4. Data Analysis

A primary function of the Status and Trends Project is to provide assessments describing the current health of the Bay and near term forecasts based on various parameters. This is accomplished through the calculation of trend lines and evaluation of their explanatory power.

The previous sections point out the spatial and temporal coverage of the datasets. Some parameters share the same temporal and spatial distributions because they are based on the same sampling scheme. For example, all of the fisheries species analyzed from a gill net collection share the same temporal and spatial sampling pattern because the collectors identify all of the species captured. On the other hand, not all of the water quality parameters share the same temporal and spatial pattern because selected parameters are measured from a subset of all water samples. Thus sample sizes for trends based on regression analysis differ.

A suite of variables were selected for trend analysis from all of the water quality parameters, sediment quality parameters and fisheries species sampled by bag seine, shrimp trawl and gill net. The variables to be studied in this set of analyses are described in the succeeding sections. All of the selected variables have been subjected to linear regression analysis from all or some of the study areas. In this report, there is an emphasis on segments of the Bay not analyzed in the 2002 Status and Trends report.

Water and sediment quality sampling has temporal variation in the number of samples analyzed each year. In some years and some areas there are special studies that yield frequent and dense measurements for some parameters. During other time periods, samples are sparse. However, the fisheries monitoring data set from the TPWD is consistent in this regard. Regression analysis is sensitive to the sample size and the distribution of samples in relation to the independent variable (e.g. years in this case).

A decision was made to emphasize long-term patterns and weight each year of sample collection equally. This would reduce the impact of multiple samples from small areas and short time periods on the overall analyses. Therefore, all trend analyses are based on annual averages that represent different sample numbers. Each trend analysis is based on a linear regression of the annual average parameter value and the collection year. Each trend graph provides the average and range of sample numbers in the years covered by the trend.

The water and sediment quality measurements began in 1969, but many parameters were not collected during the early years. The gear types used by the TPWD were employed for different periods of time. Status and Trends records include collections from gill net since 1975, bag seine since 1976, and shrimp trawl since 1982. Thus many of the trend regressions are based on different numbers of years. Missing data due to unsampled years reduces the power of the trend analysis. Although two regression tests yield the same slope to the regression equation, they may have very different significance levels due to a difference in number of years included in the analysis.

One objective of this report is to separate the results into concise summaries of patterns and detailed individual analyses. After many initial trend analyses, it became clear that significance ($p < 0.01$) was achieved for variables with records in more than 20 years and regression coefficients of more than 0.5. Therefore, an R^2 value of 0.25 as a criterion for discussion of trend status was agreed upon by the project team. For variables with fewer than 20 years of record an R^2 of 0.25 will have a probability > 0.01. For purposes of clarity, p-values are provided in the summary tables for those trends that are near or above $R^2 = 0 .25$. The authors hope that the use of a standard criterion will make comparisons easier across variables and areas.

The usual determination of scientific certainty by employing very discriminating probabilities that reduce the likelihood of errors such as false positives has served the scientific community well. Scientific probabilities are not necessarily the best approach to identifying trends of concern for management of sensitive resources. Decisions must often be made despite scientific uncertainty. It is the authors' belief that attention should be given to trends that explain 25% or more of the variation in a parameter whether they meet statistically rigorous standards of significance or not. The environmental systems represented in the datasets on Galveston Bay are inherently stochastic. As the reader will find in the report, trends meeting the above criterion are uncommon. Certainly there are patterns buried in the noise of the data that will require more complex analyses. It seems advisable to follow the clues provided by observable patterns whether they obtain accepted levels of scientific certainty or not.

4.1 Analysis of Water Quality Parameters for New Areas of Study

As shown in Table 2.1.1, the 2002 Status and Trends Project analyzed water quality data for eleven areas of study. The 2003 Status and Trends Project analyzed water quality data for five new areas of study: Christmas Bay/Bastrop Bayou complex, Galveston Channel, East Intracoastal Waterway, Trinity River, and West Bay (See Table 2.1.2). Areas discussed in the 2002 Status and Trends Report were not included here since an additional year of data did not have a significant impact on the historical trends. The exception to this is West Bay, which is included, since the separation of the Christmas Bay/Bastrop Bayou sampling stations did significantly impact the trends reported in 2002.

Trends not displayed in the report can be viewed in Appendix B. A summary of all water quality trends is located in Appendix E.

4.1.1. Conventional Parameters

Conventional parameters in the TCEQ surface water and sediment quality database include those that are monitored to provide a general physical and chemical characterization of the water column and substrate. Conventional parameters analyzed for Status and Trends include water temperature, salinity, total suspended solids, dissolved oxygen and pH. These parameters directly and indirectly reflect the chemical, physical and biological processes taking place in the estuary.

In addition to the surface water quality data collected by the TCEQ, the National Coastal Assessment (NCA) Program, administered in the state of Texas by the Texas Parks and Wildlife Department (TPWD), collects water and sediment data (see Section 2.3) on an annual basis. The NCA program is relatively new in relation to the TCEQ database, however it provides additional monitoring parameters and data to compare with the TCEQ data.

The following analyses 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 important if $R^2 < 0.25$. This approach was taken to ensure consistency for comparison across parameters. Statistical significance of a trend is achieved at a lower R^2 value if sample size is high, but when sample size is low, higher R^2 values may not be statistically significant. To avoid confusion, area-parameter combinations with low sample sizes were eliminated and a consistent R^2 value was chosen.

In some instances a trend line may extend below the x-axis to parameter values of less than zero. This is not meant to infer that the pollutant level or resource will actually fall to the zero level at a given point in time. Rather, trend lines are meant to provide the reader with an idea of the general direction of a trend.

The TCEQ and NCA use standardized sampling methodologies when collecting water quality characterization data. TCEQ and NCA sampling methodologies can be reviewed in the TCEQ Surface Water Quality Monitoring Procedures Manual (TNRCC, 1999a), the TCEQ Surface Water Quality Monitoring Data Management Reference Guide (TCEQ, 2003) and the National Coastal Assessment Field Operations Manual (U.S. EPA, 2001).

Water Temperature

Water temperature is an important parameter. Many organisms use water temperature as a cue for spawning and migration between the open waters of the Gulf of Mexico and nursery grounds of nearshore bays and estuaries. Temperature can also influence the metabolic rate of an organism and the extent to which parasites and disease affect host organisms (e.g. impacts of *Vibrio vulnificus* and Dermo on Eastern oysters). Water temperature can further affect physical and biological parameters including saturation of dissolved oxygen, chemical oxygen demand (COD), rate of aquatic plant photosynthesis, and the sensitivity of organisms to toxic substances.

Water temperature data collected by the TCEQ in the lower Galveston Bay watershed from 1969-2002 were analyzed for the five new areas of study (Christmas Bay/Bastrop Bayou Complex, Galveston Channel, East Intracoastal Waterway, Trinity River, and

West Bay). In an effort to standardize the data and mitigate for the effects of sunlight, 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). Water temperature data collected by the NCA in areas comparable to the five new study areas for TCEQ data were also analyzed and overlaid on the TCEQ annual average trends when available. Summary trend information for the TCEQ data is provided in the table below.

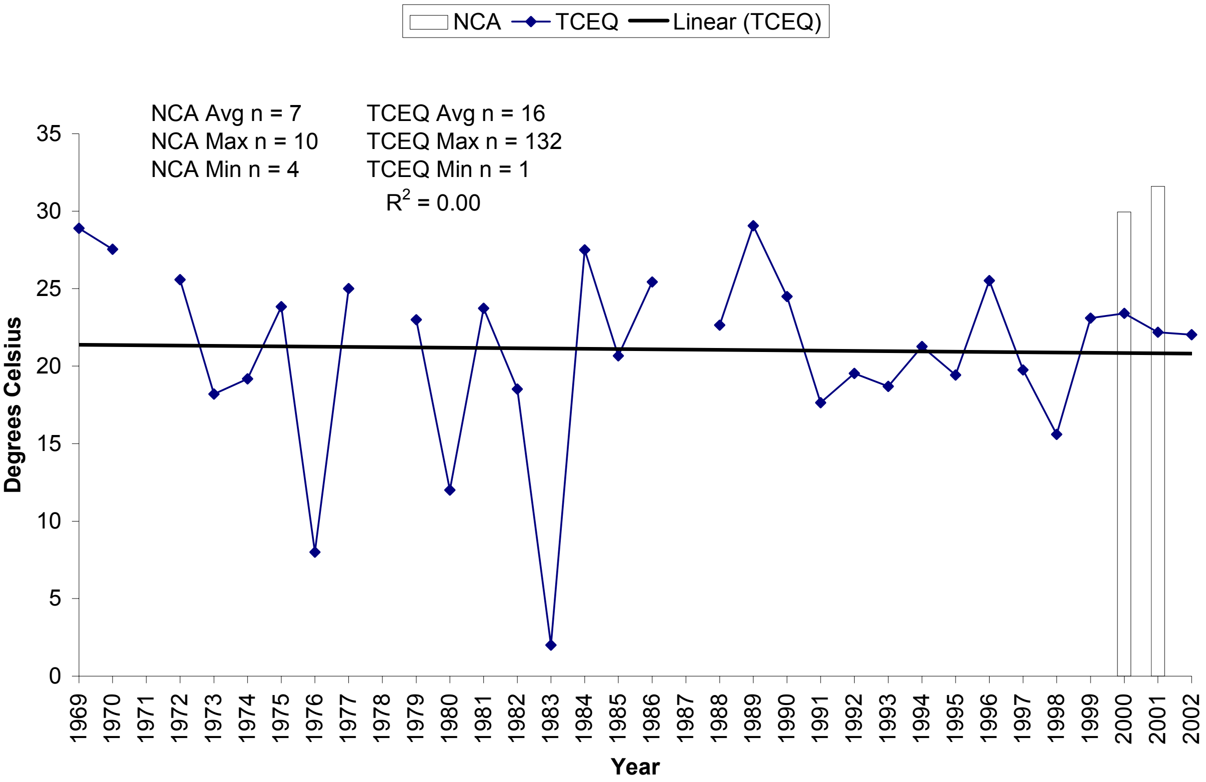
Table 4.1.1.1. Summary of Annual Trends in Water Temperature.

Study Area	**Trend Direction**	**R^2 Value**
Christmas Bay/Bastrop Bayou	No Trend	0.10
Galveston Channel	No Trend	0.08
Intracoastal Waterway East	Insufficient Data	--
Trinity River	Insufficient Data	--
West Bay	No Trend	0.00

The water temperature data sets for the Galveston Channel and Christmas Bay/Bastrop Bayou Complex exhibited data gaps resulting from the years in which no samples were collected. This is surprising for Christmas Bay due to the large amount of sampling that has taken place in that area over the years. Sufficient data for trend analysis (at least ten years) was not available for the Intracoastal Waterway East (seven years of data) and Trinity River areas (six years of data).

The annual trend graph for West Bay is shown in Figure 4.1.1.1. It is interesting to note that in December 1983 a low value of 2°C was measured in West Bay at Carancahua Reef. Because this was the only temperature reading recorded for this sub-bay in 1983, it gives the impression of a very low annual average for that year. Overall, water temperature averaged 21-22 degrees Celsius (ºC). Graphs not shown here can be viewed in Appendix B. As seen in 2000 and 2001 the NCA annual averages were slightly higher. This is due to the fact that the NCA data consist of only summer samples while the TCEQ data are collected year-round.

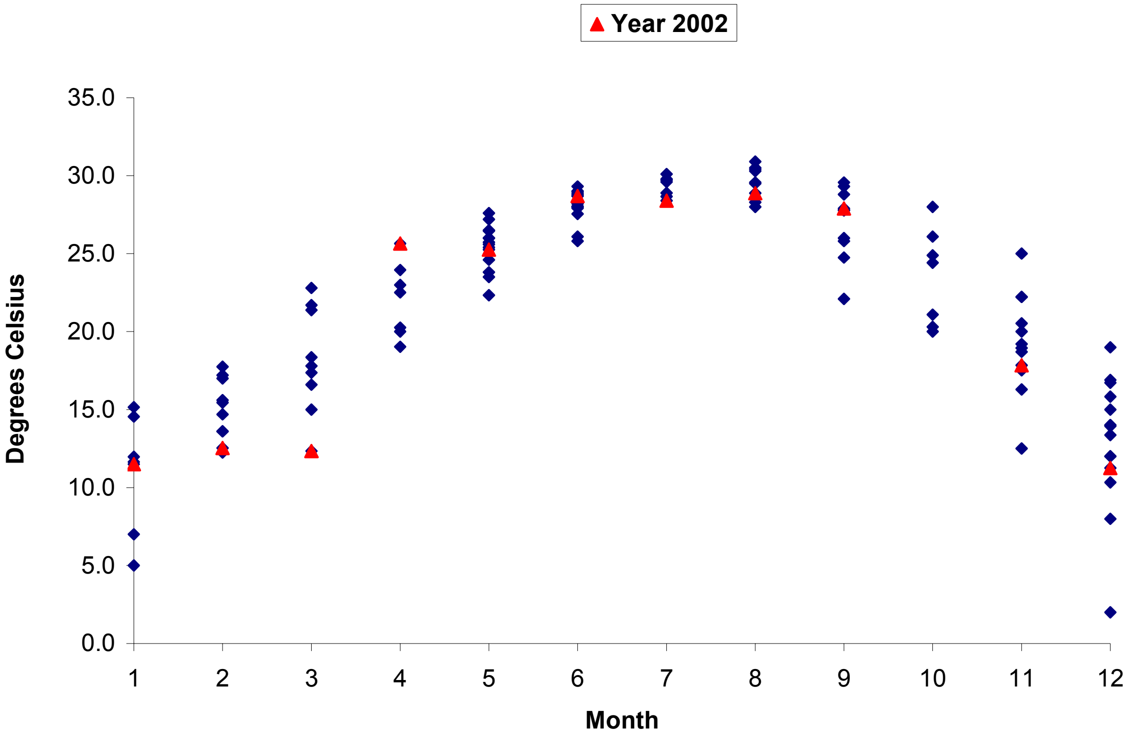
Figure 4.1.1.1. Annual Average Water Temperature in West Bay



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 4.1.1.2 shows monthly average water temperatures in West Bay, respectively, for the period 1969-2002. (See Appendix B).

Note: Each data point on the monthly average charts represents data for an individual year. Year 2002 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 4.1.1.2. Monthly Average Water Temperature in Water in West Bay, 1969 to 2002



pH

The pH of water is critical to the survival of most aquatic plants and animals. Many species have trouble surviving if pH levels drop under a level of 5.0 or rise above 9.0. Changes in pH can also alter additional aspects of the water's chemistry, usually to the detriment of aquatic organisms. Even small shifts in the water's pH can affect the solubility of some metals such as iron and copper, which can influence aquatic life indirectly. Further, if pH levels are lowered, toxic metals in the estuary's sediment can be re-suspended in the water column.

Although pH generally exhibits low variability in coastal environments due to the high buffering capacity of seawater, human activities can cause significant, short-term fluctuations in pH or long-term acidification of a freshwater body. For instance, algal blooms initiated by an overload of nutrients cause pH to fluctuate dramatically over a period of several hours, greatly stressing local organisms. Acidic precipitation in the upper freshwater reaches of an estuary can diminish the survival rate of eggs deposited by spawning fish.

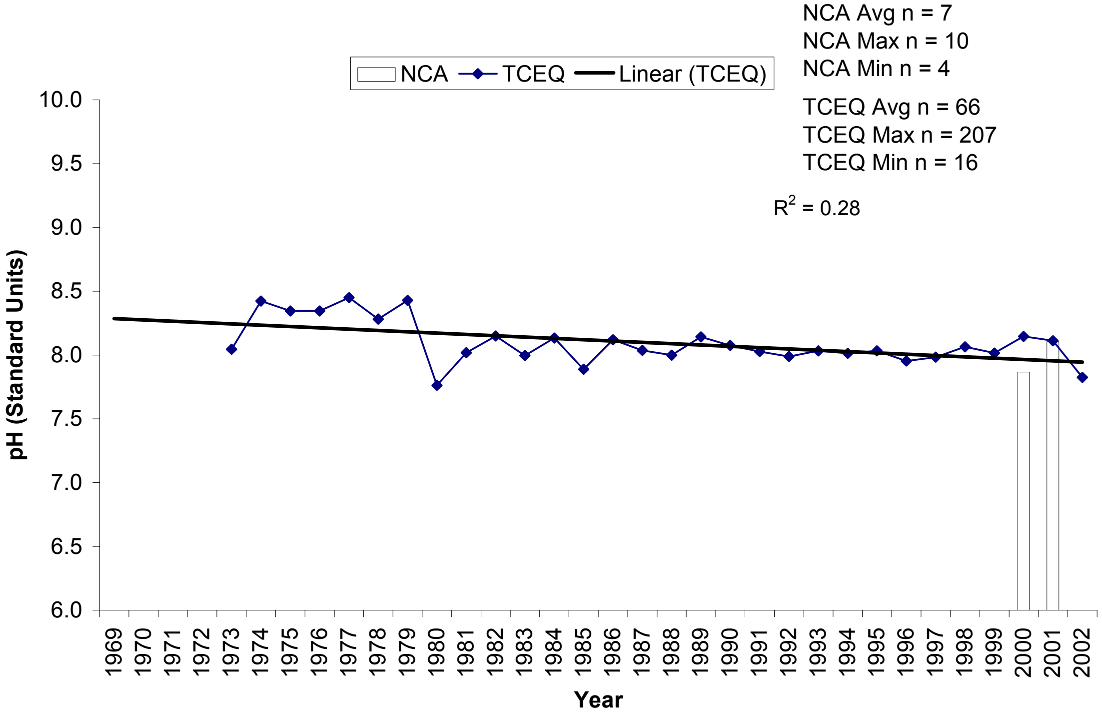
pH data collected by the TCEQ in the lower Galveston Bay watershed from 1969-2002 were analyzed for the five new areas of study in the Galveston Bay system. Samples collected at all depths and times were analyzed. While a few samples were collected by the TCEQ in 1969 and 1970, the majority of the pH record begins in 1972. pH is reported in pH standard units. pH data collected by the NCA in areas comparable to the five new study areas for TCEQ data were also analyzed and overlaid on the TCEQ annual average trends when available. Summary trend information for the TCEQ data is provided in the table below.

Table 4.1.1.2. Summary of Annual Trends in pH.

Study Area	**Trend Direction**	**R^2 Value**
Christmas Bay/Bastrop Bayou	No Trend	0.22
Galveston Channel	No Trend	0.00
Intracoastal Waterway East	No Trend	0.20
Trinity River	No Trend	2E-05
West Bay	Decreasing	0.28 ($p = 0.003$)

Most areas exhibited no trends in pH with average levels remaining at or near 8 standard units. As seen in Figure 4.1.1.3, West Bay was the only area with a significant trend ($R^2 = 0.28$) that was stable to slightly decreasing. Graphs not shown here can be viewed in Appendix B.

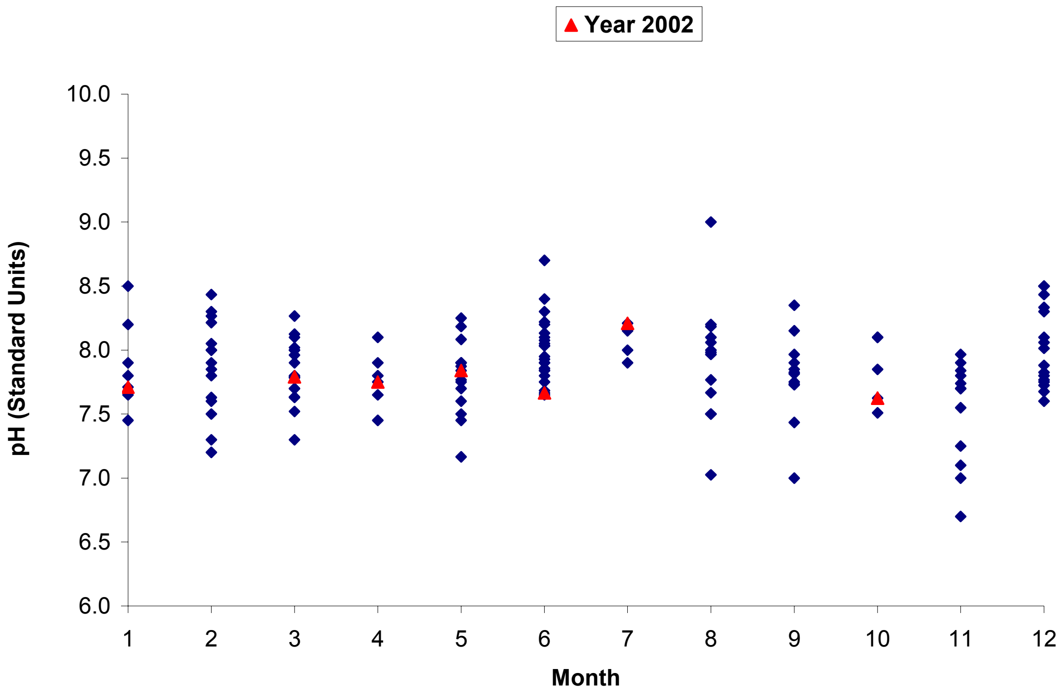
Figure 4.1.1.3. Annual Average pH in Water in West Bay



Trends in monthly average pH in water typically range from 7.0 - 9.0. Trend lines are relatively stable across all areas as seen in the graph for the Christmas Bay/Bastrop Bayou Complex (Figure 4.1.1.4)

Note: Each data point on the monthly average charts represents data for an individual year. Year 2002 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 4.1.1.4. Monthly Average pH in Water in the Christmas Bay/Bastrop Bayou Complex, 1969 to 2002



Salinity

Salinity is a measure of the amount of salts dissolved in water. The Galveston Bay Estuary exhibits a salinity gradient along its length, as freshwater entering the estuary from tributaries (rivers and bayous) mixes with seawater moving in from the Gulf of Mexico. Salinity, along with water temperature, is the primary factor in determining the stratification of an estuary. When fresh and salt water meet, the two do not readily mix. Just as warm water is less dense than cold water, fresh water is less dense than salt water and will overlie the wedge of seawater pushing in from the ocean. Storms, tides, and wind, however, can eliminate the layering caused by salinity and temperature differences by thoroughly mixing the two masses of water.

Salinity levels greatly influence the diversity of plants and animals that live in different areas of the estuary. As an example, West Bay typically has higher salinities than Trinity Bay and one would therefore expect to see different species assemblages in the two sub-bays. Salinity also has an effect on the extent to which parasites and diseases infect aquatic organisms such as commercially important Eastern oysters. It is for these reasons that freshwater inflow to bays and estuaries is such a large issue in coastal areas.

Salinity has been monitored in the Galveston Bay system by the TCEQ since 1973. Although samples were collected in the 1970s, 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 consistent data set. Salinity is reported in parts per thousand (ppt). Salinity data can also be derived from the TCEQ data on specific conductance. However, specific conductance was not analyzed by the Status and Trends Project.

Salinity data collected by the NCA in areas comparable to the five new study areas for TCEQ data were also analyzed and overlaid on the TCEQ annual average trends when available. Summary trend information for the TCEQ data is provided in the table below.

Table 4.1.1.3. Summary of Annual Trends in Salinity.

Study Area	**Trend Direction**	**R^2 Value**
Christmas Bay/Bastrop Bayou	Decreasing	0.31 ($p = 0.024$)
Galveston Channel	Increasing	0.25 ($p = 0.041$)
Intracoastal Waterway East	No Trend	0.11
Trinity River	No Trend	0.04
West Bay	No Trend	0.00

A decreasing trend was found in the Christmas Bay/Bastrop Bayou Complex with an R^2 of 0.31 (see Figure 4.1.1.5). The low average salinity in 2001 was a function of sampling location. Three salinity samples were obtained that year in the Christmas Bay/Bastrop Bayou Complex and all were collected at a station located in the tidal reach of Bastrop Bayou. An increasing trend was apparent for the Galveston Channel ($R^2 = 0.25$) (see Figure 4.1.1.6).

No trends appeared for the Intracoastal Waterway East, West Bay or the Trinity River. However, as would be expected the Trinity River exhibited the lowest annual average values near 0 parts per thousand (ppt). Graphs not shown here can be viewed in Appendix B. NCA data were collected in West Bay. When compared to TCEQ annual averages for 2000 and 2001, the NCA averages were slightly higher. This may be due to the fact that the NCA data consist of only summer samples while the TCEQ data are collected year-round.

Figure 4.1.1.5. Annual Average Salinity in Water in the Christmas Bay/Bastrop Bayou Complex

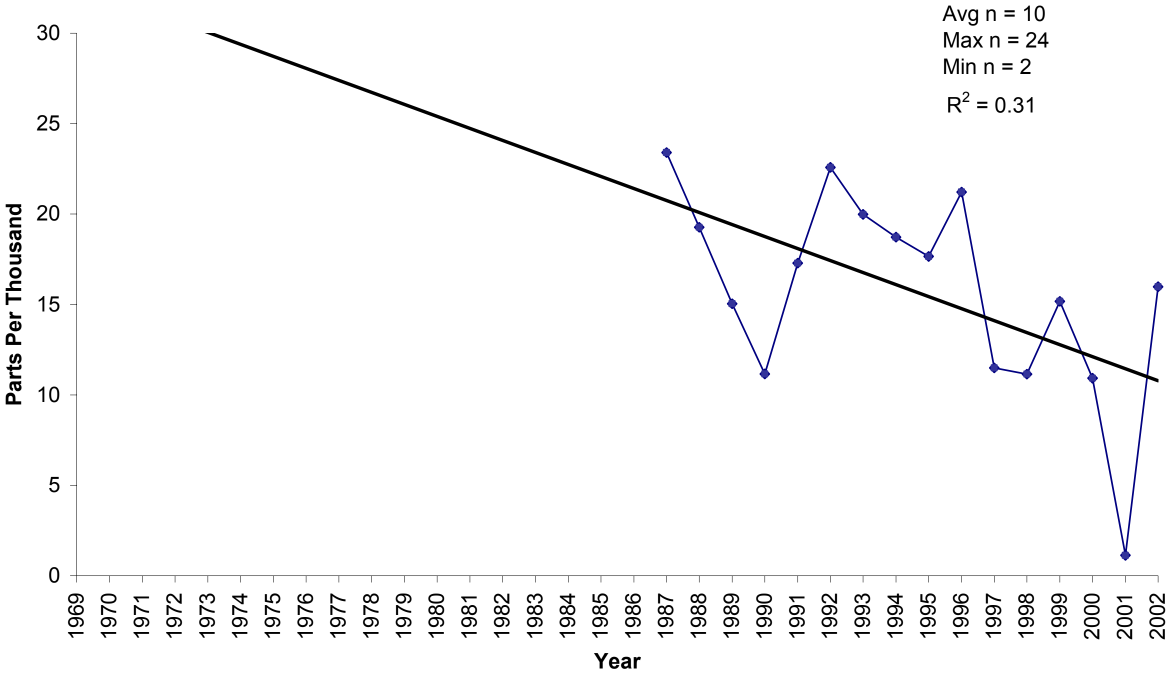
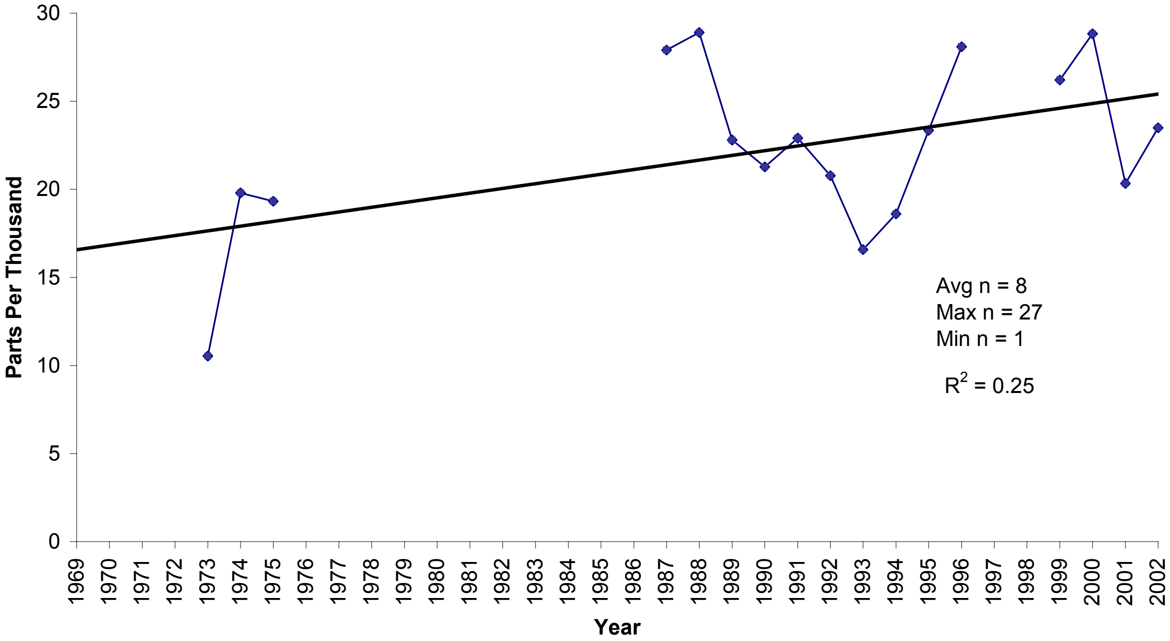


Figure 4.1.1.6. Annual Average Salinity in Water in the Galveston Channel



Monthly average salinities exhibit a similar trend across all sub-bays and tributaries of Galveston Bay. 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. West Bay exhibits the highest salinities with several summer averages approaching 45 ppt. (see Appendix B).

Dissolved oxygen

Dissolved Oxygen (DO) is one of the most important factors controlling the well-being of estuarine species. Oxygen availability to aquatic organisms is complicated by the fact that its solubility in water is generally poor and is influenced by many factors including temperature, salinity, and photosynthetic activity of aquatic plants (phytoplankton and vascular plants). According to the EPA, most aquatic organisms can grow and reproduce unimpaired when DO levels exceed 5 mg/L. When levels drop to 3-5 mg/L, living organisms often become stressed. If levels fall below 2 mg/L, a condition known as hypoxia will occur, causing mobile species to move elsewhere and resulting in the death of immobile species. Another condition known as anoxia, occurs when the water becomes totally depleted of oxygen (below 0.5 mg/l) resulting in the death of any organism that requires oxygen for survival. It should also be noted that too much DO is not always beneficial. Super-saturation (DO levels above 10 mg/L) is often a sign of eutrophication, or over enrichment, of a waterbody. Super-saturation can also occur in areas of great turbulence such as spillways.

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.

DO 5:00-10:00 a.m.

Of the five new study areas, only the Christmas Bay/Bastrop Bayou Complex exhibited a trend ($R^2 = 0.47$) that was slightly increasing from near 7.0 mg/L to 8.0 mg/L (see Figure 4.1.1.7). However, many gaps are present. West Bay had much more extensive sampling, but the R^2 was very low. Graphs not shown here can be viewed in Appendix B.

Table 4.1.1.4. Summary of Annual Trends in Morning DO.

Study Area	Trend Direction	R^2 Value
Christmas Bay/Bastrop Bayou	Increasing	0.47 ($p = 0.014$)
Galveston Channel	No Trend	0.09
Intracoastal Waterway East	Insufficient Data	--
Trinity River	Insufficient Data	--
West Bay	No Trend	0.04

DO 10:00 a.m. - 3:00 p.m.

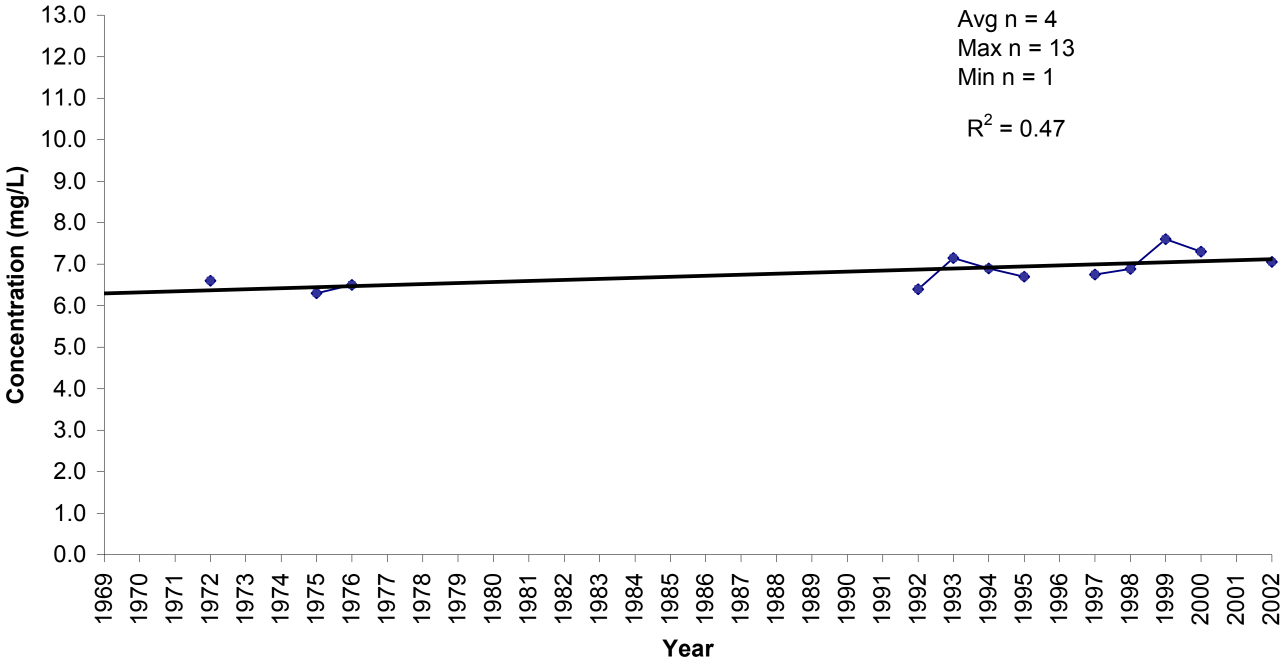
Data is more plentiful for this time of day than for the period 5:00-10:00 a.m. However, no significant trends were found for any of the five study areas. DO concentrations are highly variable, changing in relatively short periods of time not captured by the temporal scale (annual averages) employed by the Status and Trends Project.

As with the annual DO averages, monthly DO averages did not exhibit trends in most of the new study areas.

Table 4.1.1.5. Summary of Annual Trends in Afternoon DO.

Study Area	**Trend Direction**	**R^2 Value**
Christmas Bay/Bastrop Bayou	No Trend	0.00
Galveston Channel	No Trend	0.02
Intracoastal Waterway East	No Trend	0.04
Trinity River	No Trend	0.00
West Bay	No Trend	0.00

Figure 4.1.1.7. Annual Average Dissolved Oxygen in Water in the Christmas Bay/Bastrop Bayou Complex (5:00 a.m. – 10:00 a.m.)



4.1.2. Nutrients

Nutrients are essential for biological productivity, impacting the primary production of the estuarine food web. However, excess concentrations of nutrients can have detrimental effects such as eutrophication (over enrichment) of a waterbody. 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, chlorophyll-a (an indicator of phytoplankton abundance), and pheophytin-a (the breakdown product of chlorophyll-a).

The TCEQ uses standardized sampling methodologies when collecting water quality data. Sampling methodologies can be reviewed in the TCEQ Surface Water Quality Monitoring Procedures Manual (TNRCC, 1999a). When available, TCEQ water quality criteria or screening levels are provided as a point of reference. Water quality criteria have not been developed by the TCEQ for chlorophyll-a and nutrients in water (TCEQ, 2002). In these cases screening levels are provided. However, screening levels do not represent state water quality criteria. Rather, they are threshold levels used by the TCEQ to identify secondary concerns of water bodies. Secondary concerns are noted on the Texas 305(b) list and result in increased monitoring and increased parameter coverage (TCEQ, 2002). Alternately, state-adopted water quality standards are used to identify primary concerns of water bodies and are reported on the Texas 303(d) list ultimately resulting in Total Maximum Daily Load (TMDL) development.

Ammonia

Ammonia is a nutrient essential for life. However, excess ammonia in an estuarine system can lead to eutrophication, algal blooms, low dissolved oxygen and fish kills. Ammonia can also accumulate in aquatic organisms and alter their metabolism or body pH. Extremely high levels of ammonia are toxic and can result in death of the organism.

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. Screening levels as designated by the TCEQ are added as points of reference only and should not be used in a regulatory context.

As discussed in the 2002 Status and Trends report, 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 ($R^2 = 0.76$). Of the new study areas, the Galveston Channel and East Intracoastal Waterway exhibited no trends ($R^2 < 0.25$). Declining trends were seen in the Trinity River ($R^2 = 0.31$), the Christmas Bay/Bastrop Bayou Complex ($R^2 = 0.32$) (see Figure 4.1.2.1), and West Bay ($R^2 = 0.26$). Although the R^2 is low for the East Intracoastal Waterway, the data is very interesting with large values seen in the 1970s and early 1980s (see Figure 4.1.2.2).

The TCEQ created a guidance framework for identifying secondary concerns of waterbodies (TCEQ, 2002). The document identifies screening levels for nutrients in freshwater streams, reservoirs, tidal streams, and estuaries. For the most part annual average concentrations for recent years remain below screening levels. This is often not the case for annual averages from the 1970s. This may be a function of improved water quality, or it may be the result of changes in sampling and analytical methodologies.

Table 4.1.2.1. Summary of Annual Trends in Ammonia.

Study Area	Trend Direction	R^2 Value
Christmas Bay/Bastrop Bayou	Declining	0.32 ($p < 0.001$)
Galveston Channel	No Trend	0.01
Intracoastal Waterway East	No Trend	0.13
Trinity River	Declining	0.31 ($p = 0.001$)
West Bay	Declining	0.27 ($p = 0.002$)

Monthly average concentrations of ammonia were not found to have significant trends. Trend graphs for monthly average ammonia concentrations can be seen in Appendix B.

Figure 4.1.2.1. Annual Average Total Ammonia in Water in the Christmas Bay/Bastrop Bayou Complex. The tidal stream screening level was applied to the Christmas Bay/Bastrop Bayou Complex due to the large portion of samples collected from Bastrop Bayou.

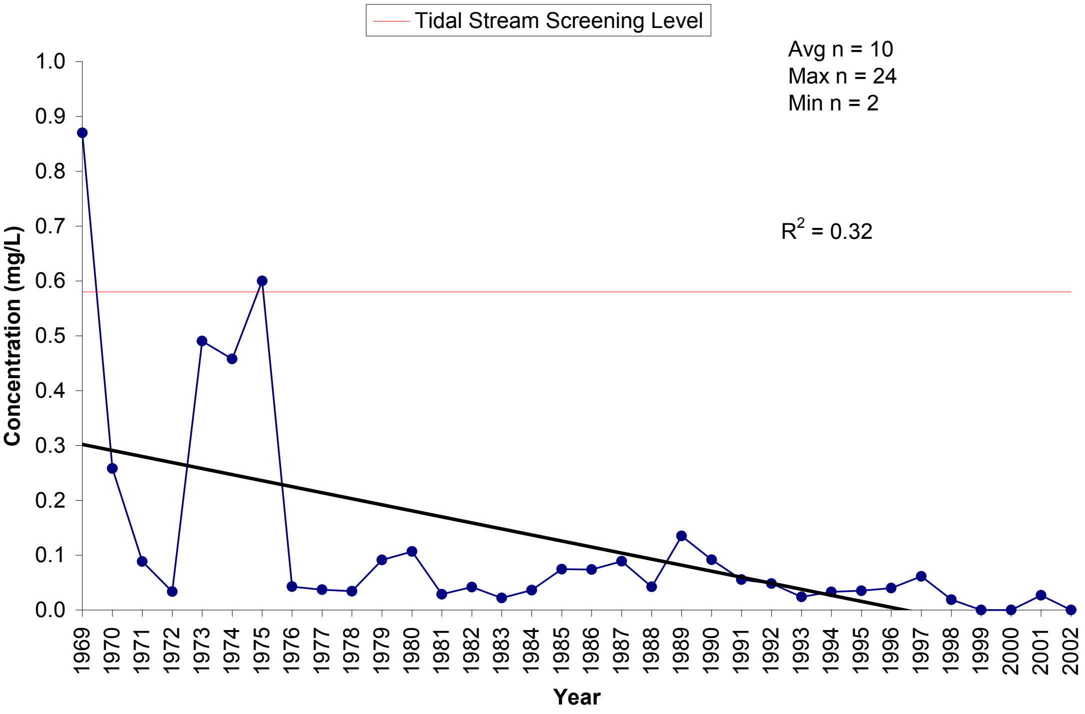
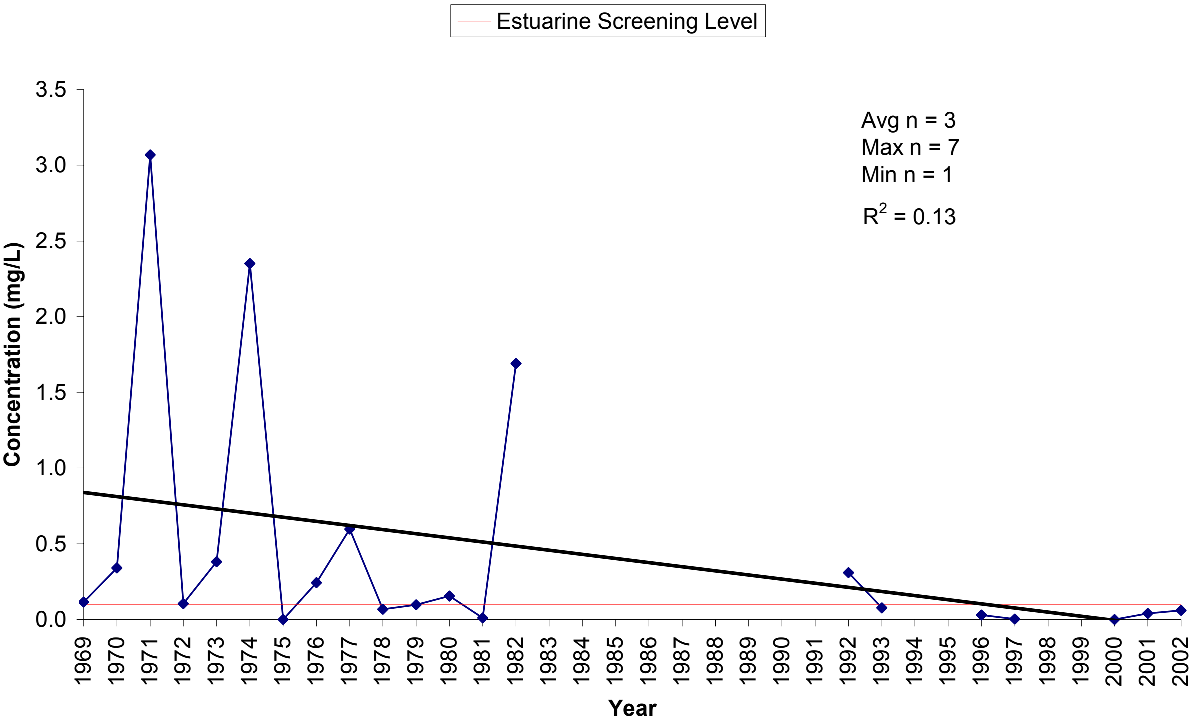


Figure 4.1.2.2. Annual Average Total Ammonia in Water in the East Intracoastal Waterway



Nitrate-Nitrite

Nitrate and nitrite are oxygenated nitrogen-based nutrients that affect the level of phytoplankton production. Too much nitrate-nitrite can lead to eutrophication, algal blooms, low dissolved oxygen levels, and fish kills. Too little nitrogen is thought to negatively impact the primary productivity of an estuary (nitrate and nitrite can be limiting nutrients). Nitrate and nitrite are two of the primary nutrients sampled in surface water quality monitoring efforts.

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 1980-2002. To create a more complete data set for analysis of nitrate-nitrite, the total nitrate and total nitrite parameters (TCEQ storet codes 00620 and 00615) are summed for each sampling event. Total nitrate-nitrate data (TCEQ storet code 00630) are then added to fill in the time periods lacking data. This combined data set is discussed below. Total nitrate-nitrite concentrations collected at all times and depths were analyzed and are reported as mg/L.

As discussed in the 2002 report, the highest annual average concentrations of nitrate-nitrite occurred in the Houston Ship Channel which demonstrated 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 significant trend ($R^2 > 0.25$) was the San Jacinto River ($R^2 = 0.43$) which displayed an increasing trend from near 0 mg/L in 1969 to 0.5 mg/L in 2001.

Of the new study areas, the Intracoastal Waterway East was the only area to exhibit a significant declining trend ($R^2 = 0.38$) (see Table 4.1.2.2 and Figure 4.1.2.3). There were no significant trends in the other four new study areas. NCA data collected in 2000 and 2001 for West Bay exhibit annual averages similar to those of the TCEQ data (Figure 4.1.2.4). Annual average nitrate-nitrite concentration trend graphs for the other study areas within the Galveston Bay estuary can be viewed in Appendix B.

Table 4.1.2.2. Summary of Annual Trends in Nitrate-Nitrite.

Study Area	**Trend Direction**	**R^2 Value**
Christmas Bay/Bastrop Bayou	No Trend	0.05
Galveston Channel	No Trend	0.01
Intracoastal Waterway East	Declining	0.38 (p = 0.005)
Trinity River	No Trend	0.03
West Bay	No Trend	0.20

Monthly average concentrations of nitrate-nitrite were not found to have significant trends. Trend graphs for monthly average nitrate-nitrite concentrations can be seen in Appendix B.

Figure 4.1.2.3. Annual Average Nitrate-Nitrite in Water in the East Intracoastal Waterway

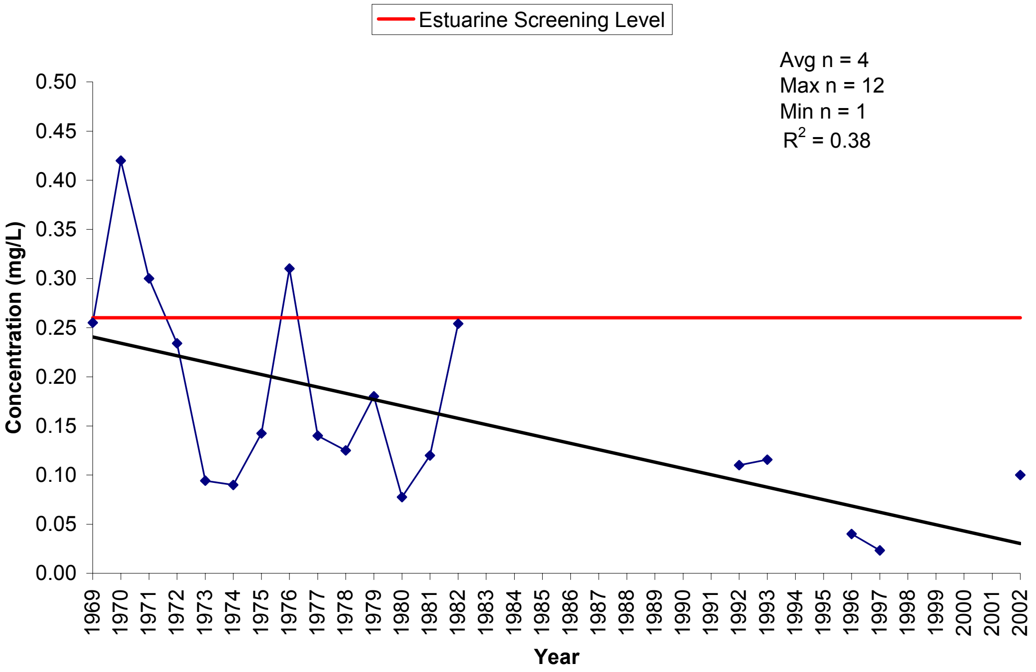
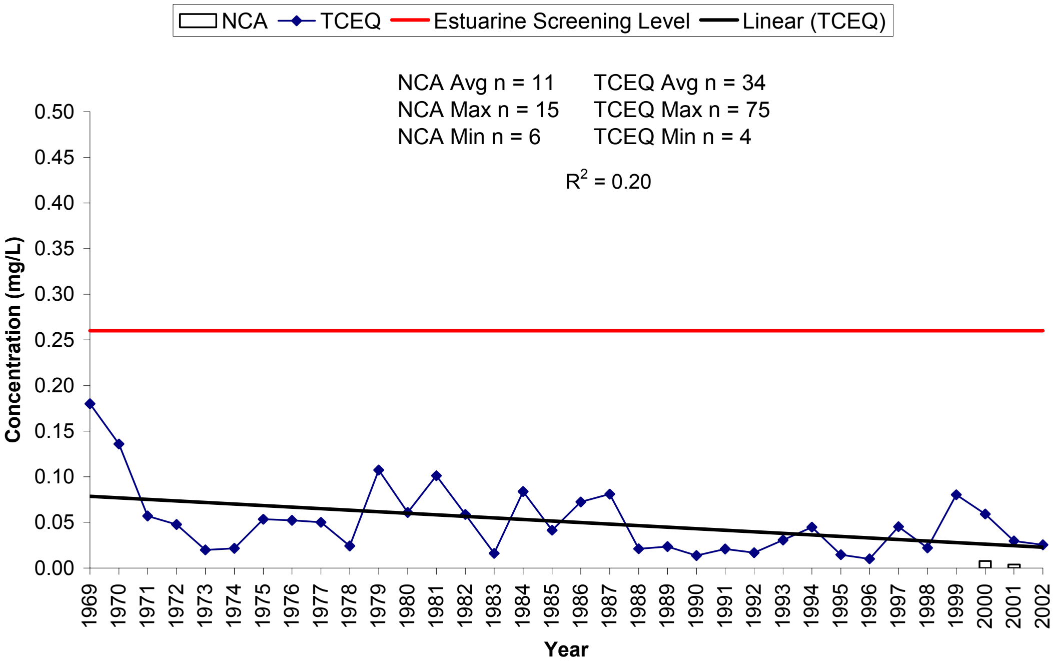


Figure 4.1.2.4. Annual Average Nitrate-Nitrite in Water in West Bay



Phosphorus

Phosphorus is an essential nutrient in estuarine food webs. Its absence can have a detrimental effect on primary productivity in a bay system, while excess levels can lead to eutrophication. 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.

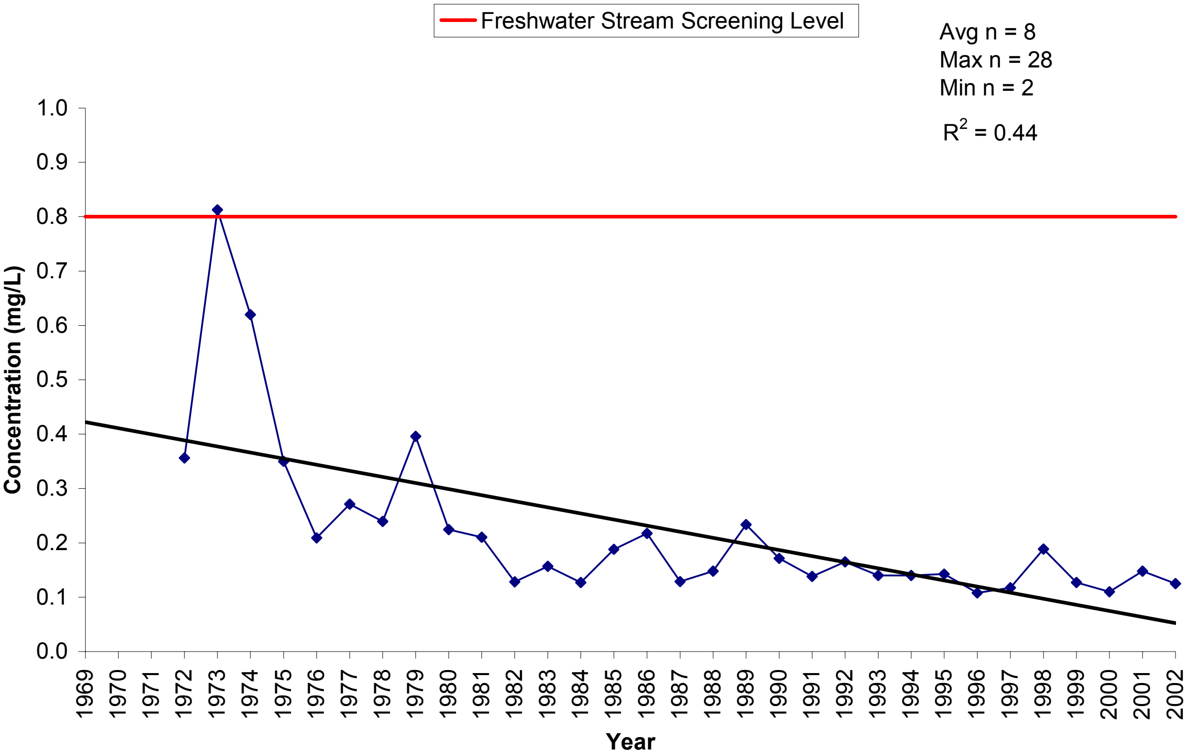
As discussed in 2002, annual average phosphorus concentrations exhibited declining or stable trends in every sub-bay and tributary of Galveston Bay. Of the eleven study areas, five had significant trends ($R^2 > 0.25$). Cedar Bayou ($R^2 = 0.41$), Dickinson Bayou and Dickinson Bay ($R^2 = 0.51$), East Bay ($R^2 = 0.24$), Upper and Lower Galveston Bay ($R^2 = 0.30$), and the Houston Ship Channel ($R^2 = 0.73$); all demonstrated declining trends. The most striking decline in phosphorus concentrations occurred in the Houston Ship Channel. A peak annual average concentration of 2.2 mg/L occurred in 1974. Year 2001 exhibited an annual average concentration of 0.72 mg/L.

Of the five new study areas, only the Trinity River had a significant declining trend, which flattened in recent years (see Figure 4.1.2.5). There were no trends in the other four areas. Note the water quality screening level of 0.71 mg/L. The only trends to exceed the screening level were for the Trinity River and the East Intracoastal Waterway in the 1970s. NCA data collected in 2000 and 2001 for West Bay exhibit annual averages similar to those of the TCEQ data. Annual average phosphorus concentration trend graphs for the other study areas within the Galveston Bay estuary can be viewed in Appendix B.

Table 4.1.2.3. Summary of Annual Trends in Phosphorus.

Study Area	**Trend Direction**	**R^2 Value**
Christmas Bay/Bastrop Bayou	No Trend	0.07
Galveston Channel	No Trend	0.23
Intracoastal Waterway East	No Trend	0.23
Trinity River	Declining	0.44 ($p < 0.001$)
West Bay	No Trend	0.24

Figure 4.1.2.5. Annual Average Total Phosphorus in Water in the Trinity River



There were no significant trends ($R^2 > 0.25$) in monthly average phosphorus concentrations in any of the five study areas. The trend graphs for monthly average phosphorus concentrations are included in Appendix B.

Chlorophyll-a and Pheophytin-a

Chlorophyll-a is a pigment commonly found in phytoplankton and is used as an indicator of phytoplankton abundance, primary productivity and eutrophication. Pheophytin-a is the breakdown product of chlorophyll-a and is often analyzed as a water quality parameter in conjunction with chlorophyll-a. 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 areas. The data set for pheophytin-a begins in the mid 1970s with some data gaps present during the early to mid 1980s. Only those chlorophyll-a and pheophytin-a samples collected at a depth of 0.3 m were analyzed. Chlorophyll-a and pheophytin-a are reported as ug/L.

In 2002, the Status and Trends Project reported on chlorophyll-a concentrations in Galveston Bay. Pheophytin-a was not analyzed. Trends in annual average concentrations of chlorophyll-a declined across all sub-bays and tributaries over the period of record. Declining trends were significant ($R^2 > 0.25$) in 8 of the eleven study areas. Clear Creek and Clear Lake, Upper and Lower Galveston Bay, and Chocolate Bayou had declining trends identified as not significant ($R^2 < 0.25$). The strongest declining trends in average annual chlorophyll-a concentrations were found in the Houston Ship Channel ($R^2 = 0.64$), the San Jacinto River ($R^2 = 0.54$), and the Texas City Ship Channel ($R^2 = 0.51$).

In the time since the publication of the Status and Trends 2002 report, some questions have come to light as to whether the chlorophyll-a and pheophytin-a concentrations in the TCEQ database are a true reflection of their proportions in the field or whether they might be influenced by laboratory analytical procedures. Water samples may warm prior to laboratory analysis hastening the breakdown of chlorophyll-a into pheophytin-a. Until that question can be answered, the Status and Trends Project will report chlorophyll-a and pheophytin-a concentrations averaged together. Readers should keep in mind the possible influence of laboratory procedures on reported concentrations.

Three of the five new study areas exhibited declining chlorophyll-a and pheophytin-a trends (see Table 4.1.2.4). The strongest declining trends were seen in the Christmas Bay/Bastrop Bayou Complex (Figure 4.1.2.6) and West Bay (Figure 4.1.2.7). As a point of reference, note the TCEQ chlorophyll-a screening levels; annual average values exceeded or neared the screening levels in the 1970s and 1980s. However, annual averages have not exceeded the screening level in the past decade. NCA data collected in 2000 and 2001 for West Bay exhibit annual averages similar to, but slightly higher than, those of the TCEQ data.

Table 4.1.2.4. Summary of Annual Trends in Chlorophyll-a and Pheophytin-a.

Study Area	**Trend Direction**	**R^2 Value**
Christmas Bay/Bastrop Bayou	Declining	0.46 ($p < 0.001$)
Galveston Channel	No Trend	0.09
Intracoastal Waterway East	Declining	0.30 ($p = 0.036$)
Trinity River	No Trend	0.23
West Bay	Declining	0.46 ($p < 0.001$)

There were no significant trends ($R^2 > 0.25$) in monthly average chlorophyll-a and pheophytin-a concentrations in any of the five study areas. The trend graphs for monthly average chlorophyll-a and pheophytin-a concentrations are included in Appendix B.

Figure 4.1.2.6. Annual Average Chlorophyll-a and Pheophytin-a in Water in the Christmas Bay/Bastrop Bayou Complex

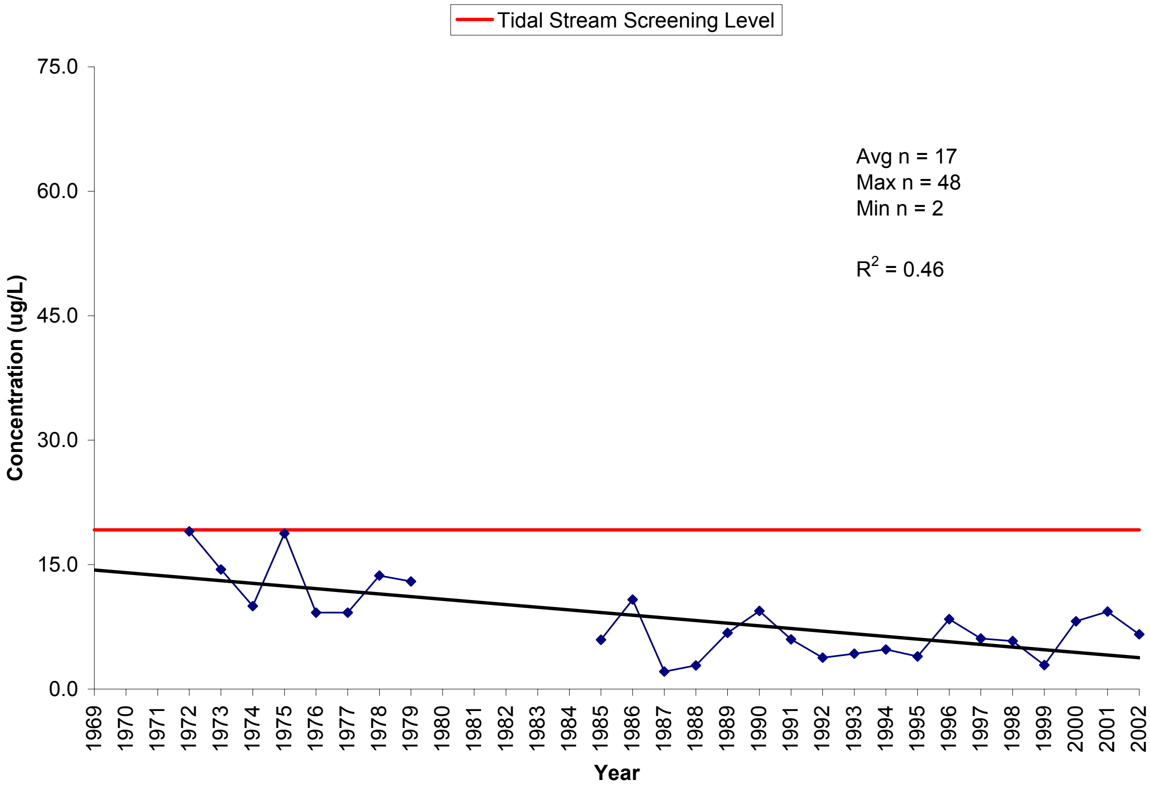
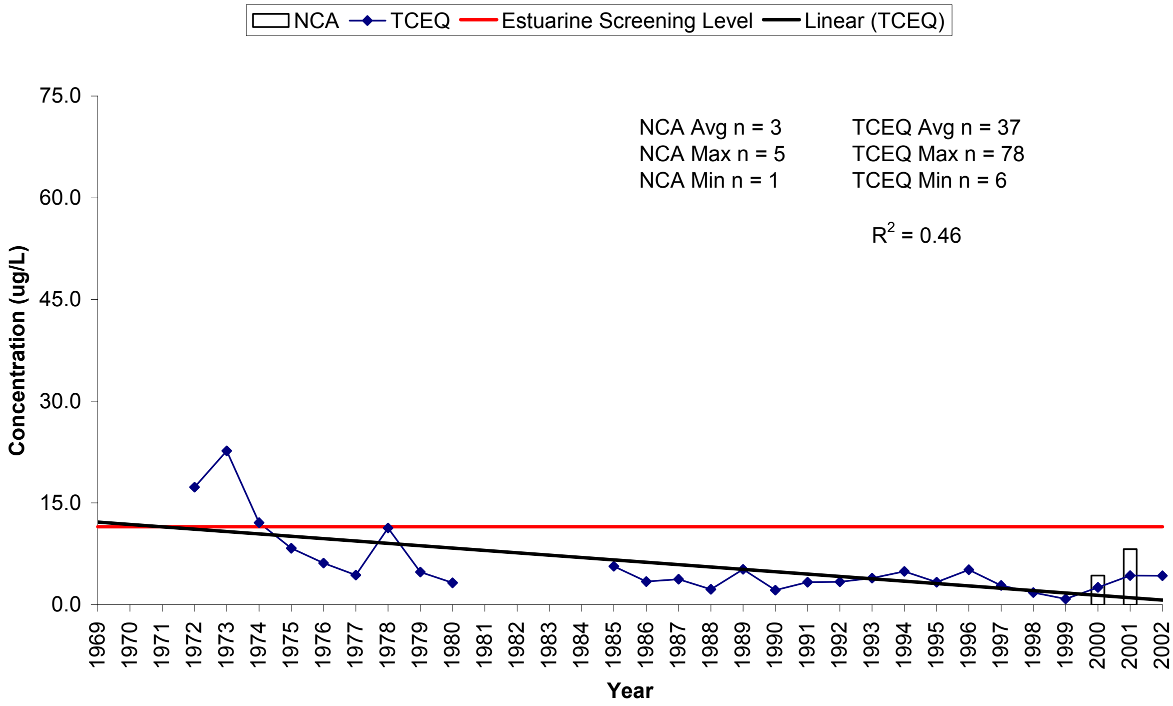


Figure 4.1.2.7. Annual Average Chlorophyll-a and Pheophytin-a in Water in West Bay



TSS

Total Suspended Solids (TSS) are small particles suspended in water that can be trapped by a filter. TSS includes a wide variety of material, such as clay, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of TSS can block light from reaching submerged aquatic vegetation, slowing photosynthetic activity and eventually killing the plants. High TSS levels in water can also mean higher concentrations of bacteria, nutrients, pesticides, and metals in the water. These pollutants may attach to sediment particles on the land and be carried into estuaries where they are released from the sediments. Alternately, TSS can bind toxic chemicals such as pesticides and metals, making the toxic compounds less bioavailable to living organisms. TSS can also affect other parameters such as temperature and dissolved oxygen.

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.

As reported in 2002, TSS exhibited declining trends in annual average concentrations across all sub-bays and tributaries 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. 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.

Decreasing trends were also found in the East Intracoastal Waterway and the Trinity River (see Figures 4.1.2.8 and 4.1.2.9). The highest concentrations were found in the East Intracoastal Waterway in the 1970s. However, concentrations in that area have since decreased to levels found in other areas. Samples collected from the Galveston Channel, the Christmas Bay/Bastrop Bayou Complex, and West Bay did not exhibit significant trends (see Table 4.1.2.5). Screening levels were not available for TSS.

There were no significant trends ($R^2 > 0.25$) in monthly average TSS concentrations in any of the five study areas. The trend graphs for monthly average TSS concentrations are included in Appendix B.

Table 4.1.2.5. Summary of Annual Trends in TSS.

Study Area	**Trend Direction**	**R^2 Value**
Christmas Bay/Bastrop Bayou	No Trend	0.13
Galveston Channel	No Trend	0.01
Intracoastal Waterway East	Declining	0.46 ($p < 0.001$)
Trinity River	Declining	0.25 ($p = 0.004$)
West Bay	No Trend	0.11

Figure 4.1.2.8. Annual Average TSS in Water in the East Intracoastal Waterway

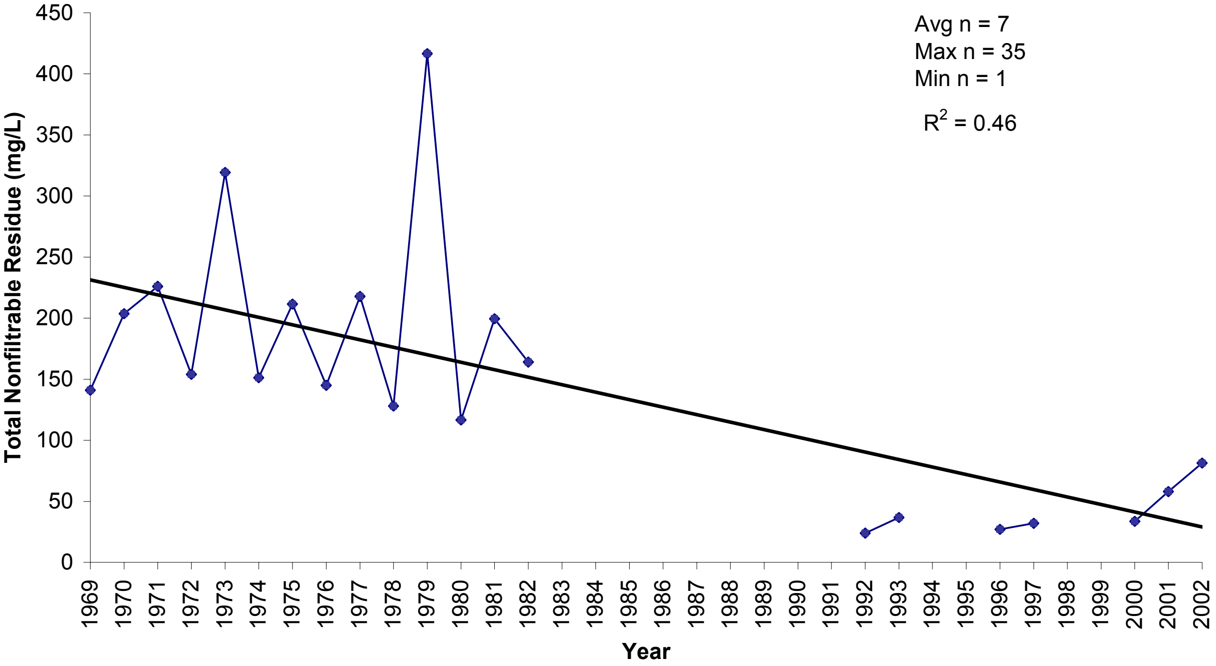
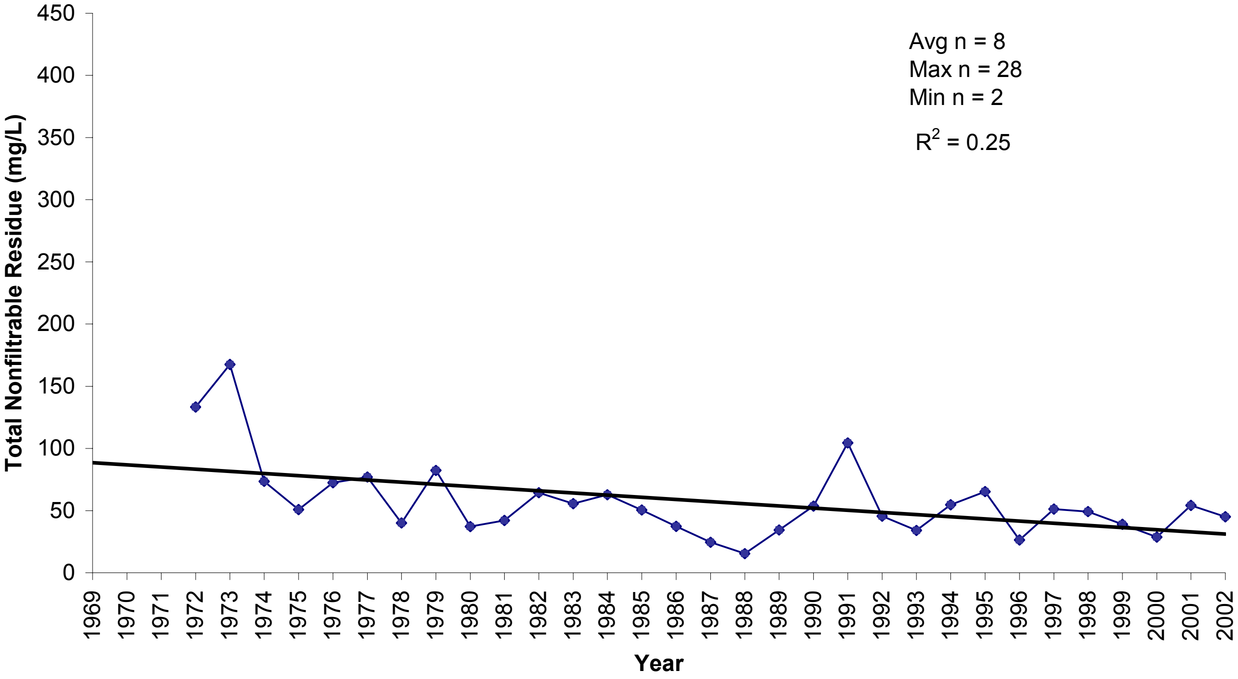


Figure 4.1.2.9. Annual Average TSS in Water in the Trinity River



TOC

Organic matter plays a major role in aquatic systems. It affects processes such as, nutrient cycling, biological availability (the degree to which compounds can be taken up by plants and animals), and chemical transport. Organic matter content is measured as total organic carbon (TOC) and dissolved organic carbon (DOC), which are essential components of the estuarine carbon cycle. TOC can also be used to monitor the performance of wastewater treatment operations. Organic matter in water consists of thousands of components, including macroscopic particles, colloids, dissolved macromolecules, and specific compounds.

The analysis of TOC in estuaries is of interest because carbon compounds serve as a food source for microorganisms. If untreated organic compounds are discharged into an estuary they can lead to algal blooms, oxygen depletion via biochemical oxygen demand, and possibly fish kills. TOC levels in an estuary are affected by nutrient levels of inflows, decaying vegetation, water temperature and treated sewage.

Concentrations of total organic carbon (TOC) in water were sampled for the Galveston Bay estuary by the TCEQ from 1973-2002. Samples collected at all depths and times were analyzed by the Status and Trends Project. Data are reported as mg/L.

As reported by the Status and Trends Project in 2002, annual average TOC concentrations declined in all sub-bays and tributaries of the Galveston Bay system over the period of record. Eight of the eleven study areas exhibited declining trends that were significant ($R^2 > 0.25$). Areas without significant trends ($R^2 < 0.25$) included Cedar Bayou, Dickinson Bayou and Dickinson Bay, and the Texas City Ship Channel.

For new areas of study, the Christmas Bay/Bastrop Bayou Complex was the only area to not have a significant trend. All other areas (the East Intracoastal Waterway, the Trinity River, the Galveston Channel (Figure 4.1.2.10), and West Bay(Figure 4.1.2.11) had significant declining trends.

Table 4.1.2.6. Summary of Annual Trends in TOC.

Study Area	**Trend Direction**	**R^2 Value**
Christmas Bay/Bastrop Bayou	No Trend	0.12
Galveston Channel	Declining	0.44 ($p < 0.001$)
Intracoastal Waterway East	Declining	0.77 ($p < 0.001$)
Trinity River	Declining	0.28 ($p = 0.003$)
West Bay	Declining	0.53 ($p < 0.001$)

There were no significant trends ($R^2 > 0.25$) in monthly average TOC concentrations in any of the five study areas. The trend graphs for monthly average TOC concentrations are included in Appendix B.

Figure 4.1.2.10. Annual Average TOC in Water in the Galveston Channel

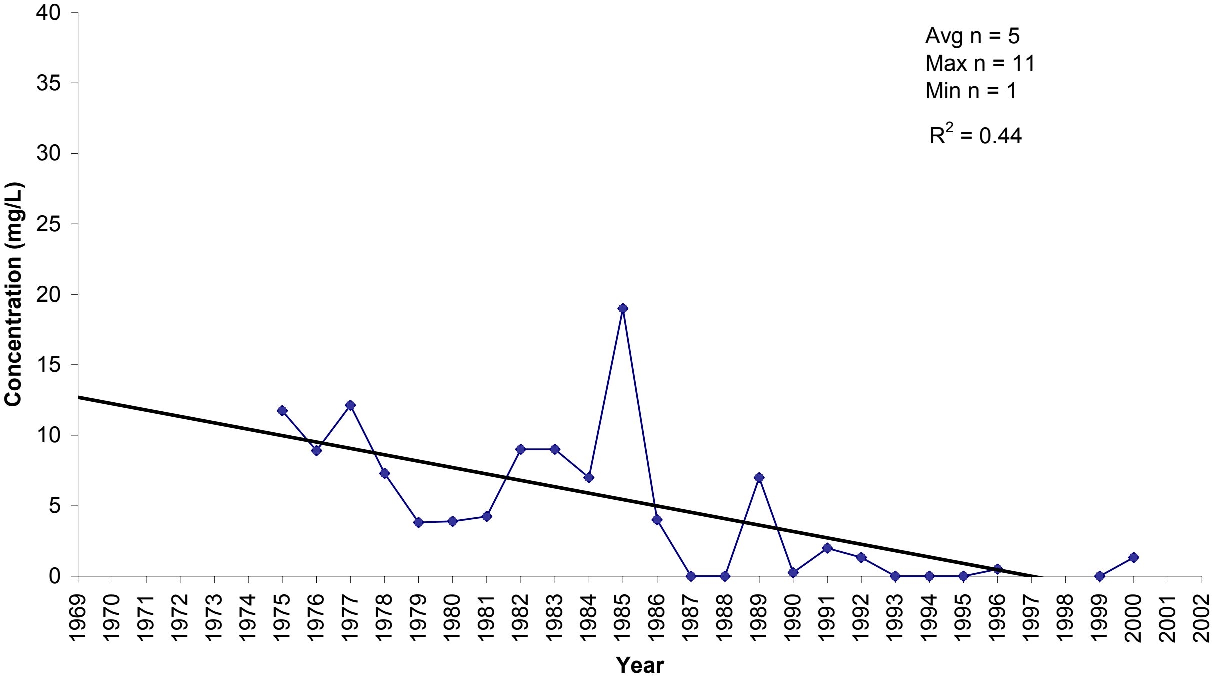
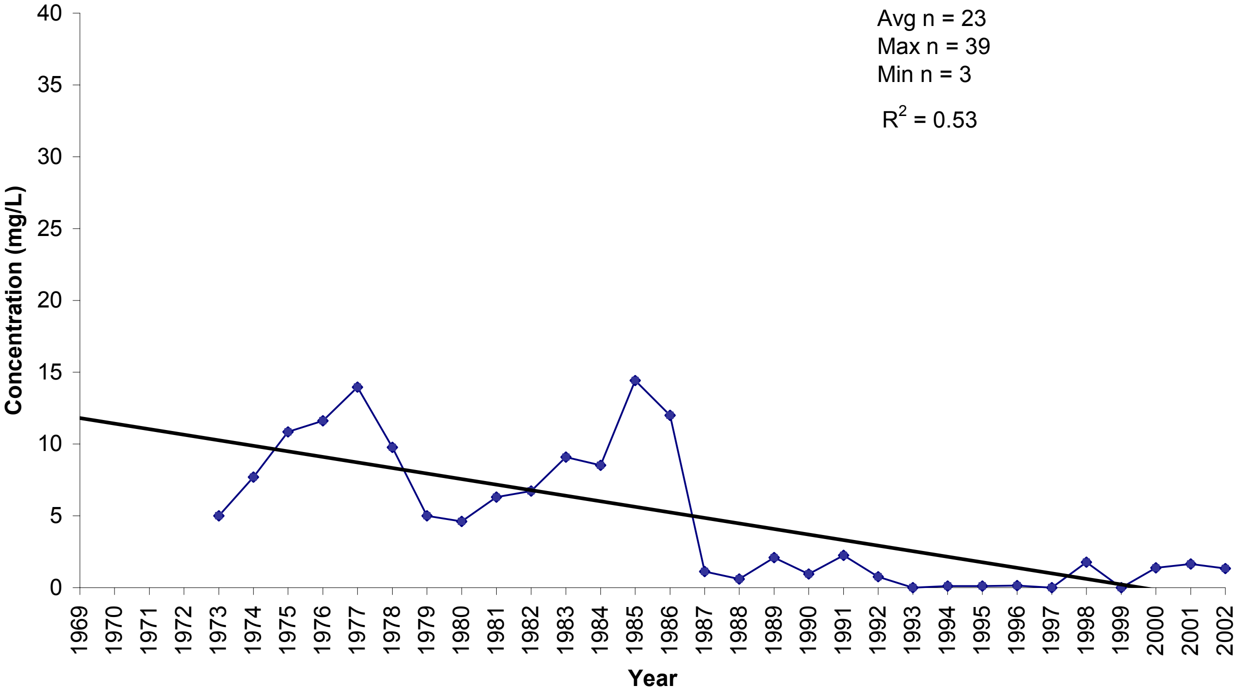


Figure 4.1.2.11. Annual Average TOC in Water in West Bay



4.1.3. Indicators of Pathogens

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

In 2000 the U.S. Environmental Protection Agency and the TCEQ recommended changes regarding appropriate bacterial indicator measures for estuarine and marine waters. The traditional bacterial indicator, fecal coliform, was replaced by *E. coli* for freshwater and by the generic group, *Enterococci*, for estuarine and marine waters. The agencies overlapped fecal coliform and Enterococci sampling for the years 2000-2002. This overlap provided additional information on the relationship between the two parameters.

The TCEQ uses standardized sampling methodologies that can be reviewed in the TCEQ Surface Water Quality Monitoring Procedures Manual (TNRCC, 1999a).

Fecal Coliform

Fecal coliform is a group of bacteria that may indicate the presence of human or animal fecal matter in water and is used as an indicator of the presence of human pathogens in water. Since the changes to bacterial indicators were instituted only recently, fecal coliform is still the bacteriological indicator most widely used to test recreational waters. Fecal coliform is also approved as an indicator by the U.S. Food and Drug Administration's National Shellfish Sanitation Program (NSSP) for classifying shellfish harvest waters. Studies have found that all members of the coliform group can regrow in natural surface water depending on the water temperature and the amount of organic matter in it. Some warm tropical waters have sufficient organic matter for the bacteria to increase in numbers. The effluents from wastewater treatment plants may, in some cases, also provide conditions under which coliform bacteria can grow. Fecal coliforms can remain in an estuary for any length of time. Bacteria may survive for weeks in the sediment to be resuspended in the water column during a storm or other event that disturbs the sediment.

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 1999-2002, 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.

Fecal coliform data are calculated as geometric means, diminishing the effect of very large or very small values. This method of averaging is particularly useful for bacteria since they reproduce exponentially and their concentrations in water can vary from 10 to 100,000 colony forming units.

Data analyzed from the five new study areas did provide some trends. A declining trend was found for the East Intracoastal Waterway (Figure 4.1.3.1). There were no trends in fecal coliform concentrations for the Trinity River, West Bay, the Christmas Bay/Bastrop Bayou Complex, or the Galveston Channel. However, the Christmas Bay/Bastrop Bayou Complex (Figure 4.1.3.2) did have the highest annual log average concentrations of the five new study areas. This is due to elevated concentrations in the middle reach of Bastrop Bayou, an area where fecal coliform concentrations are drawing increased attention from the public.

Table 4.1.3.1. Summary of Annual Trends in Fecal Coliform.

Study Area	Trend Direction	R^2 Value
Christmas Bay/Bastrop Bayou	No Trend	0.04
Galveston Channel	No Trend	0.01
Intracoastal Waterway East	Declining	0.59 ($p < 0.001$)
Trinity River	No Trend	0.04
West Bay	No Trend	0.00

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

Figure 4.1.3.1. Annual Log Average Fecal Coliform in Water in the East Intracoastal Waterway.

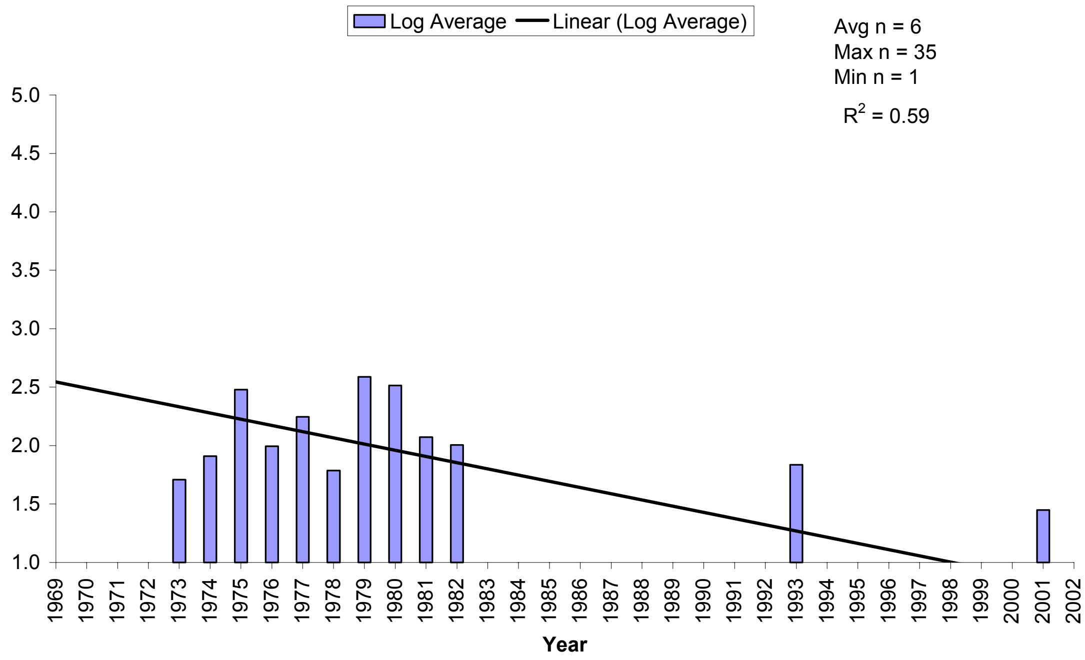
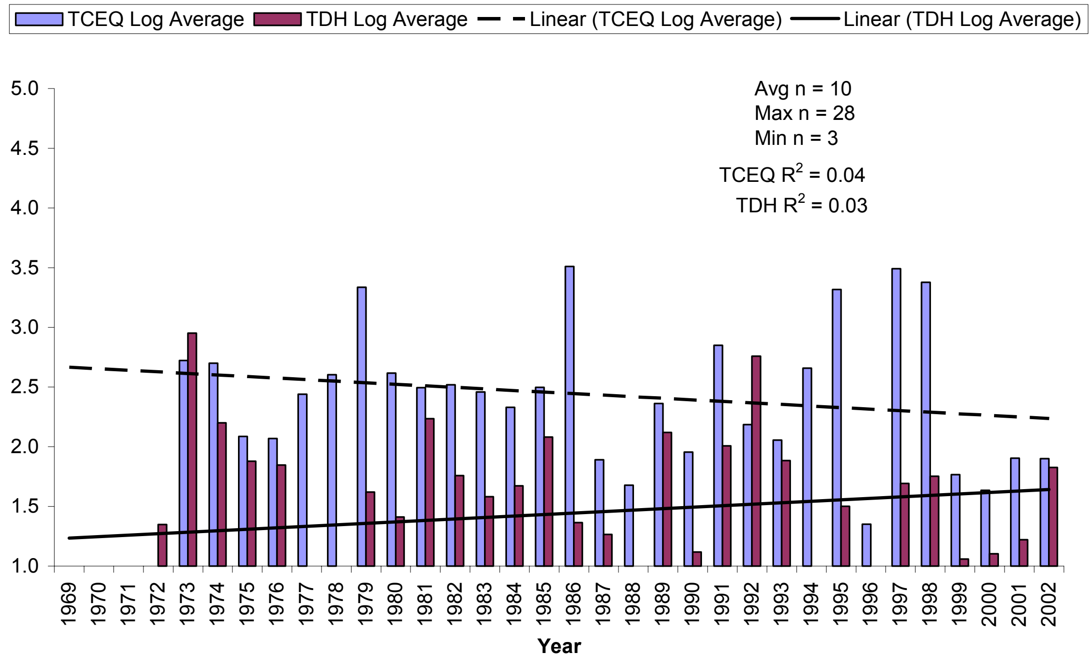


Figure 4.1.3.2. Annual Log Average Fecal Coliform in Water in the Christmas Bay/Bastrop Bayou Complex. Data from the TCEQ database are compared against TDH annual average fecal coliform concentrations.



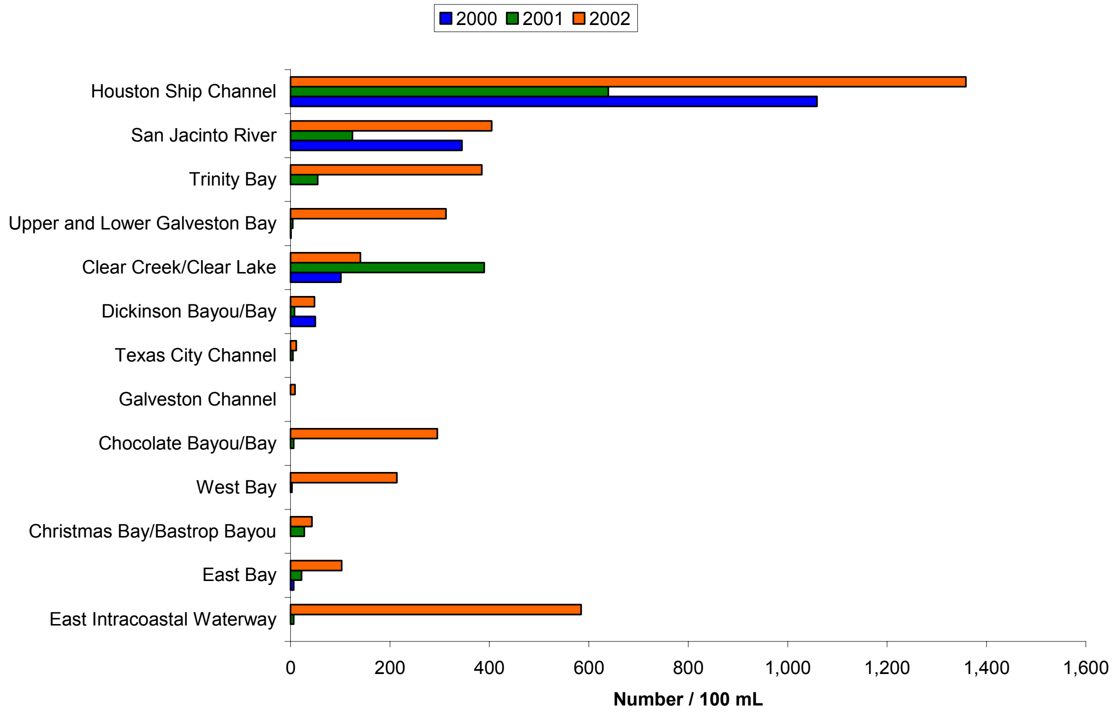
Enterococci

Enterococci are a subgroup of bacteria within the fecal streptococcus group. Enterococci are distinguished by their ability to survive in saltwater and tend to mimic many pathogens in this respect. Enterococci are typically more human-specific than the larger fecal streptococcus group.

The EPA recommends Enterococci as the best indicator of health risk in marine and estuarine waters. The EPA has found a direct relationship between the density of Enterococci in water and swimming-associated gastroenteritis in studies of marine and fresh water bathing beaches. According to the EPA, the test for Enterococci can be applied to potable, fresh, estuarine, marine and shellfish growing waters. Concentrations of Enterococci in Galveston Bay and its tributaries have been sampled by the TCEQ since 2000. Enterococci replaced fecal coliform bacteria as the pathogen indicator of choice used by water quality agencies. Enterococci are reported as colony forming units (cfu) per 100 mL.

As seen Figure 4.1.3.3, the year 2002 represents the year with the most complete record of Enterococci concentrations. In 2002 the areas of Galveston Bay with the highest annual average concentrations were the Houston Ship Channel, East Intracoastal Waterway, San Jacinto River, and Trinity Bay. Areas with the lowest concentrations were the Galveston Channel, Texas City Channel, Christmas Bay, Bastrop Bayou Complex, Dickinson Bayou/Dickinson Bay, and East Bay.

Figure 4.1.3.3. Annual Average Enterococci in the Sub-bays and Tributaries of Galveston Bay; 2000-2002



BOD

An integral part of an estuary's ecological cycle is the breakdown of organic matter. Like animal and plant respiration, this process consumes oxygen. Decomposition of large quantities of organic matter by bacteria can severely deplete the water of oxygen and make it uninhabitable for many species. Further, wastewater treatment plants or runoff from various land uses fuel the overgrowth of phytoplankton. The phytoplankton ultimately die, fall to the bottom, and are decomposed by bacteria and fungi that use up oxygen in the bottom waters of estuaries.

Concentrations of Biochemical Oxygen Demand 5-day (BOD5) in water were sampled for Galveston Bay by the TCEQ from 1969-2002. Samples collected at all depths and times were analyzed by the Status and Trends Project. Data are reported as mg/L.

As reported in 2002, 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 ten years of data and were not suitable for trend analyses. The remaining seven study areas yielded no significant trends in BOD5 concentrations.

Of the five new study areas, only three had more than ten years of data. None exhibited significant trends.

Table 4.1.3.2. Summary of Annual Trends in BOD5.

Study Area	Trend Direction	R^2 Value
Christmas Bay/Bastrop Bayou	No Trend	0.23
Galveston Channel	Insufficient Data	--
Intracoastal Waterway East	Insufficient Data	--
Trinity River	No Trend	0.15
West Bay	No Trend	0.09

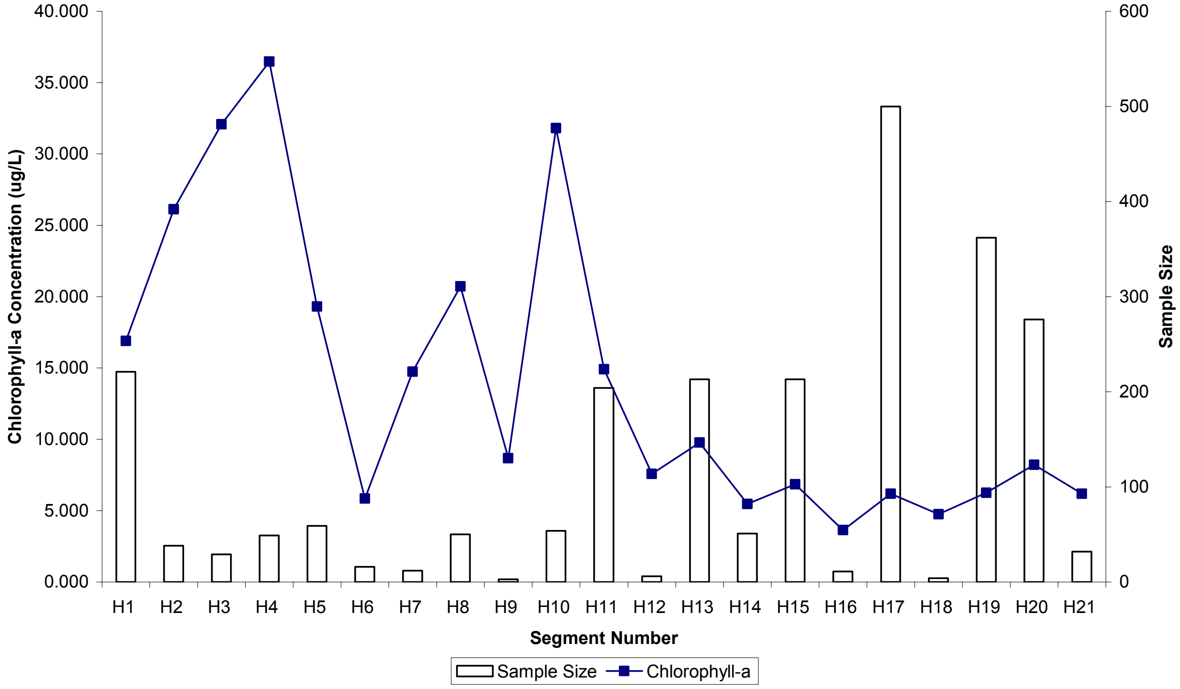
There were no significant trends ($R^2 > 0.25$) in monthly average BOD5 concentrations in any of the five study areas. The trend graphs for monthly average BOD5 concentrations are included in Appendix B.

4.1.4. Biological Productivity in the Houston Ship Channel.

The Houston Ship Channel is sampled more intensively for water and sediment quality parameters than any other area of the Galveston Bay system. There are 128 TCEQ sample sites along the water body classified in this study as the upper Houston Ship Channel. The GBEP established a segmentation scheme (modified from Ward and Armstrong, 1992; see Section 2.1), that divides the upper reaches of the Houston Ship Channel into 21 sections. The first H segment (H1) begins at Morgan's Point on the western boundary and subsequent segments are delineated as the Houston Ship Channel proceeds from Morgan's Point to Downtown Houston (H21) and the end of tidal influence on Buffalo Bayou. The Turning Basin (H19) is the last segment to serve as a location for shipping activities.

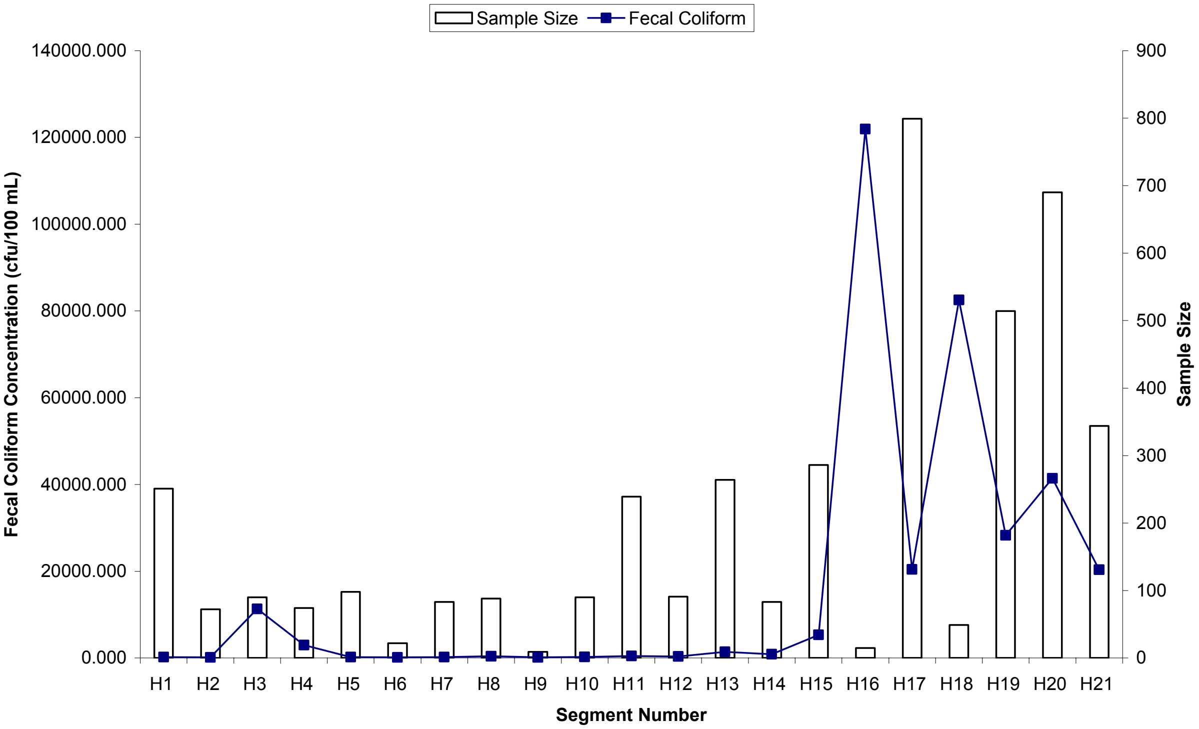
As the figures below demonstrate, there is a shift in the basis of productivity as one proceeds from the mouth of the Houston Ship Channel at the Bay (H1) to the tidal reaches of Buffalo Bayou (H21). Phytoplankton, indicated by the concentration of chlorophyll-a in the water, are more abundant in the segments from H10 toward the Bay than in the segments from H11 toward the downtown area.

Figure 4.1.4.1. Mean chlorophyll-a concentration by GBEP segment in the Houston Ship Channel. The plotted values are obtained by averaging the annual means obtained from the TCEQ water and sediment quality database for each GBEP segment in the Houston Ship Channel. The bars show the number of samples on which each mean is based. H1 is the Houston Ship Channel at the Bay while H21 is the upper tidal reaches of Buffalo Bayou.



The spatial distribution of coliform bacteria is very different compared to the distribution of chlorophyll-a. Using the TCEQ parameters for fecal coliform (TCEQ storet codes 31613 and 31616), Figure 4.1.4.2 plots the mean of annual averages for each of the 21 GBEP segments in the Houston Ship Channel. Bacterial concentrations are low from segments H1 to H15 and high from segments H16 to H21. Fecal coliform concentrations at H16 appear extremely high, but the value in the graph is based on only 15 samples, 13 of which were collected in 1976 and 1977. Fecal coliform values for H17, H19, H20 and H21 are more reliable because they are based on much larger sample sizes.

Figure 4.1.4.2. Mean fecal coliform concentrations by GBEP segment in the Houston Ship Channel. The plotted values are obtained by averaging the annual means obtained from the TCEQ WSQ database for each GBEP segment in the Houston Ship Channel. The bars show the number of samples on which each mean is based.



Ecological theory predicts that the lowest trophic levels in an ecosystem are the most responsive to the concentrations of nutrients. Under conditions of long water residence time, the biological producers will reduce the concentrations of nutrients as they are incorporated into cells. In many aquatic systems, phytoplankton appear to be the biological producer that causes the largest changes in nutrient concentrations. Phytoplankton are autotrophs that use carbon dioxide, nitrogen and phosphorus and produce oxygen as they photosynthesize. Bacteria are heterotrophs that use oxygen, nitrogen and phosphorus and give off carbon dioxide and ammonia as they break down organic matter. The graphs below indicate that bacteria are the dominant biological producers in the aquatic ecosystem found in the upper reaches of the Houston Ship Channel and phytoplankton are more important from H10 to the Bay.

Figure 4.1.4.3. Mean nitrate-nitrite concentrations by GBEP segment in the Houston Ship Channel. The plotted values are obtained by averaging the annual means obtained from the TCEQ water and sediment quality database for each GBEP segment in the Houston Ship Channel. The bars show the number of samples on which each mean is based.

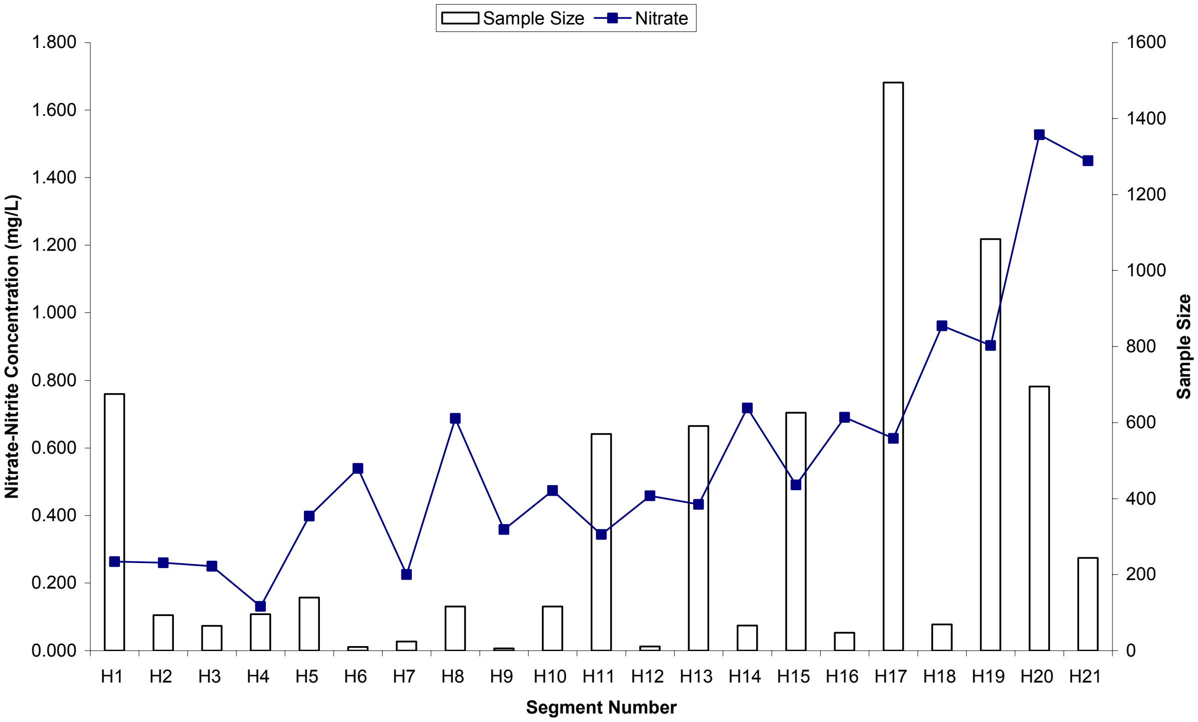
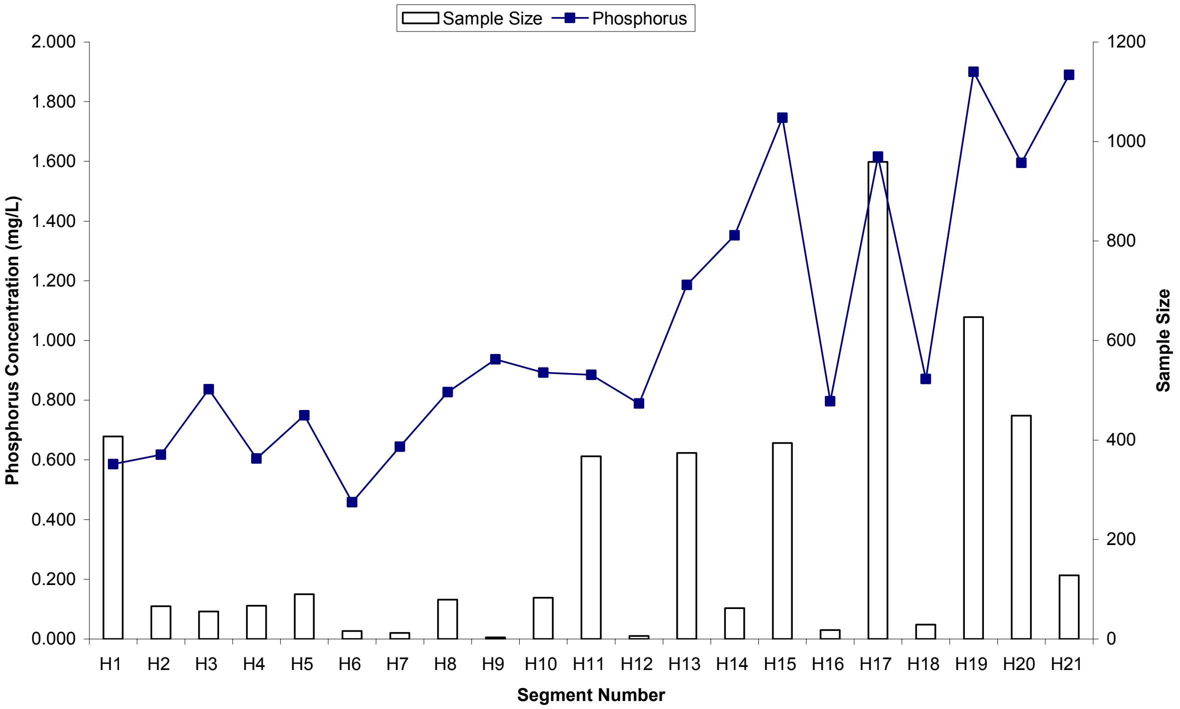


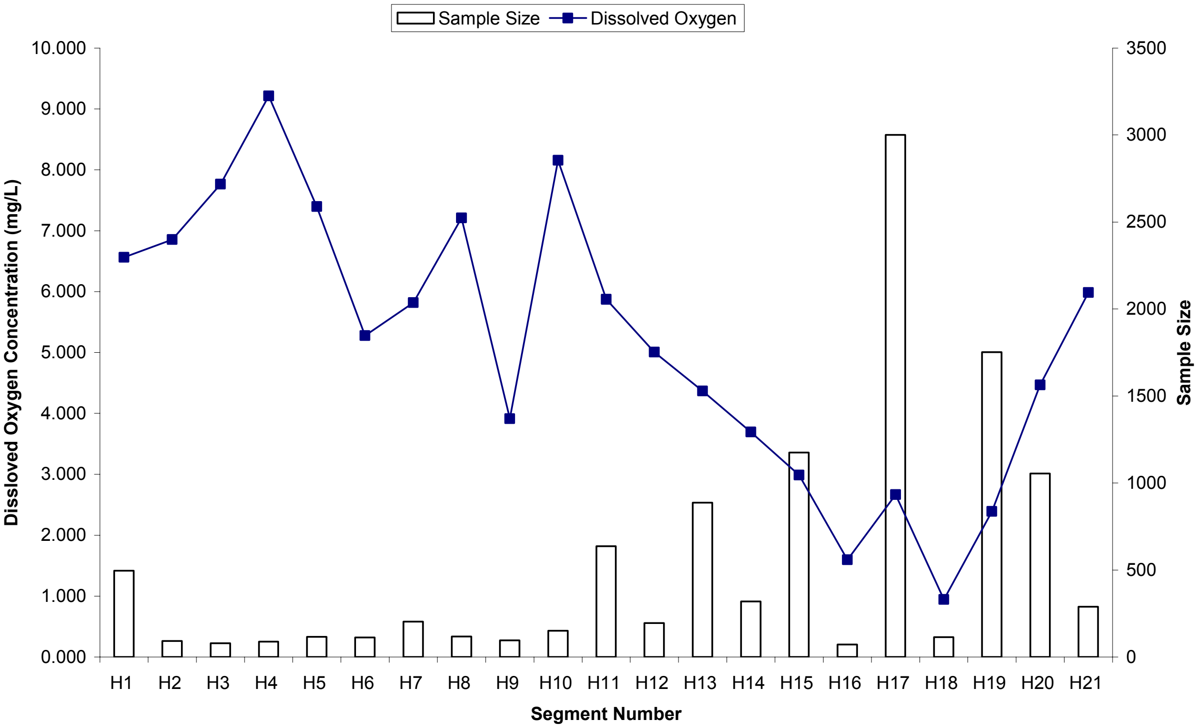
Figure 4.1.4.3 shows the decline in nitrate-nitrite concentration as sampling moves from the upper tidal reaches (H21) to the mouth of the channel at Morgan's Point (H1). Phosphorus concentrations shown in Figure 4.1.4.4 follow the same pattern as the nitrate concentrations, declining from the upper reaches to the lower reaches of the Houston Ship Channel. The concentrations of nitrate-nitrite and phosphorus could be declining because the nutrients are being diluted or because biological production is using them.

Figure 4.1.4.4. Mean phosphorus concentrations by GBEP segment in the Houston Ship Channel. The plotted values are obtained by averaging the annual means obtained from the TCEQ water and sediment database for each GBEP segment in the Houston Ship Channel. The bars show the number of samples on which each mean is based.



The shift from bacterial dominance to phytoplankton dominance is shown by the graph of afternoon dissolved oxygen (DO) values. Cool water is saturated with oxygen at around 6 mg/L. As water temperature goes up, oxygen saturation levels decrease. Aquatic systems with high concentrations of phytoplankton or macroalgae often show supersaturated conditions during daylight hours with oxygen levels well above 6 mg/L. GBEP segments H11 to H21 show average annual values of midday DO below 6 mg/L, but the segments nearer the Bay tend to show supersaturated DO levels in midday.

Figure 4.1.4.5. Mean DO concentrations for samples taken between 10 a.m. and 3 p.m. by GBEP segment in the Houston Ship Channel. The plotted values are obtained by selecting measurements taken during the relevant time period and averaging the annual means obtained from the TCEQ water and sediment quality database for each GBEP segment in the Houston Ship Channel. The bars show the number of samples on which each mean is based.



More information about the relationship between the phytoplankton and bacteria in this aquatic system can be obtained from analysis of the correlations shown in Table 4.1.4.1. As one would expect, chlorophyll-a has a significant positive correlation with the midday concentrations of dissolved oxygen. Photosynthesis during daylight hours and respiration are the primary forces changing DO on a daily cycle. However, chlorophyll-a has a significant negative correlation with phosphorus and ammonia concentrations and a non-significant correlation with nitrate-nitrite. Coliform concentrations are positively correlated with ammonia and phosphorus and negatively correlated with afternoon DO as predicted. Thus ammonia (and high nutrient levels in general) is a signature for high abundance of bacteria and low abundance of phytoplankton. The bacterial concentrations appear to be sufficiently high to be strongly correlated with TSS.

Table 4.1.4.1. Correlations (r) of annual average concentration of water quality parameters by GBEP Segment in the Houston Ship Channel are shown. Values significant at $p < 0.05$ are highlighted in red.

		Ammonia	**Nitrate**	**Phosphorus**	**TSS**	**TOC**	**Chlorophyll-a**	**DO afternoon**
Nitrate	**r**	0.31	--	--	--	--	--	--
	p	0.173	--	--	--	--	--	--
Phosphorus	**r**	**0.66**	**0.48**	--	--	--	--	--
	p	0.001	0.028	--	--	--	--	--
TSS	**r**	0.43	0.37	0.31	--	--	--	--
	p	0.054	0.100	0.170	--	--	--	--
TOC	**r**	**0.50**	**0.50**	**0.62**	**0.64**	--	--	--
	p	0.021	0.021	0.003	0.002	--	--	--
Chlorophyll-a	**r**	**-0.50**	-0.35	**-0.48**	-0.29	-0.10	--	--
	p	0.020	0.121	0.029	0.196	0.672	--	--
DO Afternoon	**r**	**-0.75**	-0.23	**-0.46**	-0.31	-0.10	**0.86**	--
	p	<0.001	0.326	0.036	0.168	0.670	<0.001	--
Fecal Coliform	**r**	**0.52**	0.30	0.12	**0.60**	0.17	-0.40	**-0.63**
	p	0.017	0.188	0.612	0.004	0.449	0.072	0.002

4.1.5. Variation in Water Quality Parameters Over Depth in the Houston Ship Channel

The Galveston Bay system is generally shallow and well mixed by wind and circulation patterns. However, miles of deep channel have been dredged in the Bay bottom. Intercontinental shipping requires deep draft ships that necessitate deep channels. There is great concern by many stakeholders about the impact of deep channels on water quality and other qualities of the Bay. In this study, a preliminary examination of the effect of depth on water quality parameters in the upper Houston Ship Channel was performed.

The Houston Ship Channel is dredged to a depth of about 13 meters from Bolivar Roads at the entrance to the Gulf of Mexico to the Turning Basin in Segment H19. This channel is subject to tidal movement and has a wedge of saline water extending from the Gulf into the Bay. In the Upper Houston Ship Channel, the water is primarily freshwater from discharges and runoff. The residence time of water in the Upper Houston Ship Channel is unknown, but the flow rate is generally low.

The water quality parameters selected for investigation are ammonia, nitrate-nitrite, phosphorus, total organic carbon (TOC), total suspended solids (TSS), chlorophyll-a, dissolved oxygen between 10 a.m. and 3 p.m. (DO-pm), and Do between 5 a.m. and 10 a.m. (DO-am). Sample depths were categorized into four classes: 0 to 1 meter (m), 1 to 2 m, 2 to 5 m, and more than 5 m. The mean values over the time period of the data set for each of the parameters in each of the depth categories are shown in Table 4.1.5.1. A comparison of means test (Tukey) was performed and homogeneous subsets were identified. Membership in a homogeneous subset is shown by shared alphabetic superscripts.

Table 4.1.5.1. Water quality parameters, ammonia, nitrate-nitrite, total phosphorus, total organic carbon (TOC), total suspended solids (TSS), chlorophyll-a (Chl-a), dissolved oxygen in afternoon samples (DO-pm), and dissolved oxygen in morning samples (DO-am) were combined over all H segments and subdivided by depth. Samples are grouped for depths from 0 to 1 m, 1 to 2 m, 2 to 5 m, and greater than 5 m. Numbers of samples on which values are based are shown in parentheses. Values that are not significantly different across depths are indicated by the same superscript letter. Significance was determined by Tukey test of means ($p < 0.05$).

	Parameter							
Depth	**Ammonia (N)**	**Nitrate-Nitrite (N)**	**Phosphorus (N)**	**TOC (N)**	**TSS (N)**	**Chl-a (N)**	**DO-pm (N)**	**DO-am (N)**
0-1 m	1.29^{a} (4552)	0.85^{a} (5040)	1.36^{a} (3219)	11.8^{a} (3316)	35.7^{a} (4477)	10.7^{a} (2025)	4.95^{a} (3902)	5.06^{a} (973)
1-2 m	$0.60^{a,b}$ (19)	$0.69^{a,b}$ (34)	1.24^{a} (19)	12.4^{a} (7)	$31.6^{a,b}$ (19)	12.3^{a} (15)	4.16^{b} (744)	$4.78^{a,b}$ (165)
2-5 m	$0.89^{a,b}$ (21)	$1.74^{a,b}$ (30)	1.79^{a} (21)	13.6^{a} (17)	$34.9^{a,b}$ (21)	2.8^{a} (12)	3.50^{c} (2007)	4.12^{b} (302)
+5 m	1.75^{b} (949)	0.24^{b} (1522)	1.41^{a} (946)	12.2^{a} (773)	58.5^{b} (972)	13.3^{a} (245)	2.98^{d} (4393)	3.06^{c} (470)

The values shown in Table 4.1.5.1 confirm the impression that part of the Houston Ship Channel is a bacterial dominated system. Chlorophyll-a concentrations are low and do not correlate to the pattern of nutrients (see Table 4.1.4.1). Ammonia is significantly higher below 5 meters than in the surface waters. (Most bacteria are negatively buoyant.) Nitrate-nitrite is significantly lower at depth than at the surface, suggesting use by biological producers. TSS corresponds with ammonia in being significantly higher at depth. Ammonia is a signature for bacterial respiration and TSS can be partially composed of bacterial cells.

Phosphorus and TOC show no pattern, suggesting that the water masses at the various depths are similar in origin. The parameters in Table 4.1.5.1 that differ by depth are those that would be affected by in situ heterotrophic activity, i.e. ammonia, nitrate-nitrite, DO and TSS.

DO declines from the surface to depth as one would expect, but the afternoon DO level is slightly lower or statistically indistinguishable from morning values. This suggests that photosynthesis has almost no effect on the DO level when looking at the entire Houston Ship Channel as one system. DO levels are generally low, probably due to a large oxygen demand in the areas where most samples are taken.

Phytoplankton-dominated systems normally show an afternoon DO greater than 6 mg/L due to photosynthesis. Table 4.1.4.1 shows a correlation of chlorophyll-a and afternoon DO over spatial segments, but this spatial relationship disappears over depths. Sampling of the Houston Ship Channel segments is much more common in the upper reaches where the spatial analysis suggests that bacteria dominate. Thus the combination of samples across segments at specific depths leads to an emphasis on the impacts of bacterial respiration. The high values of ammonia and TSS below 5 meters combined with the significantly lower afternoon DO at depth shows the strong influence of bacterial abundance at depth in the Houston Ship Channel.