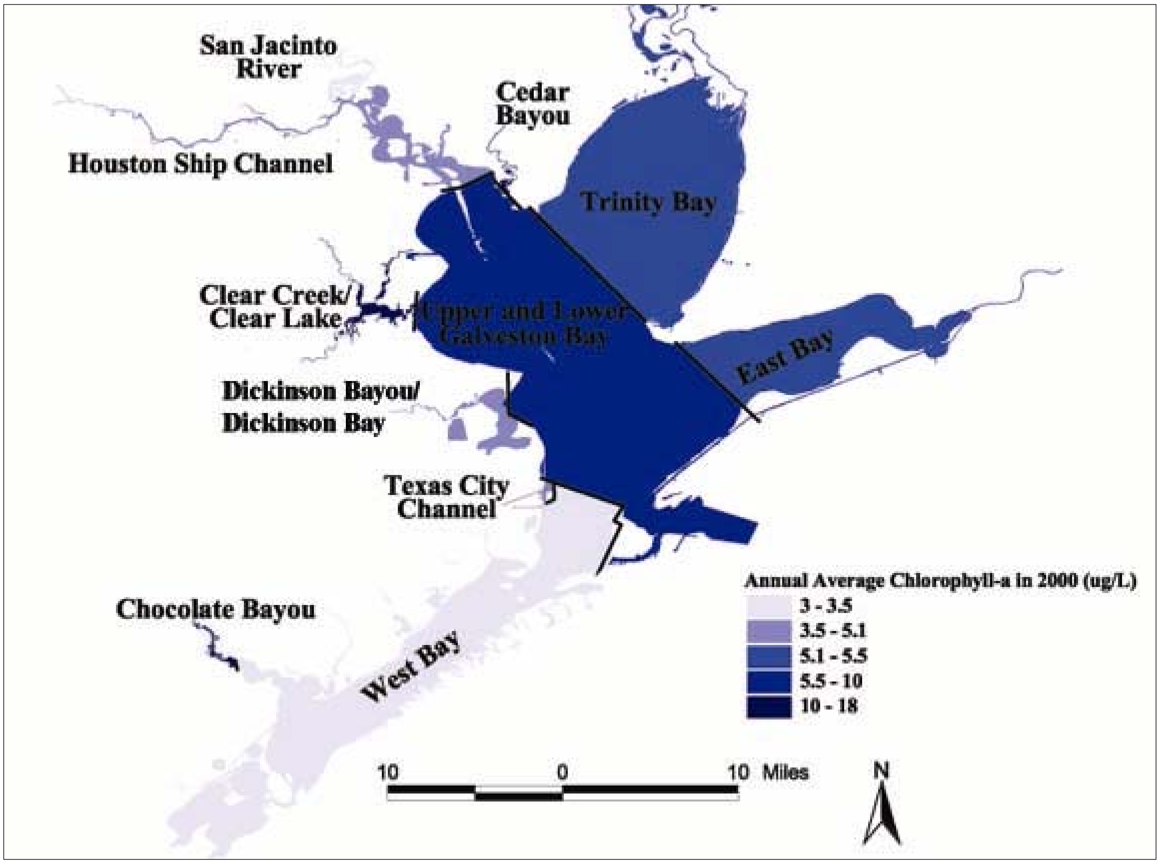


Figure 4.2.34. The status of annual average chlorophyll-a concentrations in waters of the Galveston Bay estuary in the year 2000.



4.2.3 Pathogens

Data on the pathogen parameters analyzed in this study were originally collected by the TCEQ and acquired from their water and sediment quality database. The analyzed parameters were fecal coliform bacteria and Enterococci, which are used indicators for water quality since their presence is often related to the presence of other, more harmful pathogens.

It should be noted that the U.S. Environmental Protection Agency and the TCEQ have recommended changes regarding appropriate bacterial indicator measures for estuarine and marine waters. The traditional bacterial indicator, fecal coliform, will be replaced by *E. coli* for freshwater and *Enterococci* for estuarine and marine waters.

The TCEQ uses standardized sampling methodologies when collecting these data. These sampling methodologies can be reviewed in the TCEQ Surface Water Quality Monitoring Procedures Manual (TCEQ, 1999).

Fecal Coliform Bacteria
Concentrations of fecal coliform bacteria in Galveston Bay and its tributaries have been sampled by the TCEQ since 1973. For the period 1973-1993, the TCEQ utilized a broth medium for bacterial culture. For the time period 1994-1998 the agency utilized an agar medium for bacterial cultures. For the time period 1999-2001, data on both bacterial culture methods were reported by the agency. Since both methods result in comparable data, the data sets were combined for trend analysis. Data are reported as number of colonies per 100 mL. Because of the large differences in fecal coliform concentrations between sub-bays and tributaries, the y-axes of the trends graphs are set on a logarithmic scale.

There were no statistically significant ($R^2 > 0.25$) trends in annual average fecal coliform concentration found in any of the sub-bays or tributaries of the Galveston Bay system. The highest overall levels were observed in the Houston Ship Channel, Clear Creek and Clear Lake, and Dickinson Bay and Dickinson Bayou in that order.

Concentrations in the Houston Ship Channel (which included samples collected from White Oak and Buffalo Bayous) were very high when compared to the other tributaries and sub-bays of Galveston Bay (see Figure 4.2.35). The highest annual average concentration of 74,092 colonies per 100 mL occurred in the Houston Ship Channel in 1979. Since that time, concentrations in the Houston Ship Channel remained below 20,000 colonies per 100 mL. No data existed for fecal coliform concentrations in the Houston Ship Channel for the years 1996-1998. To facilitate the computation of a trend line, the 1996-1998 data points are an annual average of fecal coliform bacteria concentrations for all years in the Houston Ship Channel.

Annual average concentrations of fecal coliform bacteria were also relatively high in Clear Creek and Clear Lake. The highest annual average of 4,660 colonies per 100 mL occurred in 1994. An earlier peak of 4,400 colonies per 100 mL occurred in 1975 (see

Appendix B).

Dickinson Bayou and Dickinson Bay saw a high annual average concentration of 14,807 colonies per 100 mL in 1989. Peak concentrations were also evident in 1991, 1995 and 1998. Chocolate Bayou saw peak concentrations in the early to mid 1980's as well as throughout the 1990's (see Appendix B).

The Texas City Ship Channel saw the lowest annual average concentrations of fecal coliform for any of the tributaries or channels analyzed in Galveston Bay. Concentrations remained below 200 colonies per 100 mL with the exception of a peak of 2,340 colonies per 100 mL in 1990 (see Figure 4.2.36).

Annual average concentrations of fecal coliform bacteria remained considerably lower in the sub-bays than in the tributaries and channels of Galveston Bay. With the exception of several years where concentrations peaked near 10,000 colonies per 100 mL in West Bay and East Bay, concentrations remained near or below 500 colonies per 100 mL in all sub-bays (see Appendix B).

There were no statistically significant trends ($R^2 > 0.25$) in monthly average fecal coliform concentrations in any of the eleven Galveston Bay study areas. However, the trend graphs for monthly average fecal coliform concentrations are included in Appendix B.

As seen in the status table for the year 2000 (Table 4.2.1), the highest fecal coliform concentrations occurred in the Houston Ship Channel, Clear Creek and Clear Lake, and Dickinson Bayou and Dickinson Bay. The lowest annual average fecal coliform concentrations in 2000 were seen in Trinity Bay, the Texas City Ship Channel, and East Bay. Chocolate Bayou also saw a low annual average fecal coliform concentration in 2000. However, the sample seize was very small (n=4).

Figure 4.2.35. Annual Average Fecal Coliform Concentrations in Water in the Houston Ship Channel

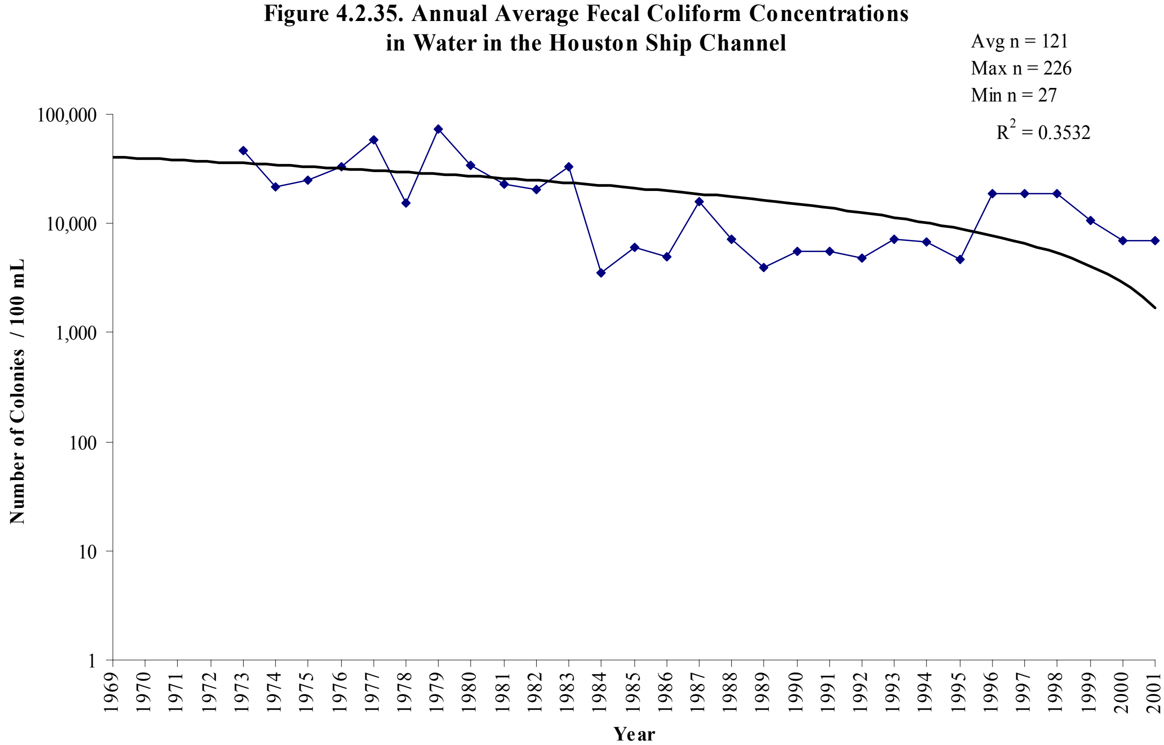


Figure 4.2.36. Annual Average Fecal Coliform Concentrations in Water in the Texas City Ship Channel

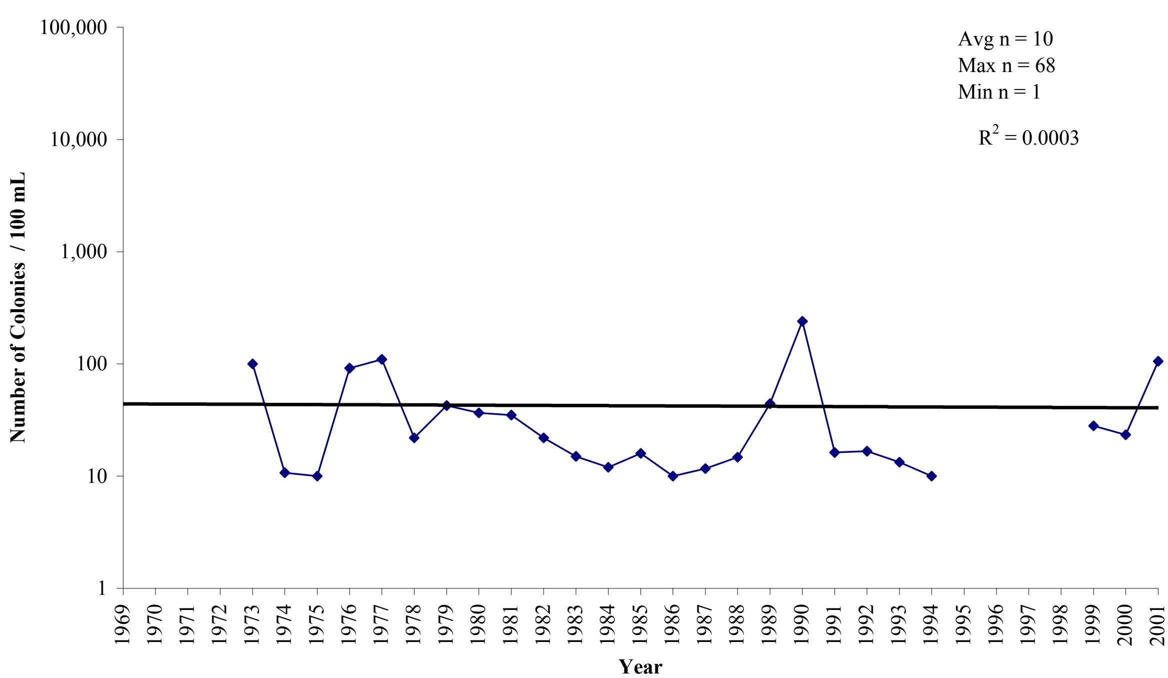


Table 4.2.1. The status of annual average fecal coliform concentrations in waters of the Galveston Bay estuary in the year 2000.

GBEP Segment ID	**Sub-Bay or Tributary Name**	**Annual Average Concentration in 2000 (colonies/100 mL)**	**Number of Samples (n)**
C	Clear Creek and Clear Lake	2,397.9	128
C6	Cedar Bayou	28.0	2
D	Dickinson Bayou and Dickinson Bay	1,493.9	189
E	East Bay	24.0	44
G	Upper and Lower Galveston Bay	97.6	125
H	Houston Ship Channel	6,088.3	279
S	San Jacinto River	81.4	15
T	Trinity Bay	15.8	46
W	West Bay	49.5	137
W8	Chocolate Bayou	10.0	4
W18	Texas City Ship Channel	22.4	45

<u>*Enterococci*</u>

The TCEQ water quality database contains data for the parameter, *Enterococci*, as analyzed under the IDEXX method. The TCEQ began sampling this water quality parameter in 2000 in addition to the continued sampling of fecal coliform bacteria. In the future, *Enterococci* will replace fecal coliform as the bacterial water quality indicator for estuarine and marine waters. The Status and Trends *Enterococci* data set contains data for the years 2000-2002. It should be noted that 2001 is the only year for which the Status and Trends project has a complete year of data for all sub-bays and tributaries of the Galveston Bay system. Data are reported as most probable number (MPN) per 100mL.

Since there is only one complete year of data, it is not possible to determine a trend in annual average *Enterococci* concentrations for the Galveston Bay estuary. Rather, *Enterococci* concentrations can best be shown in the form of a status table (see Table 4.2.2. below).

In the year 2001, the highest annual average *Enterococci* concentration of 2,876.3 (MPN per 100 mL) occurred in Cedar Bayou. However, that number is based on a small number of samples (n=4). Of those areas with the largest sample size, the Houston Ship Channel had the highest annual average *Enterococci* concentration of 639.5 (MPN per 100 mL; n=47), while the lowest annual average concentration of 10.5 (MPN per 100 mL) occurred in West Bay (n=22).

Table 4.2.2. The status of annual average *Enterococci* concentrations in waters of the Galveston Bay estuary in the year 2001.

GBEP Segment ID	Sub-Bay or Tributary Name	Annual Average Concentration in 2001 (MPN/100 mL)	Number of Samples (n)
C	Clear Creek and Clear Lake	390.7	12
C6	Cedar Bayou	2,876.3	4
D	Dickinson Bayou and Dickinson Bay	14.2	5
E	East Bay	19.4	14
G	Upper and Lower Galveston Bay	11.8	57
H	Houston Ship Channel	639.5	47
S	San Jacinto River	127.7	3
T	Trinity Bay	21.3	32
W	West Bay	10.5	22
W8	Chocolate Bayou	10.0	3
W18	Texas City Ship Channel	10.0	4

4.2.4 Inorganic Compounds

Data on the concentration of inorganic compounds in water in Galveston Bay were collected by the TCEQ. The Status and Trends Project analyzed these data for the major sub-bays in the Galveston Bay system and the Houston Ship Channel. Inorganic compounds include metals such as dissolved arsenic, dissolved cadmium, dissolved chromium, dissolved copper, total mercury, dissolved nickel, dissolved lead and dissolved zinc.

Concentrations of dissolved metals in Galveston Bay were sampled by the TCEQ from 1989-2001. Concentrations of total mercury have been sampled in Galveston Bay since 1973. Samples collected at all depths and times were analyzed. Data are reported as ug/L. See Appendix B for additional graphs.

Arsenic

Inorganic arsenic compounds are mainly used to preserve wood and are also used as pesticides, primarily on cotton plants (ATSDR, 2002).

There were no statistically significant trends ($R^2 > 0.25$) in annual or monthly average dissolved arsenic concentrations in any of the eleven Galveston Bay study areas. Annual average concentrations of dissolved arsenic in the four sub-bays, the Houston Ship Channel (see Figure 4.2.37) and the San Jacinto River peaked in 1996 for reasons unknown to the investigators. The highest annual average concentrations of dissolved arsenic in the Galveston Bay estuary were seen in West Bay in 1991, 1996 and 1999 (see Figure 4.2.38). In East Bay, annual average concentrations remained below 15 ug/L with the exception of 1996 and 1997, which saw annual averages of 33.5 ug/L and 31.7 ug/L respectively.

There were not enough data to determine trends in monthly average dissolved zinc concentrations in any of the eleven Galveston Bay study areas. Trend graphs not included here can be viewed in Appendix B.

Figure 4.2.37. Annual Average Dissolved Arsenic in Water in the Houston Ship Channel

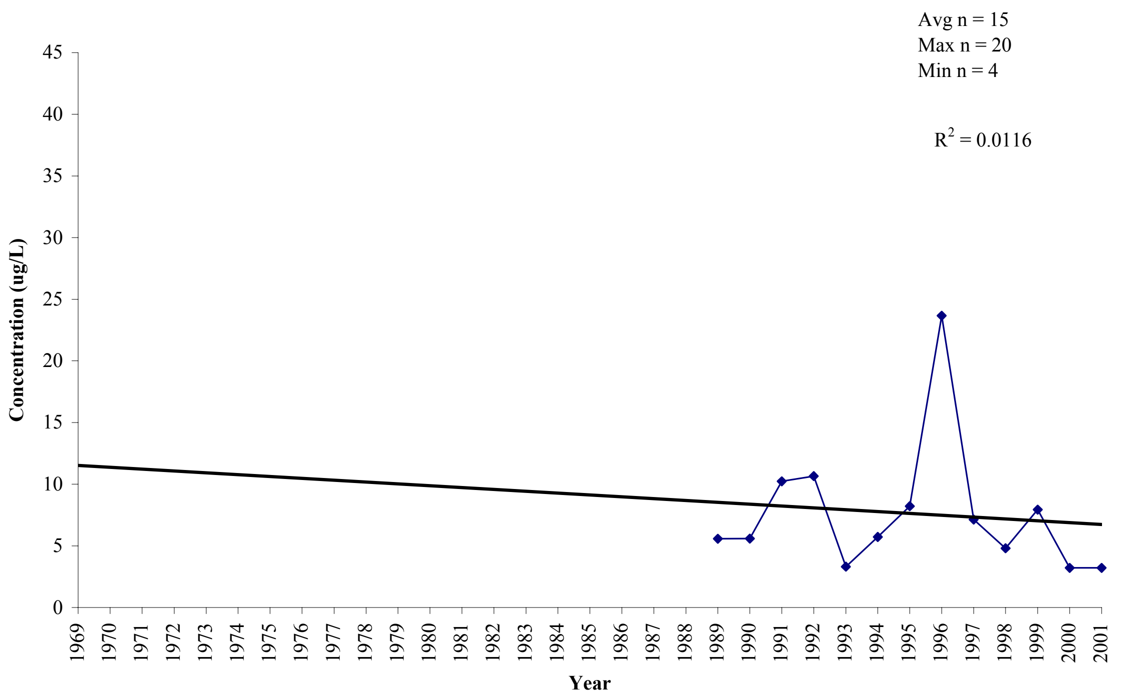
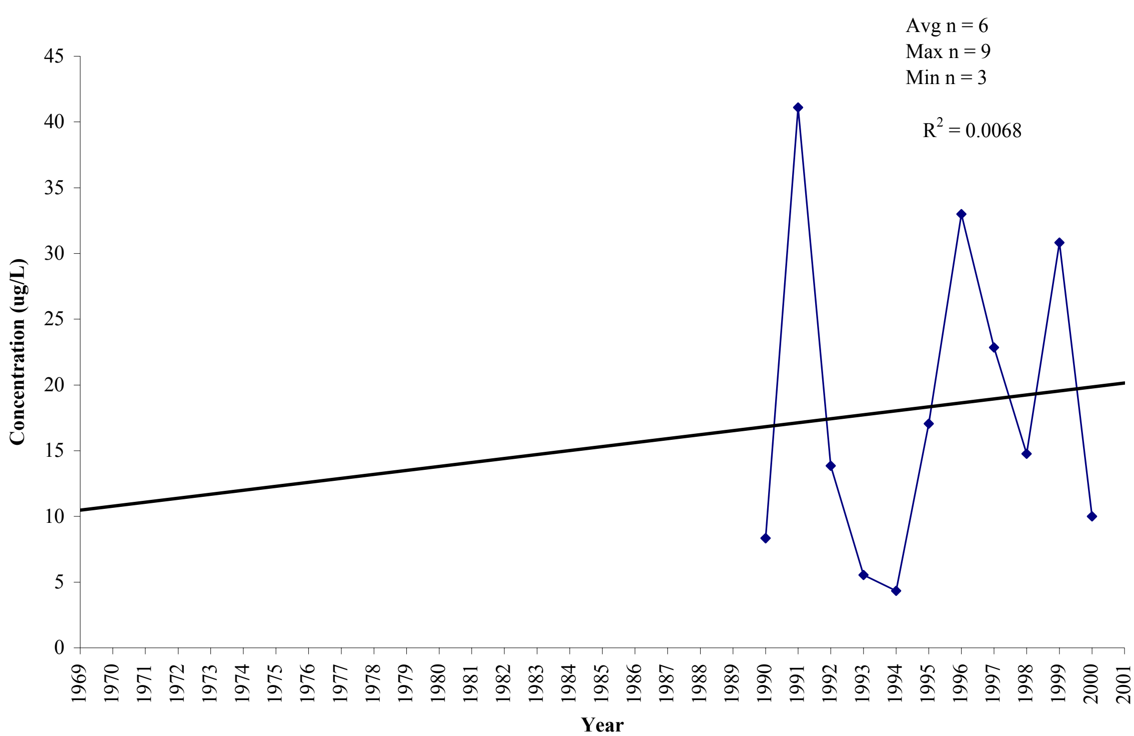


Figure 4.2.38. Annual Average Dissolved Arsenic in Water in West Bay



Cadmium

Besides being a naturally occurring element, cadmium is extracted during the production of other metals like zinc, lead, and copper. Cadmium does not corrode easily and has many uses, including batteries, pigments, metal coatings, and plastics (ATSDR, 2002).

Annual average dissolved cadmium concentrations in water increased ($R^2 > 0.25$) across all four sub-bays, the Houston Ship Channel, and the San Jacinto River for the period 1989-2001. Annual average concentrations range from 1 to 7 ug/L. The lowest annual average of approximately 1 ug/L occurred in 1991 in each of the sub-bays, the Houston Ship Channel, and the San Jacinto River (see Figures 4.2.39, 4.2.40 and Appendix B). There were not enough data to determine statistically significant trends ($R^2 > 0.25$) in monthly average dissolved cadmium concentrations in any of the eleven Galveston Bay study areas.

Figure 4.2.39. Annual Average Dissolved Cadmium in Water in the Houston Ship Channel

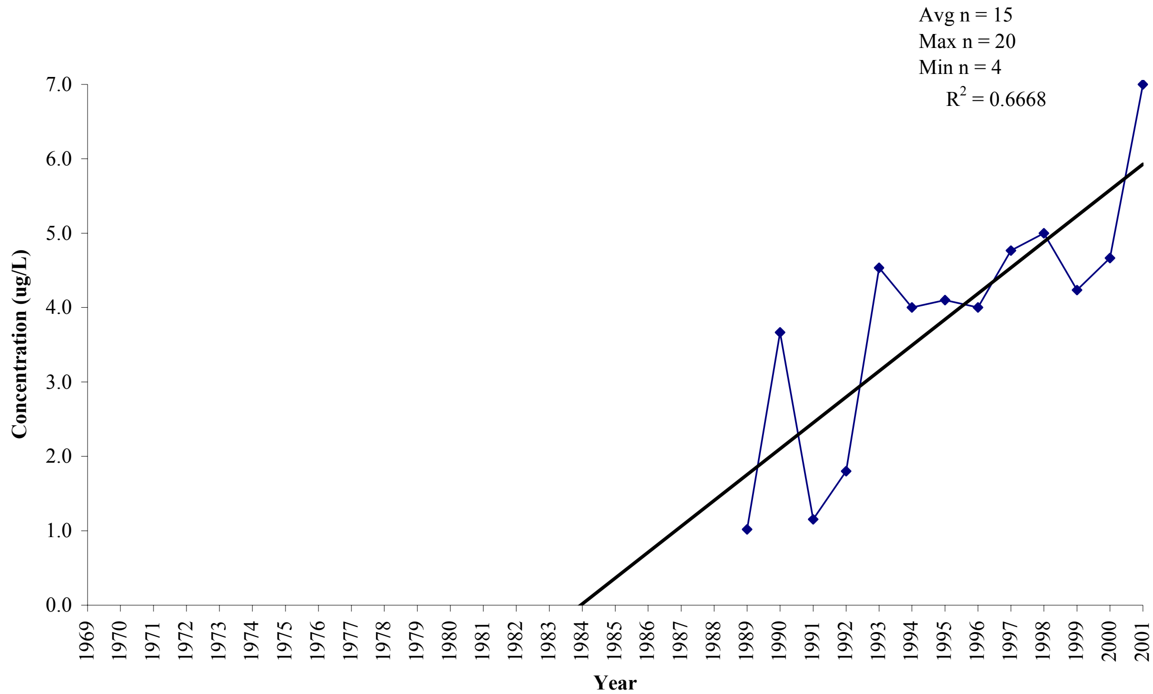
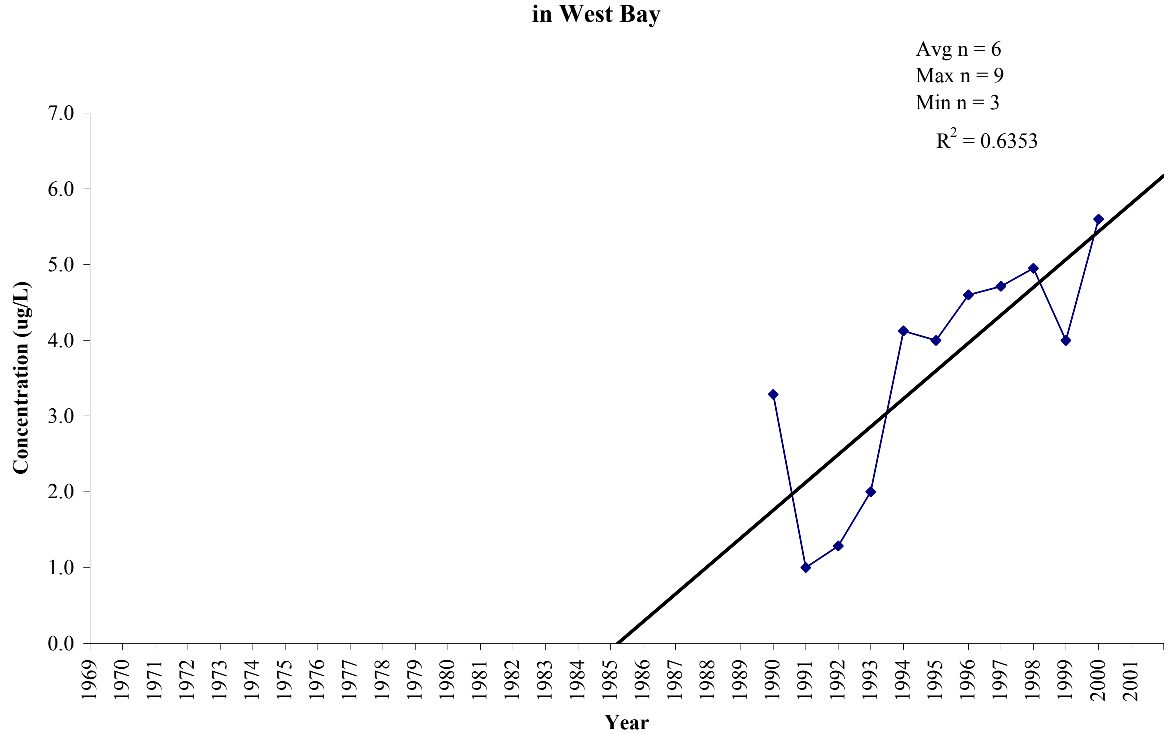


Figure 4.2.40. Annual Average Dissolved Cadmium in Water in West Bay



Chromium

Chromium can be found in the environment in several forms. Chromium(III) occurs naturally in the environment and is an essential nutrient. Chromium(VI) and chromium(0) are generally produced by industrial processes (ATSDR, 2002). The metal chromium, which is the chromium(0) form, is used for making steel while chromium(VI) and chromium(III) are used for chrome plating, dyes and pigments, leather tanning, and wood preserving (ATSDR, 2002).

Annual average dissolved chromium concentrations in water significantly ($R^2 > 0.25$) decreased across East Bay, Trinity Bay, West Bay, the Houston Ship Channel, and the San Jacinto River for the period 1989-2001. Upper and Lower Galveston Bay was the only sub-bay to not show a statically significant trend. Annual average concentrations ranged from less than 1ug/L to approximately 66 ug/L.

As seen in Figure 4.2.41, West Bay had a peak average concentration of 66.1 ug/L in 1991. The Houston Ship Channel also saw its highest annual average concentration of 27.8 ug/L that year. Concentrations continued to decline in the following years.

In 1992 East Bay, Trinity Bay and Upper and Lower Galveston Bay (see Figure 4.2.42 and Appendix B) exhibited peak annual average concentrations of 6 ug/L, 23.3 ug/L and 53.8 ug/L, respectively. Concentrations continued to decline since. There were not enough data to determine statistically significant trends ($R^2 > 0.25$) in monthly average dissolved chromium concentrations in any of the eleven Galveston Bay study areas.

Figure 4.2.41. Annual Average Dissolved Chromium in Water in West Bay

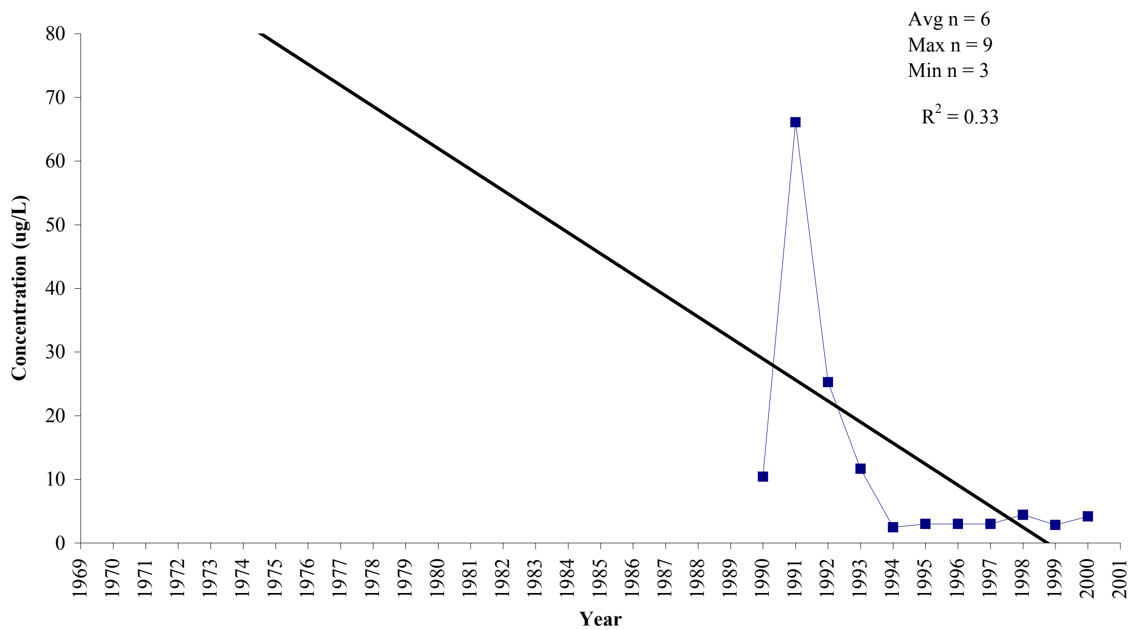
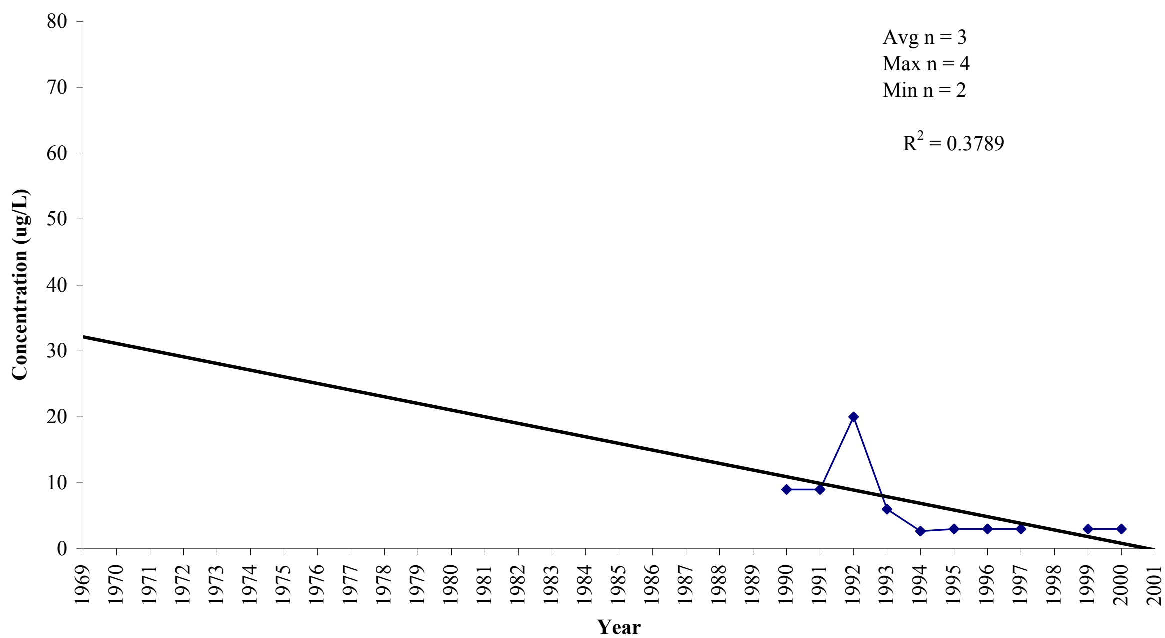


Figure 4.2.42. Annual Average Dissolved Chromium in Water in East Bay



Copper
Copper is a metal that occurs naturally in the environment and is an essential element for all living things. Copper is mined in the United States and is used to make wire, sheet metal, pipes, and pennies. It is also used agriculturally to treat some plant diseases; in water treatment; and to preserve wood, leather, and fabrics (ATSDR, 2002).

Annual average dissolved copper concentrations in water decreased across all four sub-bays, the Houston Ship Channel, and the San Jacinto River for the period 1989-2001 (See Figure 4.2.43, Figure 4.2.44, and Appendix B). Annual average concentrations ranged from near 3 ug/L to approximately 14 ug/L. There were not enough data to determine statistically significant trends ($R^2 > 0.25$) in annual average dissolved copper concentrations in the remaining five Galveston Bay study areas.

As seen in Figure 4.2.43, West Bay had a peak average concentration of 14.25 ug/L in 1993. The Houston Ship Channel saw its highest annual average concentration of 9.3 ug/L in 1991 (see Figure 4.2.44). There were not enough data to determine statistically significant trends ($R^2 > 0.25$) in monthly average dissolved copper concentrations in any of the eleven Galveston Bay study areas.

Figure 4.2.43. Annual Average Dissolved Copper in Water in West Bay

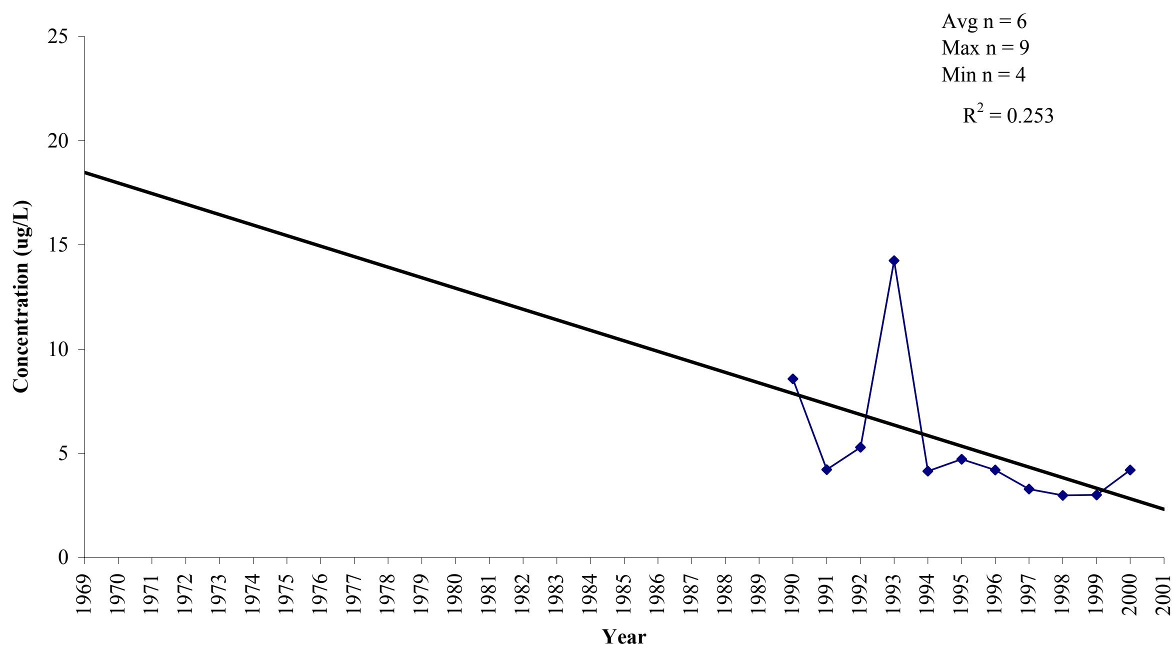
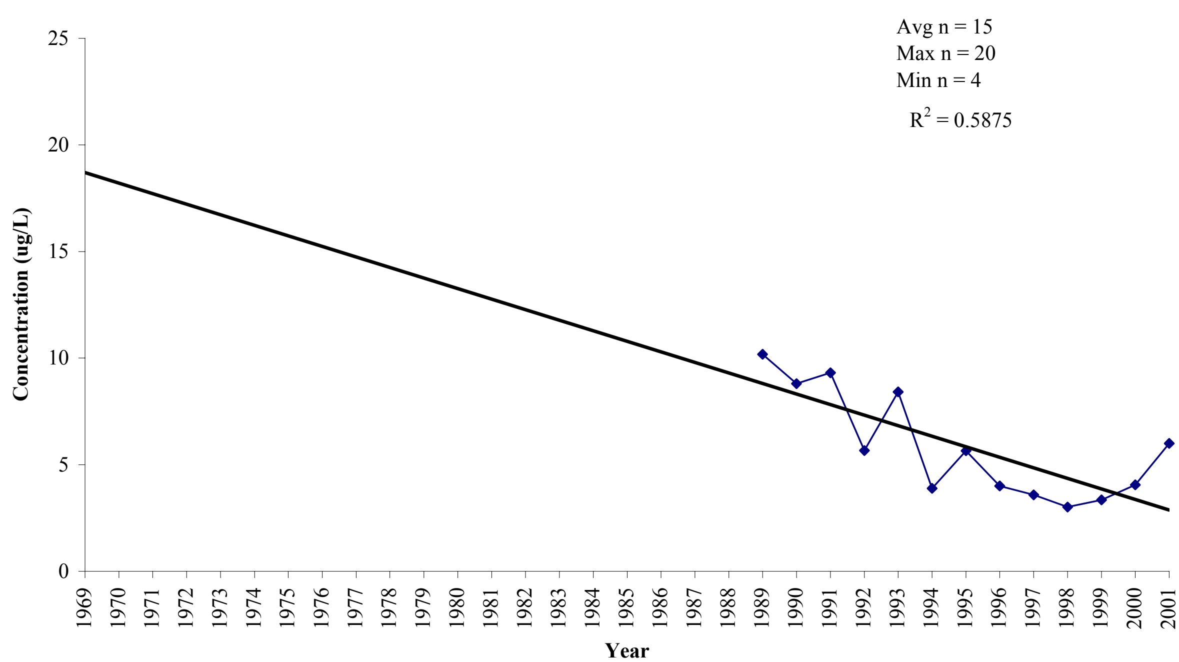


Figure 4.2.44. Annual Average Dissolved Copper in Water in the Houston Ship Channel



Mercury

Mercury is a naturally occurring metal and has several forms. Mercury can be metabolically transformed to methylmercury by organisms. This form of mercury is highly toxic and is readily bioaccumulated by organisms. Metallic mercury is used to produce chlorine gas and caustic soda, and is also used in thermometers, dental fillings, and batteries (ATSDR, 2002). Mercury salts are sometimes used in skin lightening creams and as antiseptic creams and ointments (ATSDR, 2002).

Trends in annual average concentrations of total mercury in water were difficult to discern. Four study areas (Clear Creek and Clear Lake, Cedar Bayou, Dickinson Bayou and Dickinson Bay, and East Bay) had less than 10 years of data, making them unsuitable for trend analysis. Of the seven areas with more than ten years of data, only two yielded statistically significant trends ($R^2 > 0.25$) for the period 1973-2001. Annual average concentrations ranged from near 0 ug/L to 3.6 ug/L. Trends graphs not included here can be viewed in Appendix B.

As seen in Figure 4.2.45, the Houston Ship Channel exhibited an obviously declining trend ($R^2 = 0.43$). This area saw the highest mercury concentrations of any of the areas studied in Galveston Bay. The highest average concentration of 3.6 ug/L occurred in 1974. Annual average concentrations declined steadily since. The San Jacinto River (Figure 4.2.46) also exhibited a declining trend ($R^2 = 0.75$) from approximately 0.4 ug/L to near 0 ug/L.

There were not enough data to determine trends in monthly average total mercury concentrations in any of the eleven Galveston Bay study areas.

Figure 4.2.45. Annual Average Total Mercury in Water in the Houston Ship Channel

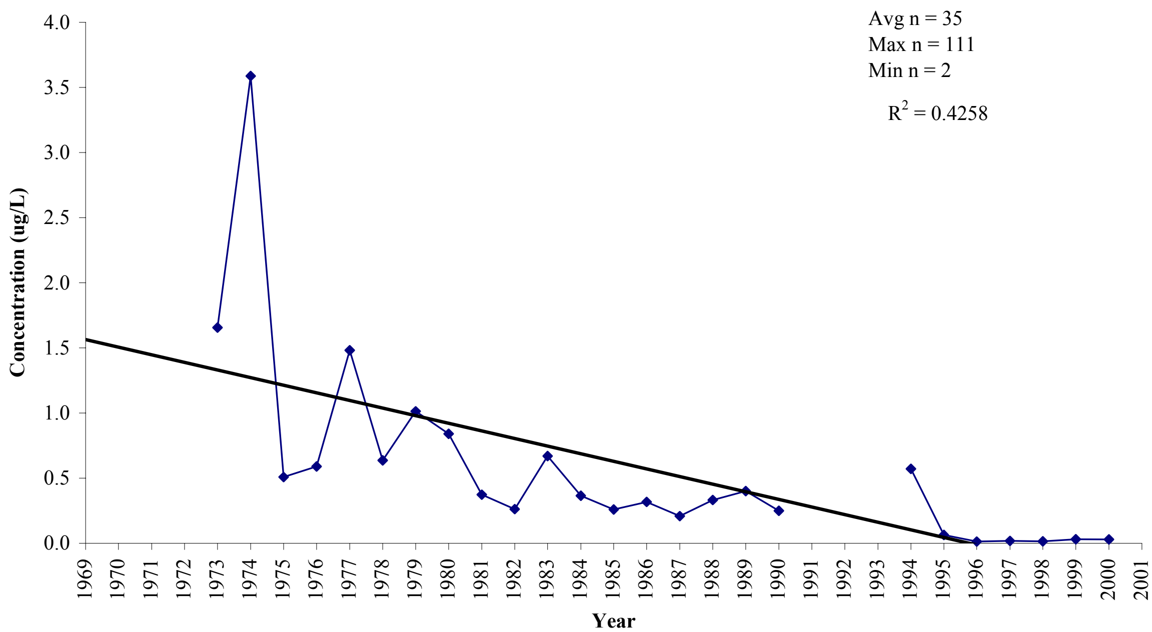
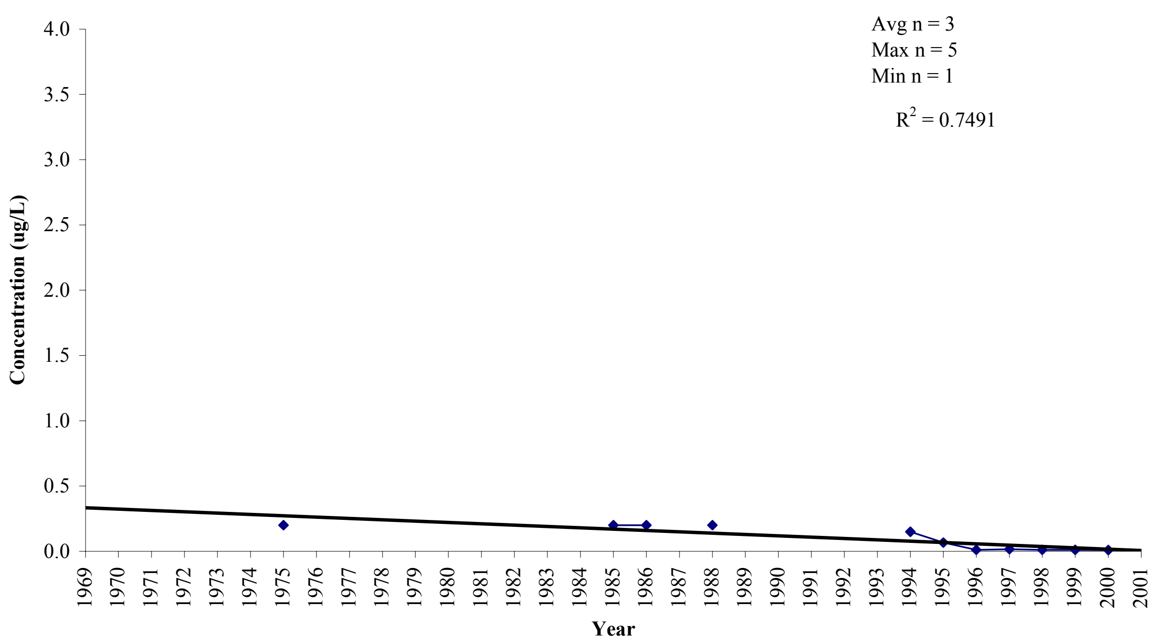


Figure 4.2.46. Annual Average Total Mercury in Water in the San Jacinto River



Nickel

Nickel is a naturally occurring element. It can be combined with other metals to form alloys and are used in the making of metal coins and jewelry Nickel compounds are also used for nickel plating, to color ceramics, to make some batteries, and as substances known as catalysts that increase the rate of chemical reactions. Nickel and its compounds have no characteristic odor or taste (ATSDR, 2002).

Trends in annual average concentrations of dissolved nickel in water were difficult to determine. Five study areas (Clear Creek and Clear Lake, Cedar Bayou, Dickinson Bayou and Dickinson Bay, Chocolate Bayou, and the Texas City Ship Channel) had less than 10 years of data, making them unsuitable for trend analysis.

Of the six study areas with more than ten years of data, only two yielded statistically significant trends ($R^2 > 0.25$) for the period 1989-2001. Even so, dissolved nickel concentrations appeared to be in decline across most of Galveston Bay. Annual average concentrations in the Galveston Bay estuary ranged from approximately 9 ug/L to 97 ug/L.

As seen in Figure 4.2.47, West Bay saw the highest nickel concentration of any of the areas studied in Galveston Bay. The highest annual average concentration of 97.2 ug/L occurred in 1991. Concentrations then declined and remained near 10 ug/L.

Declining trends occurred in Upper and Lower Galveston Bay ($R^2 = 0.27$) (Figure 4.2.48) and East Bay ($R^2 = 0.27$) (Appendix B). The remaining sub-bays and tributaries showed slightly declining linear trends ($R^2 < 0.25$; see Appendix B). Peak concentrations occurred in the early 1990's in all areas. Concentrations then lowered to near 10 ug/L in succeeding years.

There were not enough data to determine trends in monthly average dissolved nickel concentrations in any of the eleven Galveston Bay study areas.

Figure 4.2.47. Annual Average Nickel in Water
in West Bay

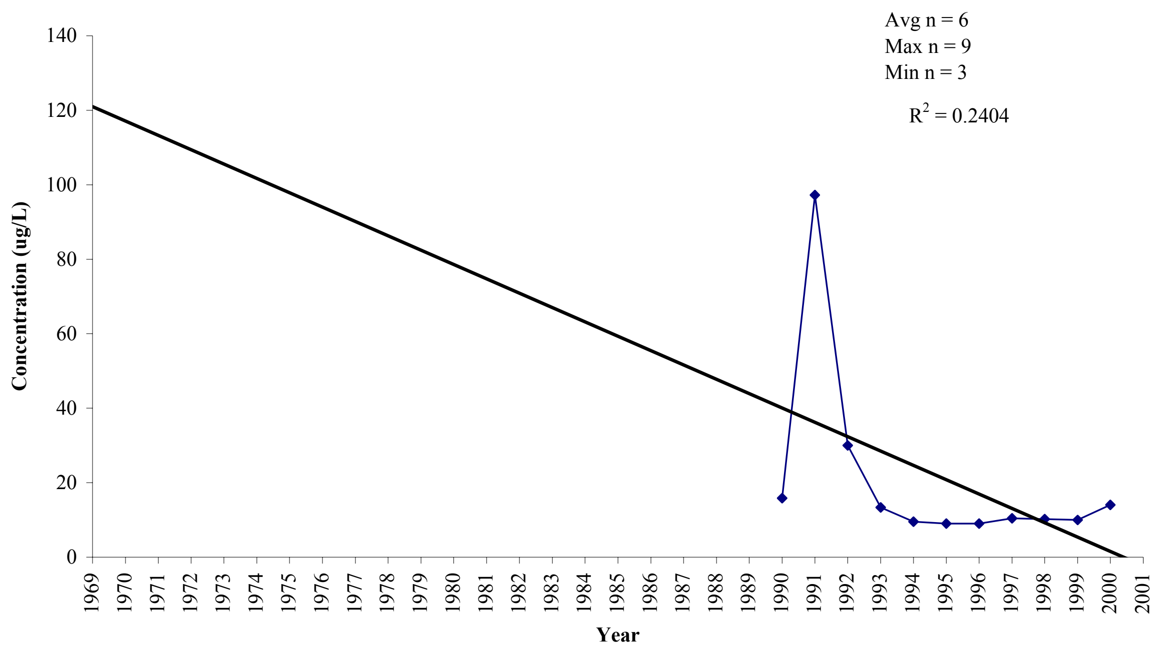
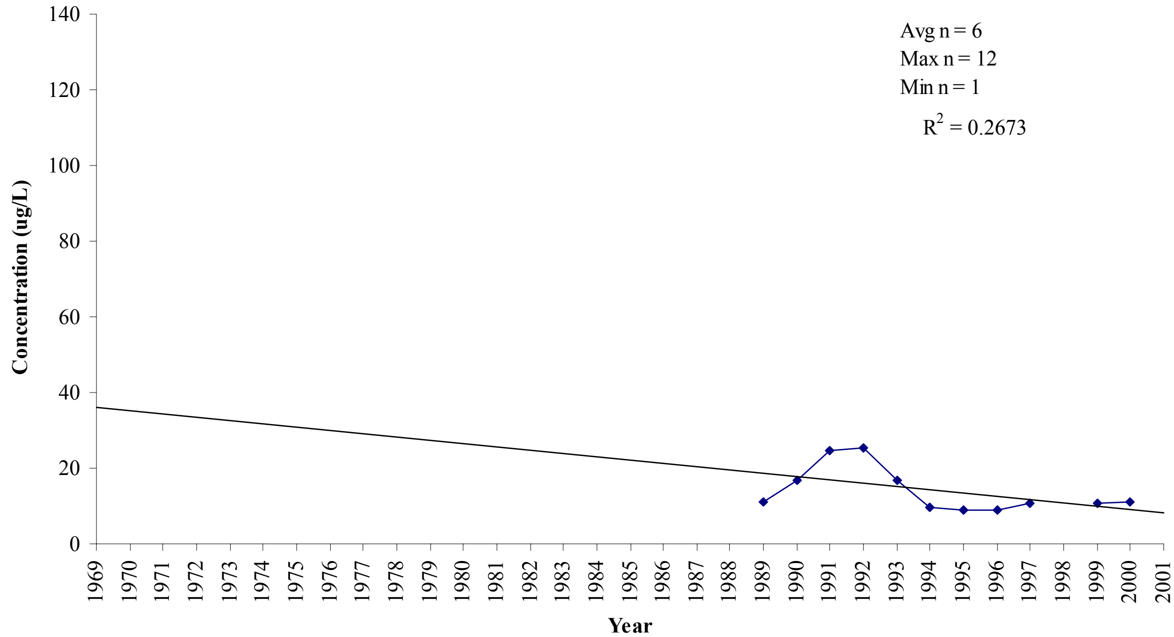


Figure 4.2.48. Annual Average Nickel in Water
in Upper and Lower Galveston Bay



Lead

Lead is a naturally occurring metal and can be found in all parts of our environment. Much of it comes from human activities including burning fossil fuels, mining, and manufacturing. Lead is used in the production of batteries, ammunition, metal products (solder and pipes), and devices to shield X-rays (ATSDR, 2002). The use of lead as an additive to gasoline and paint has declined over the years due to health concerns.

Trends in annual average concentrations of dissolved lead in water were difficult to determine. Five study areas (Clear Creek and Clear Lake, Cedar Bayou, Dickinson Bayou and Dickinson Bay, Chocolate Bayou, and the Texas City Ship Channel) had less than 10 years of data, making them unsuitable for trend analysis. Annual average lead concentrations across the Estuary ranged from near 0 ug/L to 48 ug/L.

Of the six study areas with more than ten years of data, only two yielded statistically significant trends ($R^2 > 0.25$) for the period 1989-2001. Annual average dissolved lead concentrations in water increased in West Bay ($R^2 = 0.35$) (Figure 4.2.49) and East Bay ($R^2 = 0.27$) (Figure 4.2.50) over the period 1989-2001. West Bay displayed the most obvious increasing trend and saw the highest lead concentrations of any of the areas studied in Galveston Bay. The highest average concentration of 48.3 ug/L occurred in West Bay in 1999. Lead concentrations in East Bay also exhibited an increasing trend though not at the same magnitude as West Bay. East Bay's highest annual average lead concentration of 25.7 ug/L occurred in 1997.

There were not enough data to determine trends in monthly average dissolved lead concentrations in any of the eleven Galveston Bay study areas. Trend graphs not included here can be viewed in Appendix B.

Figure 4.2.49. Annual Average Dissolved Lead in Water in West Bay

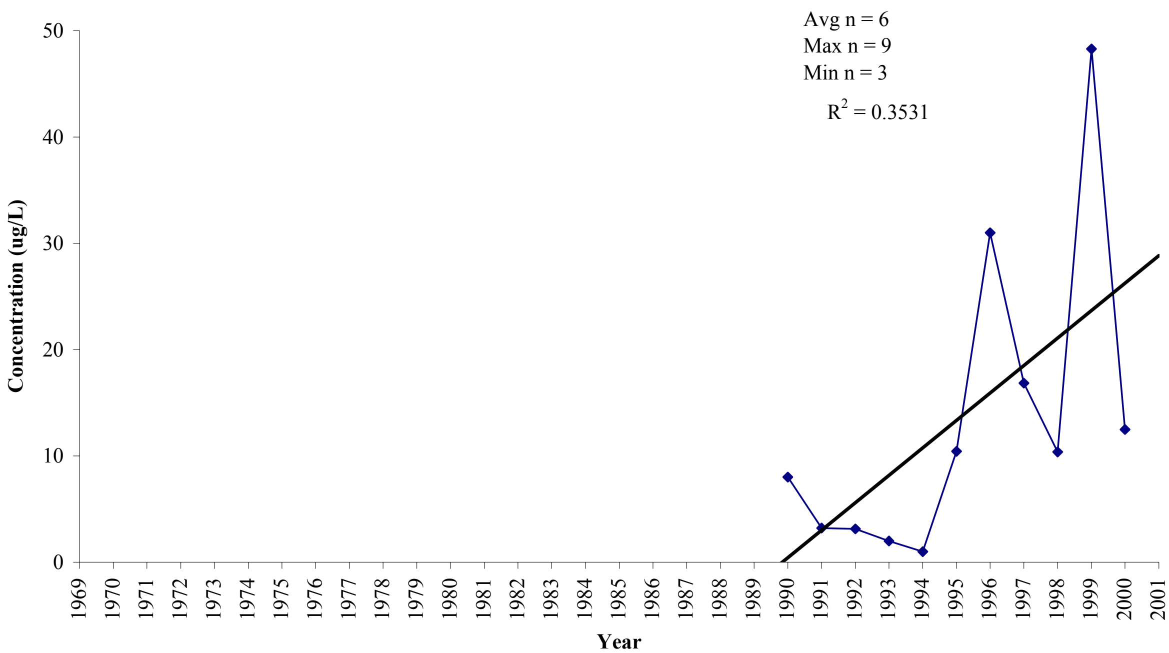
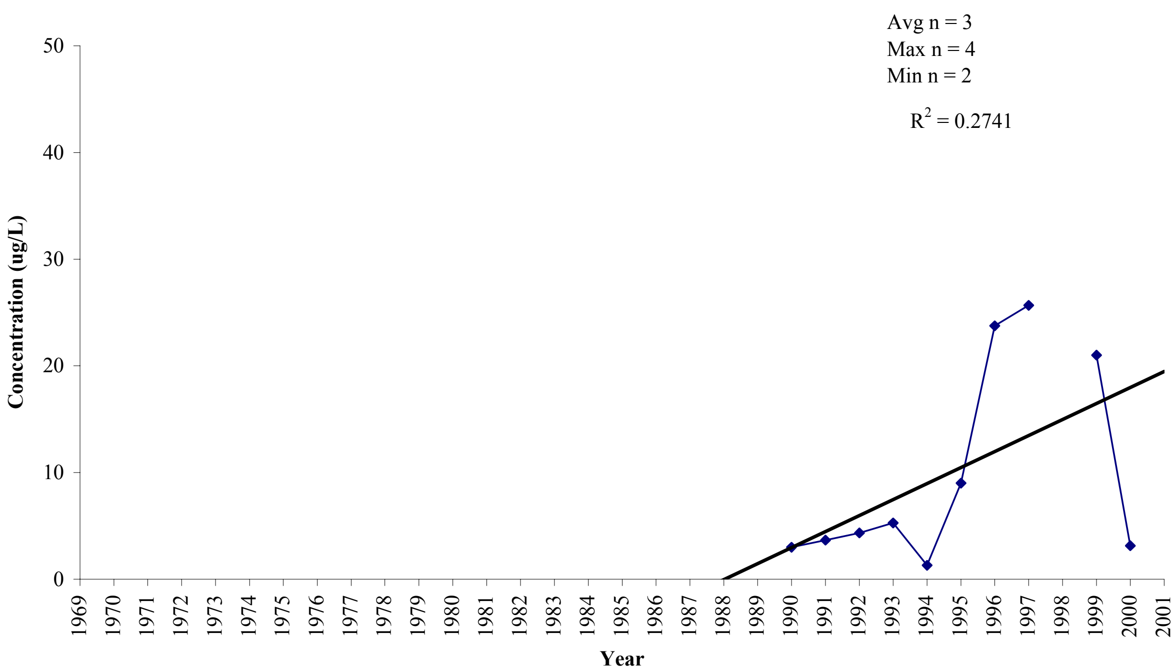


Figure 4.2.50. Annual Average Dissolved Lead in Water in East Bay



Zinc

Zinc is a plentiful element and has many commercial uses as coatings to prevent rust, in dry cell batteries, and mixed with other metals to make alloys like brass and bronze. Zinc compounds are widely used in industry to make paint, rubber, dye, wood preservatives, and ointments (ATSDR, 2002).

Five study areas (Clear Creek and Clear Lake, Cedar Bayou, Dickinson Bayou and Dickinson Bay, Chocolate Bayou, and the Texas City Ship Channel) had less than 10 years of dissolved zinc data, making them unsuitable for trend analysis. Of the six study areas with more than ten years of data, four yielded statistically significant trends ($R^2 > 0.25$) for the period 1989-2001.

Annual average dissolved zinc concentrations in water decreased ($R^2 > 0.25$) over the period of record in East Bay, the Houston Ship Channel, the San Jacinto River and West Bay. Annual average concentrations across the Estuary ranged from near 0 ug/L to 439 ug/L (in Trinity Bay in 1991).

As seen in Figure 4.2.51, trends for the Houston Ship Channel decreased ($R^2 = 0.55$) from near 50 ug/L in the early 1990's to less than 10 ug/L in 2001. Similar declines were seen in East Bay ($R^2 = 0.50$), the San Jacinto River ($R^2 = 0.52$), and West Bay ($R^2 = 0.37$) (see Figure 4.2.52).

There were not enough data to determine trends in monthly average dissolved zinc concentrations in any of the eleven Galveston Bay study areas. Trend graphs not included here can be viewed in Appendix B.

Figure 4.2.51. Annual Average Zinc in Water in the Houston Ship Channel

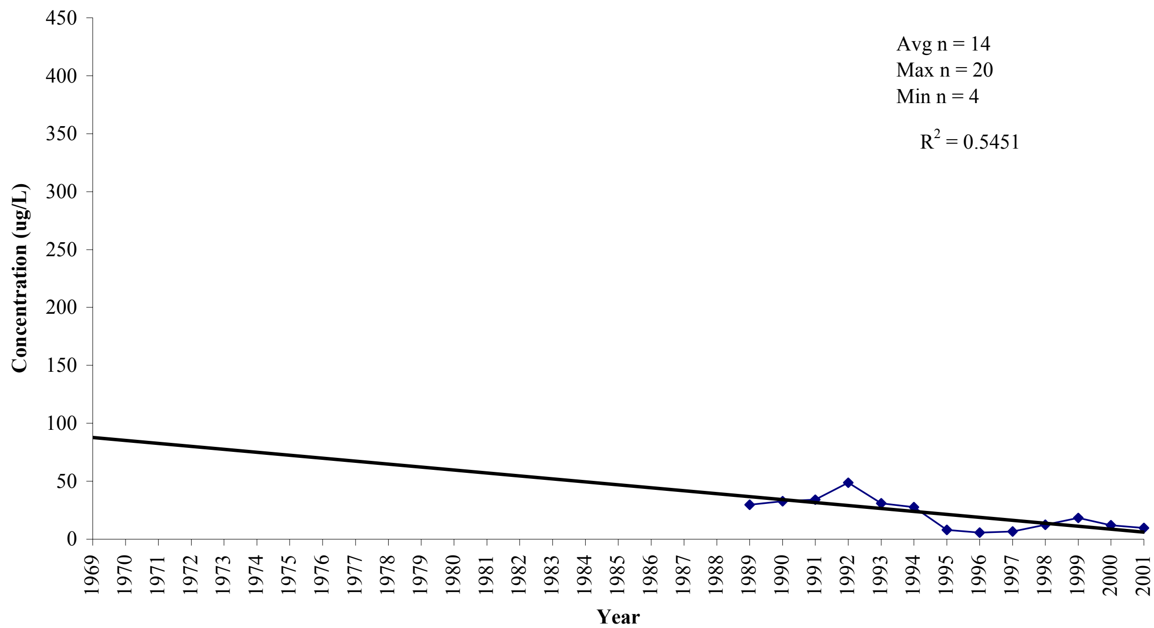
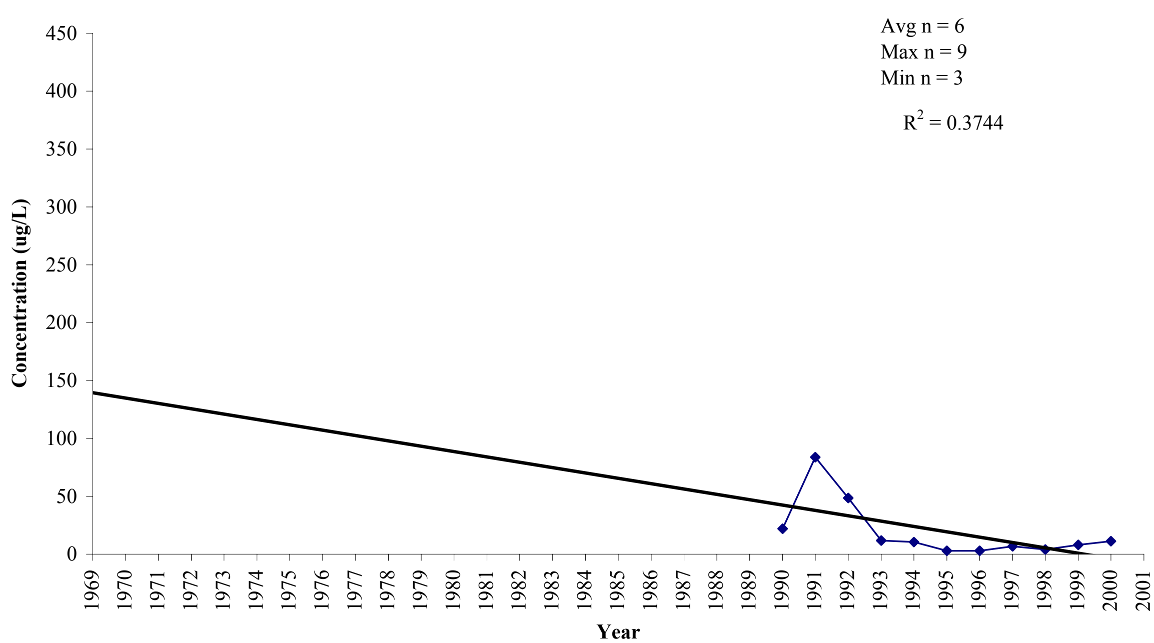


Figure 4.2.52. Annual Average Zinc in Water in West Bay



4.2.5 Organic Compounds

Data on the concentration of organic compounds in water in Galveston Bay were collected by the TCEQ. The Status and Trends Project analyzed these data for the major sub-bays in the Galveston Bay system and the Houston Ship Channel.

Organic Compounds discussed in this section include biochemical oxygen demand (BOD5) and total organic carbon (TOC). Water quality data sets for benzene, naphthalene, polychlorinated biphenyls (PCB's), toluene, and pesticides did not contain enough measurements to justify trend analyses. As a result, organic compounds and pesticides not analyzed in the water quality analyses will be discussed in the section on sediment quality.

Biochemical Oxygen Demand

Concentrations of BOD5 in water were sampled for Galveston Bay by the TCEQ from 1969-2001. Samples collected at all depths and times were analyzed by the Status and Trends project. Data are reported as mg/L. Annual average biochemical oxygen demand (BOD5) in water ranged from approximately 1.6 mg/L to 56.6 mg/L.

Data sets for Cedar Bayou, Trinity Bay, Chocolate Bayou and the Texas City Ship Channel contained less than 10 years of data and were not suitable for trend analyses. The remaining seven study areas yielded no statistically significant trends in BOD5 concentrations.

As seen in Figure 4.2.53, BOD5 concentrations in Upper and Lower Galveston Bay appear stable over the period of record. However, a large data gap exists for the period from 1990-1998. For the years where data is reported, annual average concentrations remained below 10 mg/L.

Annual average BOD5 concentrations in the Houston Ship Channel remained near or below 10 mg/L over most years. However, a peak annual average concentration of 56.6 mg/L occurred in 1974 (see Figure 4.2.54).

There were not enough data to determine trends in monthly average BOD5 concentrations in any of the eleven Galveston Bay study areas. Trend graphs not included here can be viewed in Appendix B.

Figure 4.2.53. Annual Average BOD5 in Water in Upper and Lower Galveston Bay

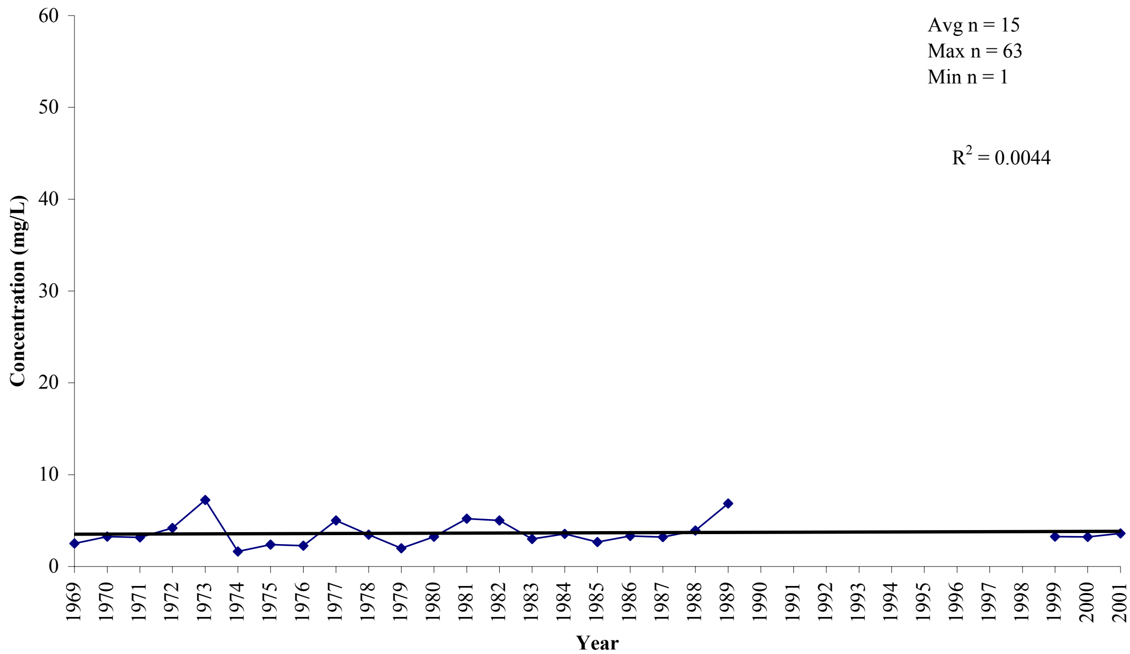
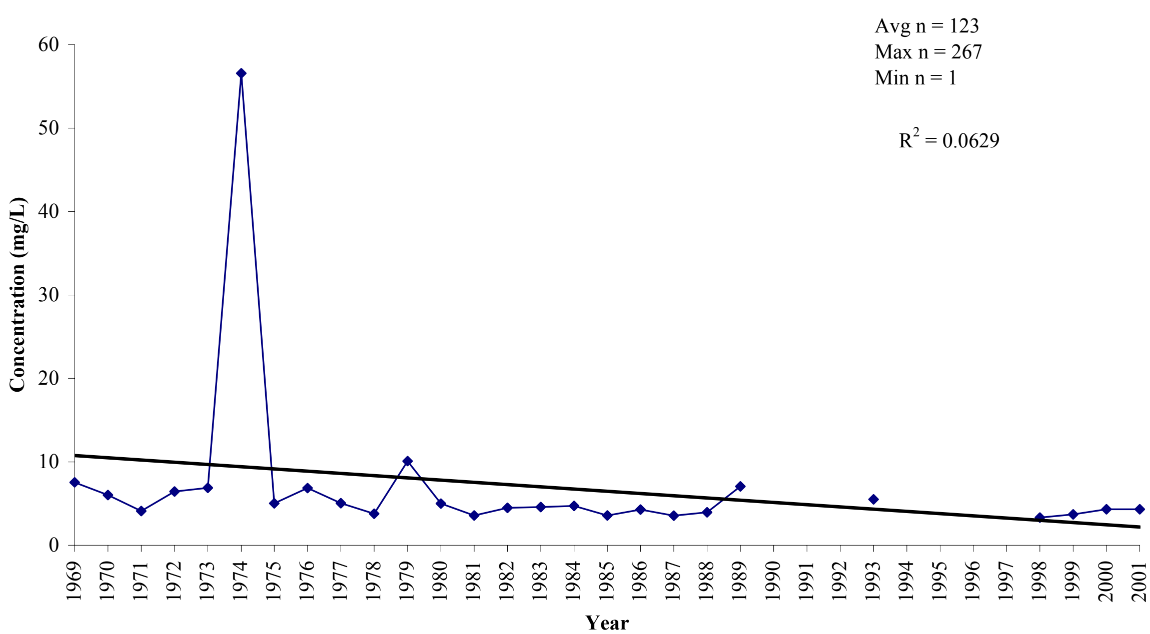


Figure 4.2.54. Annual Average BOD5 in Water in the Houston Ship Channel



Total Organic Carbon

Concentrations of total organic carbon (TOC) in water were sampled for the Galveston Bay estuary by the TCEQ from 1973-2001. Samples collected at all depths and times were analyzed by the Status and Trends project. Data are reported as mg/L.

Annual average TOC concentrations declined all sub-bays and tributaries of the Galveston Bay system over the period of record. Eight of the 11 study areas saw declining trends that were statistically significant ($R^2 > 0.25$). Areas that exhibited trends not statistically significant ($R^2 < 0.25$) included Cedar Bayou, Dickinson Bayou and Dickinson Bay, and the Texas City Ship Channel.

As seen in Figure 4.2.55, the strongest trend was seen in the Houston Ship Channel ($R^2 = 0.54$) where annual average concentrations declined from near 20 mg/L in the 1970's to 5 mg/L in 2001. A similar trend was seen in East Bay (see Figure 4.2.56). Most other areas of the Estuary saw peak TOC concentrations in 1985-1986 and 1977-1978 (see Appendix B).

There were not enough data to determine trends in monthly average total organic carbon concentrations in any of the eleven Galveston Bay study areas. Trend graphs not included here can be viewed in Appendix B.

Figure 4.2.55. Annual Average Total Organic Carbon in Water in the Houston Ship Channel

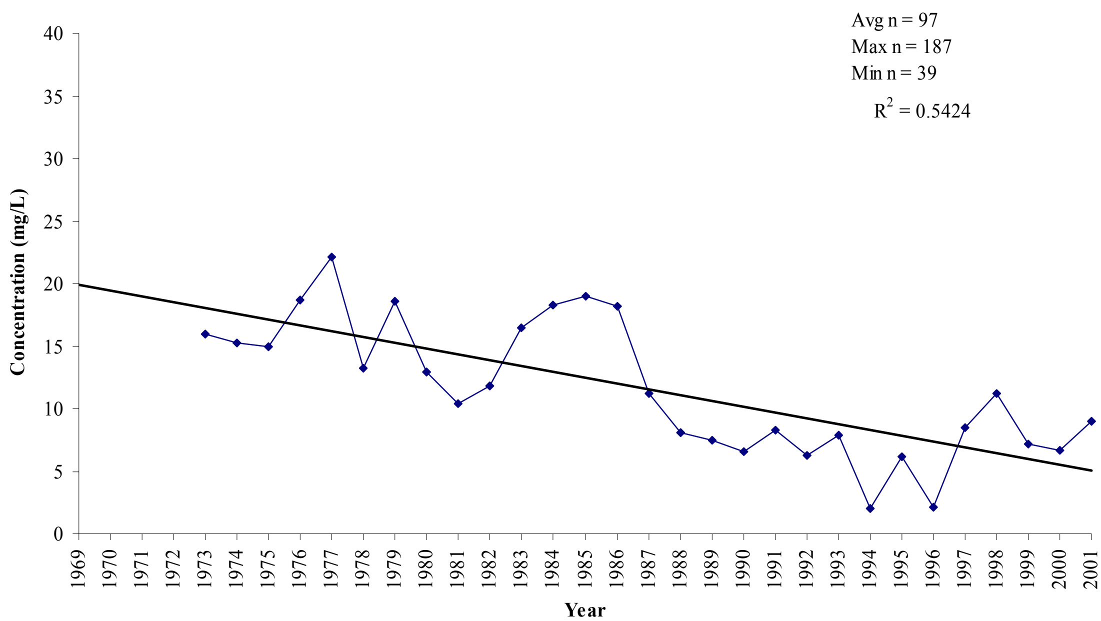
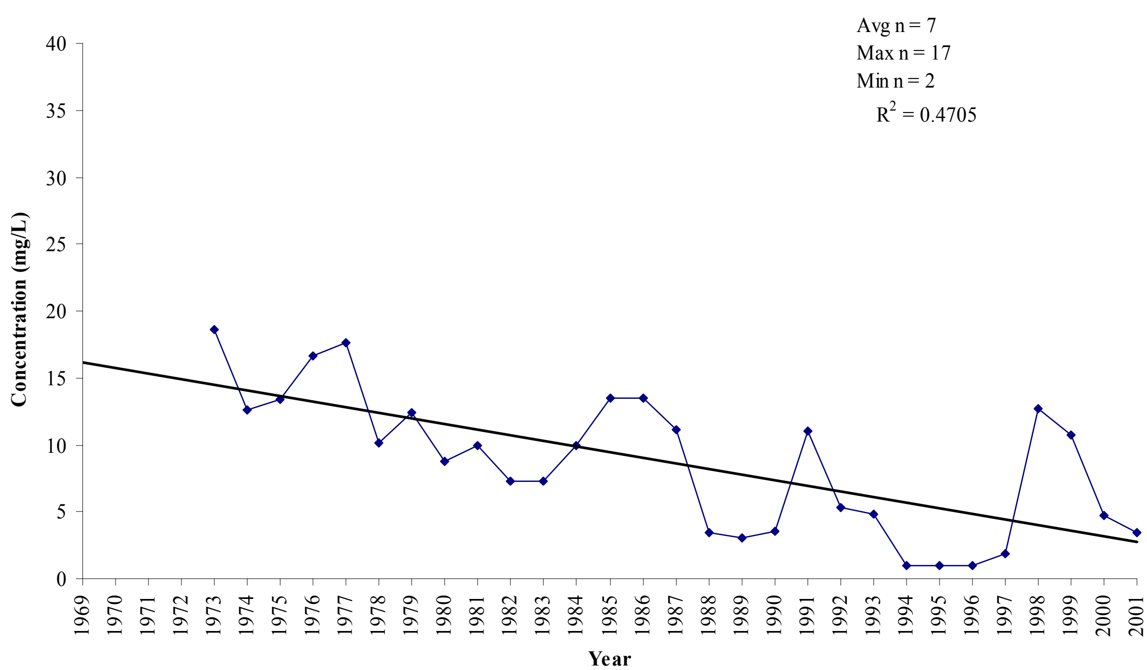


Figure 4.2.56. Annual Average Total Organic Carbon in Water in East Bay



4.2.6 Multivariate Analysis

Univariate analysis can only describe the change of a variable in relation to some consistent measure such as time or space. All of the graphs above describe the changes of single variables over time. Many natural processes involve interactions of parameters often in complex ways. Knowing the change of a single variable over time may not permit one to judge how the processes and interactions are changing. Information on other variables is needed. We have examined the data sets for evidence of some of the processes and complex relationships that could be indicative of the health of Galveston Bay.

Some of the ecological processes are best detected by seeing correlated changes in related variables. For example, standard ecological theory suggests that the concentration of chlorophyll-a should increase when the limiting nutrient increases. So a correlation between chlorophyll-a concentration and a nutrient is a measure of the strength of this theoretical explanation. We have used correlation analysis extensively to investigate the relationships between individual variables in the several data sets. A correlation value simply shows the degree to which two parameters co-vary, i.e. going up or down together. A high correlation could be fortuitous. The absence of a correlation does not mean the lack of a relationship in the ecological processes of the Bay. The number of correlation analyses run suggests that some significant correlations will be false positives. Only correlation values that meet the significance criteria stated are shown in the tables below.

In some cases, the number of variables and their correlations are large. Interpretation is impeded by the number of pair-wise relationships that must be examined. There are multivariate techniques that can condense variables for simplification of analysis. One of these techniques is principal component analysis. This method uses the correlations between single variables to combine them into new orthogonal variables. It is similar to the creation of new axes to explain a cluster of points on a graph. The statistical process provides a set of loadings of the original variables on the new synthetic variable or principal component (PC). These loadings can be understood as the correlations of the old variables to the new PC. Often a PC represents only some of the original variables and will be used as a representative of those parameters. In other cases, all or most of the variables may load on a PC almost equally. The statistical analysis also provides the proportion of the variance in the original data that is explained by each of the new PCs. In several instances below, we have provided a principal component analysis because there was value in showing the pattern of a single PC rather than the pattern of many original variables.

Many of the variables analyzed were monitored over 30 years but the sampling was temporally and spatially clumped. This makes statistical analysis less reliable. Data on specific chemical contaminants were generally impossible to employ in multivariate analysis because the number of samples was too low. The seafood safety data set from the TDH is examined for correlations between contaminants in recent samples, but the data set does not have a temporal scope to permit study of changes in relationships over time.

The data on species abundance in the TPWD fisheries resource and USFWS colonial nesting bird surveys lend themselves to correlation and multivariate analysis because all variables are assessed at the same time with the same method. Water quality parameters are sometimes measured from the same sample, but may not be. There is some loss of accuracy when water quality parameters taken from different water samples or at slightly different times are paired for correlation analysis. However, condensation of the data over time and space is necessary to obtain databases that can be manipulated for all of the status and trends purposes. In most cases, variables collected with the same method at the same time in the same place are paired for correlation, but this is not always possible.

Conventional Water Quality Parameters

The following results were obtained using water quality parameters related to general physical and biological conditions and eutrophication, rather than contamination by anthropogenic toxicants. Eleven variables were selected for a correlation matrix because they had large numbers of samples and extensive temporal ranges. These were ammonia, biological oxygen demand (BOD5), chlorophyll-a, fecal coliform, nitrate and nitrite, total phosphorus, pH, salinity, total organic carbon (TOC), total suspended solids (TSS), and water temperature.

Nitrate and nitrite concentrations were problematic parameters in the water quality data set because there were values from two different methodologies. At the start of the data set, nitrate and nitrite were collected separately. The variables were collected until 1994, but often only nitrate was measured from a water sample. In 1980, a new method was introduced for the simultaneous measurement of nitrate and nitrite. This method became the standard. Both methods were used from 1980 to 1994. For the purposes of this correlation analysis, nitrate and nitrite were summed for months in which there was no combined measurement of nitrate + nitrite and both variables were measured. This no doubt introduced some error, but extended the time period of the data for correlation analysis.

Tables 4.2.3a, 4.2.3b and 4.2.3c show those correlations that had significant values. Significance was set at $p < 0.01$ because so many correlations were calculated that false positives could be a problem.

Table 4.2.3a shows the correlations for Galveston Bay segments using the 11 standard water quality parameters related to productivity. Based on these correlations, it appears that phosphorus concentrations drive the phytoplankton productivity of the Bay. Chlorophyll-a concentrations obtained from water samples are primarily representative of algal cells in the water. These same algal cells appear to be a major component of the organic carbon in the water as evidenced by the correlation between TOC and chlorophyll-a. The highest correlation is between phosphorus and chlorophyll-a, whereas TOC has a lower correlation with both phosphorus and chlorophyll-a suggesting that the TOC relationship is derivative.

In Upper and Lower Galveston Bay, but not Trinity Bay or West Bay, nitrogen appears to be related to freshwater inflow because it has a negative correlation with salinity and pH (freshwater has a lower pH than salt water).

Table 4.2.3a. Correlations between Galveston Bay Water Quality Variables.
Only relationships related to eutrophication or general conditions are shown.

	Ammonia	**Nitrate + Nitrite**	**Phosphorus**	**TOC**	**TSS**
Ammonia					
BOD					
Chlorophyll-a			0.55*** n=196	0.36*** n=182	
Fecal Coliform					
Nitrate + Nitrite					
Phosphorus	0.22** n=297				
PH		-0.23** n=241		0.34*** n=239	
Salinity		-0.46*** n=118			
TOC			0.29*** n=259		
TSS					
Water Temperature					

*= p < 0.01
**= p<0.001
***= p<0.0001

Table 4.2.3b shows the significant correlations for productivity related parameters in Trinity Bay. The correlations offer a set of relationships different from those seen in Upper and Lower Galveston Bay. There is no indication that freshwater inflow is primarily responsible for nitrogen input. This could be due to the dominance of river flow rather than run-off in determining the salinity of Trinity Bay. In this bay the nutrients are related to the concentration of total suspended solids. Phosphorus has a very high correlation to TSS and is again the nutrient with a significant correlation to chlorophyll-a. In this system suspended solids, phosphorus and ammonia show similar patterns

Table 4.2.3b. Correlations between Trinity Bay Water Quality Variables.
Only relationships related to nutrients or sediment are shown.

	Ammonia	Nitrate + Nitrite	Phosphorus	TOC	TSS
BOD					
Chlorophyll-a			0.31* n=106	0.42*** n=97	0.33** n=107
Fecal Coliform					
Nitrate + Nitrite					
Phosphorus					
pH					
Salinity					
TOC					
TSS	0.25* n=149		0.65*** n=148		
Water Temperature					

*= $p < 0.01$
**= $p<0.001$
***= $p<0.0001$

The correlations of West Bay water quality parameters are interesting because they reveal a second trophic pathway, the bacterial breakdown of detritus. Bacteria are often the primary cause of biological oxygen demand in water samples and release ammonia as they process organic matter. West Bay sample sites include locations where fecal coliform contamination has been a problem and the high bacterial levels are correlated to high ammonia concentrations. Bacteria are the principal form of organic carbon in many samples as indicated by the correlation between TOC and fecal coliforms. The water is apparently also rich in phosphorus at these locations.

The phytoplankton trophic system is also operating in West Bay and is again primarily responsive to phosphorus. However, the algal cells do not appear to be a major form of organic carbon. The lower correlations between phosphorus and pH and TOC suggest a relationship between phosphorus concentrations and the breakdown of detrital material, but the relationship must be weak for the relationship between these variables and ammonia to be non-significant.

The correlation between temperature and TSS indicates a seasonal pattern to the concentration of suspended solids. This could be the result of West Bay's orientation which results in spring easterly and summer and fall westerly winds having the greatest effect on sediment resuspension.

Table 4.2.3c. Correlations between West Bay Water Quality Variables.
Only relationships related to nutrients or sediment are shown.

	Ammonia	Nitrate + Nitrite	Phosphorus	TOC	TSS
Ammonia					
BOD	0.36*** n=118				
Chlorophyll-a			0.21* n=165		
Fecal Coliform	0.46*** n=149			0.31** n=128	
Nitrate + Nitrite					
Phosphorus	0.19* n=265				
PH			0.19* n=207	0.21* n=195	
Salinity					
TOC			0.17* n=224		
TSS					
Water Temperature					0.30** n=125

*= $p < 0.01$
**= $p<0.001$
***= $p<0.0001$

Analysis of the Chlorophyll-a Trend
Figure 4.2.57 below shows the consistent pattern of a declining trend in chlorophyll-a concentration throughout the Galveston Bay system over the last 30 years. The analysis presented above shows that declines in phosphorus appear to be the causative explanation for the decline in chlorophyll-a. This relationship can be visualized for three sub-bays of the Galveston Bay system by comparing the graph of chlorophyll-a in Figure 4.2.57 with that of total phosphorus shown in Figure 4.2.58.

Chlorophyll-a is considered to be an indicator of the quantity of phytoplankton in the water and the primary productivity available to species in the food web dependent on that source of energy. Thus a long-term decline in the primary productivity of the Bay should be detectable in higher trophic levels. Two data sets were available to test this hypothesis of correlated declines in trophically dependent species. One was the monitoring data from the Texas Parks and Wildlife Department (TPWD) that included catch per unit effort (CPUE) data on planktivorous and higher trophic level fishes. Another was the U.S Fish and Wildlife Service (USFWS) colonial nesting water bird data on the abundance of species of birds feeding on small planktivorous fish.

Ammonia, total suspended solids and total organic carbon are included with phosphorus and chlorophyll-a in the analysis of relationships among nutrients, primary energy sources and higher trophic levels.

Three species of low trophic level fish: bay anchovy, Gulf menhaden, and striped mullet, were used in the analysis. CPUE values for collections by bag seine and shrimp trawl in the major sub-bays (Upper and Lower Galveston Bay, Trinity Bay and West Bay) were used to indicate abundance. Spotted seatrout were used as an indicator species for higher trophic level fishes. The CPUE from bag seine collections was used as a measure of their abundance at sizes most likely to be trophically dependent on plankton or small planktivorous fishes.

No significant correlations of monthly CPUE from bag seine collections of these species with ammonia or phosphorus concentration were found in Upper and Lower Galveston Bay, Trinity Bay or West Bay. Annual CPUE of spotted seatrout collected by bag seine correlated with phosphorus in Trinity Bay.

No correlation was found between monthly average bag seine CPUE of bay anchovy, Gulf menhaden or striped mullet and chlorophyll-a. Small spotted seatrout (monthly CPUE of bag seine) correlated with chlorophyll-a in all three sub-bays.

Figure 4.2.57. Chlorophyll-a concentrations over the last 30 years in three sub-bays of the Galveston Bay system.

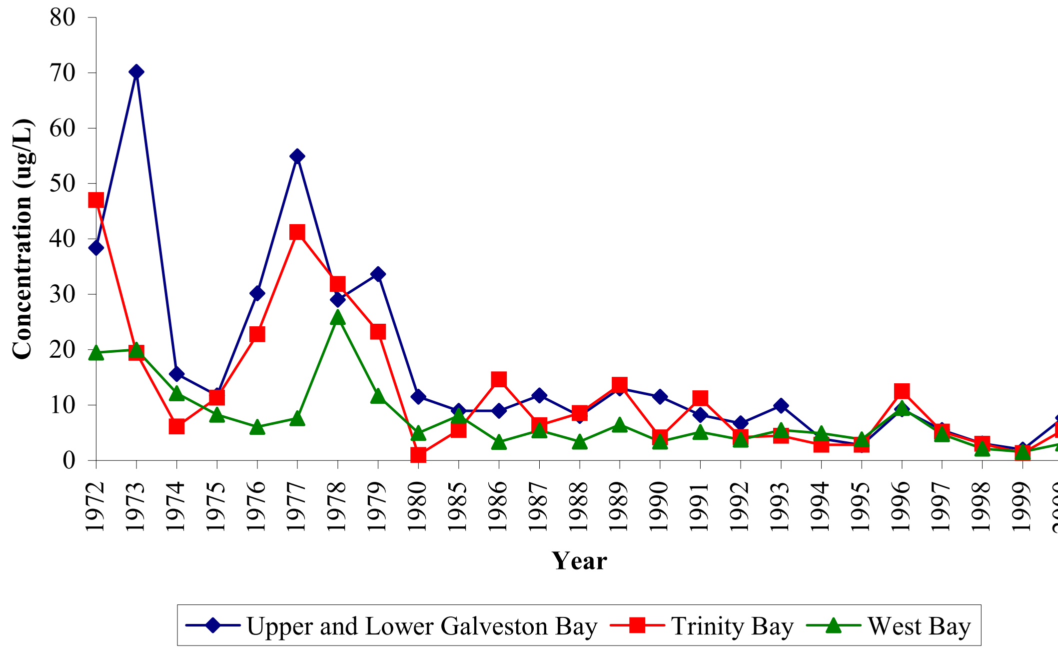
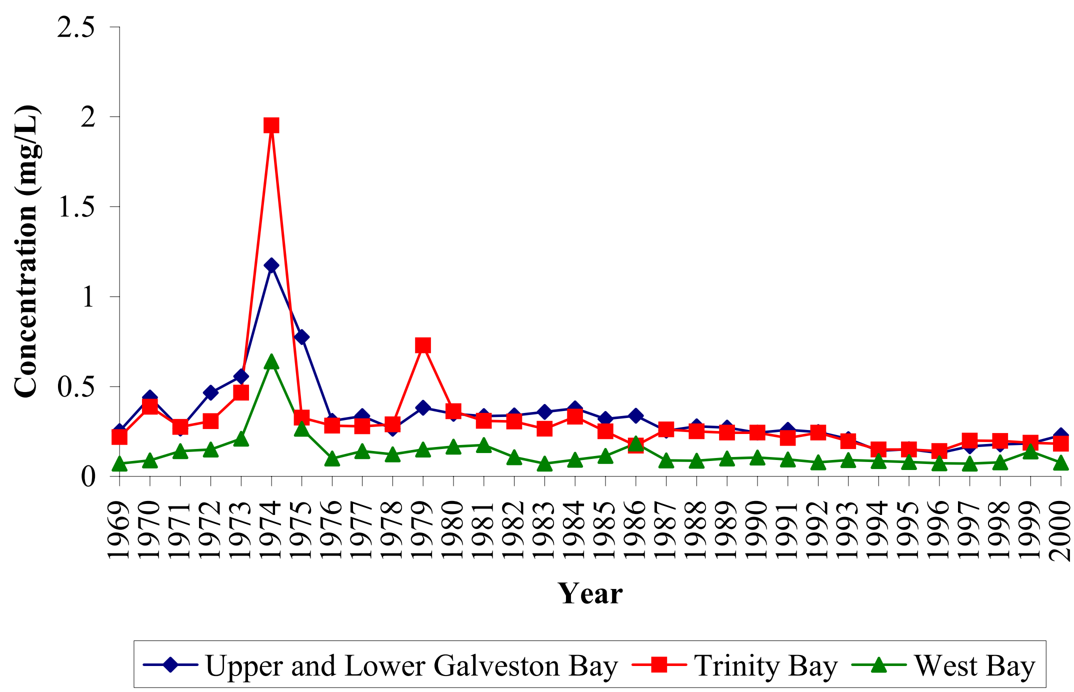
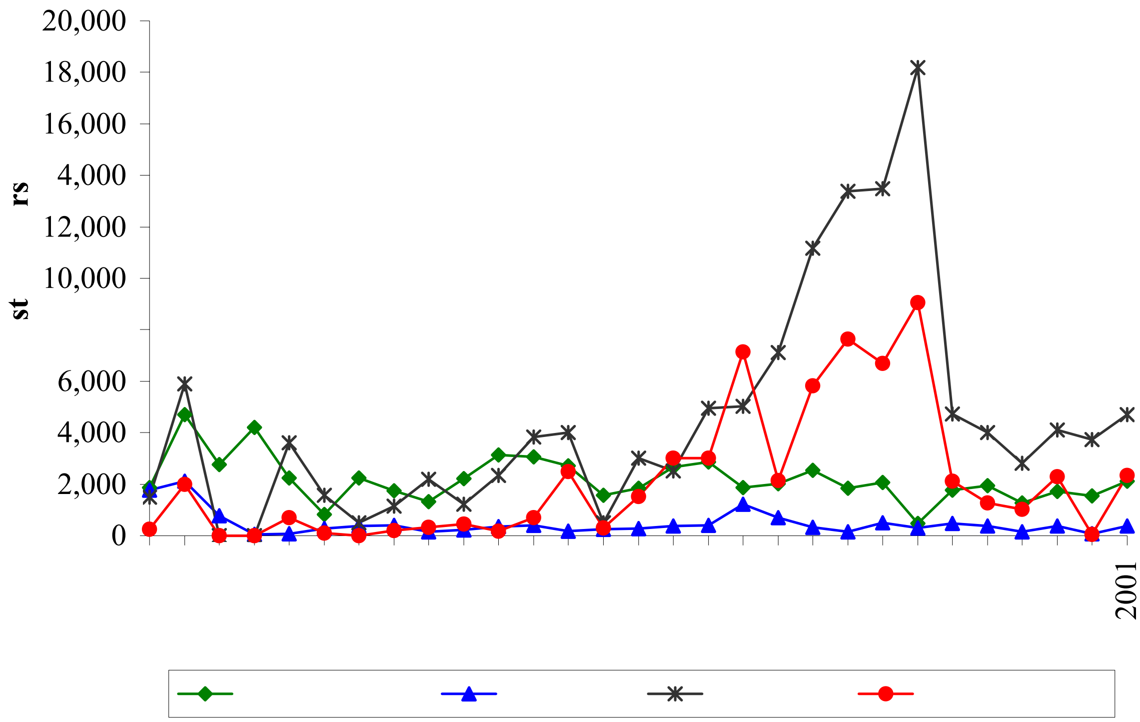


Figure 4.2.58. Phosphorus concentrations over the last 30 years in three sub-bays of the Galveston Bay system.



Six species of birds that prey on small fishes in open bay waters were used in the analysis. The annual estimate of number of nesting pairs in the Galveston Bay system for black skimmer, least tern, Forster's tern, Royal tern, Caspian tern and sandwich tern were used to estimate feeding demand on small planktivorous fishes. Correlations were calculated between number of nesting pairs and the water quality variables and the CPUEs of the small fishes. A graph of the annual number of nesting pairs of four species, least tern, royal tern, sandwich tern and black skimmer is shown in Figure 4.2.59.

Figure 4.2.59. Annual numbers of nesting pairs of least tern, royal tern, sandwich tern and black skimmer in Galveston Bay.



Black skimmer and least tern numbers of nesting pairs were correlated with annual averages of ammonia and phosphorus in sub-bays as shown in Table 4.2.4. The correlation of nesting abundances of these two bird species with ammonia implies a contribution of detritus-based energy to the abundance of nesting birds.

Table 4.2.4. Correlations of number of nesting pairs of colonial nesting water birds from 1973 to 2000 and the annual average concentration of ammonia and phosphorus found in three major sub-bays of the Galveston Bay system.

	Ammonia			**Phosphorus**		
Species	**Upper and Lower Galveston Bay**	**Trinity Bay**	**West Bay**	**Upper and Lower Galveston Bay**	**Trinity Bay**	**West Bay**
Black skimmer	0.61**	0.37*	0.45*	0.49**	0.57**	0.48**
Least tern	0.71**	0.46*	0.54**	0.63**	0.70***	0.73***

*= $p<0.05$
**= $p<0.01$
***= $p<0.001$

There was no correlation of annual number of nesting pairs of the six water bird species and chlorophyll-a annual average concentration. This is surprising given the relationship between chlorophyll-a and phosphorus shown in the tables above. Phosphorus appears to be a more common limiting nutrient for chlorophyll-a than nitrogen in Galveston Bay. Black skimmer and least tern showed correlations between number of nesting pairs and annual average concentration of phosphorus, but no correlation with chlorophyll-a concentration.

The declining trend of chlorophyll-a is not reflected in the abundance of bay anchovy, Gulf menhaden or striped mullet. The species that most represent the lower trophic levels of aquatic animals in this data set appear to fluctuate in numbers independent of plankton productivity. Small spotted seatrout, a predatory fish, does show a correlation with chlorophyll-a when very young as indicated by the CPUE of bag seine collections.

The correlations found between predatory birds and small fish are consistent with expected trophic relationships. A seen in Table 4.2.5, there are correlations between least, royal and sandwich tern numbers of nesting pairs and the CPUE values for bag seine and shrimp trawl collections of bay anchovy, gulf menhaden and striped mullet. Royal and sandwich terns often feed offshore; therefore, the relationship may be spurious or the result of some ecological connection other than a predator-prey relationship.

Table 4.2.5. Correlations between annual CPUE of low trophic level fishes captured by bag seine or shrimp trawl in the three major sub-bays of the Galveston Bay system and the annual number of nesting pairs of three species of colonial nesting water birds.

Species	Least tern	Royal tern	Sandwich tern
Bay anchovy		*West Bay* Shrimp Trawl 0.55*	
Gulf menhaden	*West Bay* Shrimp Trawl 0.71**	*Trinity Bay* Bag Seine 0.67**	*Trinity Bay* Bag Seine 0.78***
Striped mullet	*West Bay* Bag Seine 0.49*	*Upper and Lower Galveston Bay* Bag Seine 0.65**	

*= $p<0.05$
**= $p<0.01$
***= $p<0.001$

From this study of the correlations between variables from three different data sets on Galveston Bay there are few conclusions to be drawn. Correlations are less frequent than simple ecological theory would predict. Plankton productivity as indicated by chlorophyll-a is not directly correlated with the estimations of abundance available for fish species that are low in the trophic structure of the Bay ecosystem. Bird predators that might be affected in some way by plankton productivity are more correlated to nutrient concentration than chlorophyll-a. In fact, the analysis suggests that higher trophic levels of the Galveston Bay food web may be more dependent on energy from detritus than energy from phytoplankton.