3 Methodology and Results

3.1 Water and Sediment Quality

Background

The Texas Commission on Environmental Quality (TCEQ) maintains the Surface Water Quality Monitoring (SWQM) database for the State of Texas. The Status and Trends Project downloaded the data set for the coastal and river basins of the Lower Galveston Bay watershed (Neches-Trinity Coastal Basin, Trinity River Basin, Trinity-San Jacinto Coastal Basin, San Jacinto River Basin, San Jacinto-Brazos Coastal Basin, Brazos River Basin, and Bays & Estuaries) from the TCEQ website (http://www.tceq.state.tx.us/compliance/monitoring/crp/data/samplequery.html).

The TCEQ data set includes 3,970 specific parameters (storet codes) relating to water and sediment quality, which the TCEQ regularly samples as a function of its regulatory duties. The complete Galveston Bay data set includes samples collected from 1969-2005. Data are also collected by the TCEQ through the Clean Rivers Program. Locally, the Clean Rivers Program is administered by the Houston-Galveston Area Council (H-GAC). It coordinates the local monitoring efforts of government entities including the U.S. Geological Survey, the TCEQ Houston field office, the Galveston County Health District (former partner), Harris County Pollution Control, the City of Houston, the City of Pearland, the San Jacinto River Authority, and the Environmental Institute of Houston (EIH) at the University of Houston-Clear Lake.

The data were managed under the Status and Trend Project's Quality Assurance Project Plan (QAPP). Data were filtered by depth, time of day (dissolved oxygen), detection limits, and minimum number of samples. Data were grouped spatially by subbay and tributary according to the Galveston Bay Segmentation Scheme shown in Figure 3.1.1. Subbay and tributary groupings are as follows:

Subbays:

1. Christmas Bay Complex
2. East Bay
3. Trinity Bay
4. Upper and Lower Galveston Bay
5. West Bay

Tributaries:

6. Armand Bayou
7. Bastrop Bayou
8. Buffalo Bayou
9. Cedar Bayou
10. Chocolate Bayou/Bay
11. Clear Creek/Lake
12. Dickinson Bayou/Dickinson Bay
13. East Intracoastal Waterway
14. Galveston Channel
15. Houston Ship Channel
16. Oyster Bayou
17. San Jacinto River
18. Texas City Channel
19. Trinity River

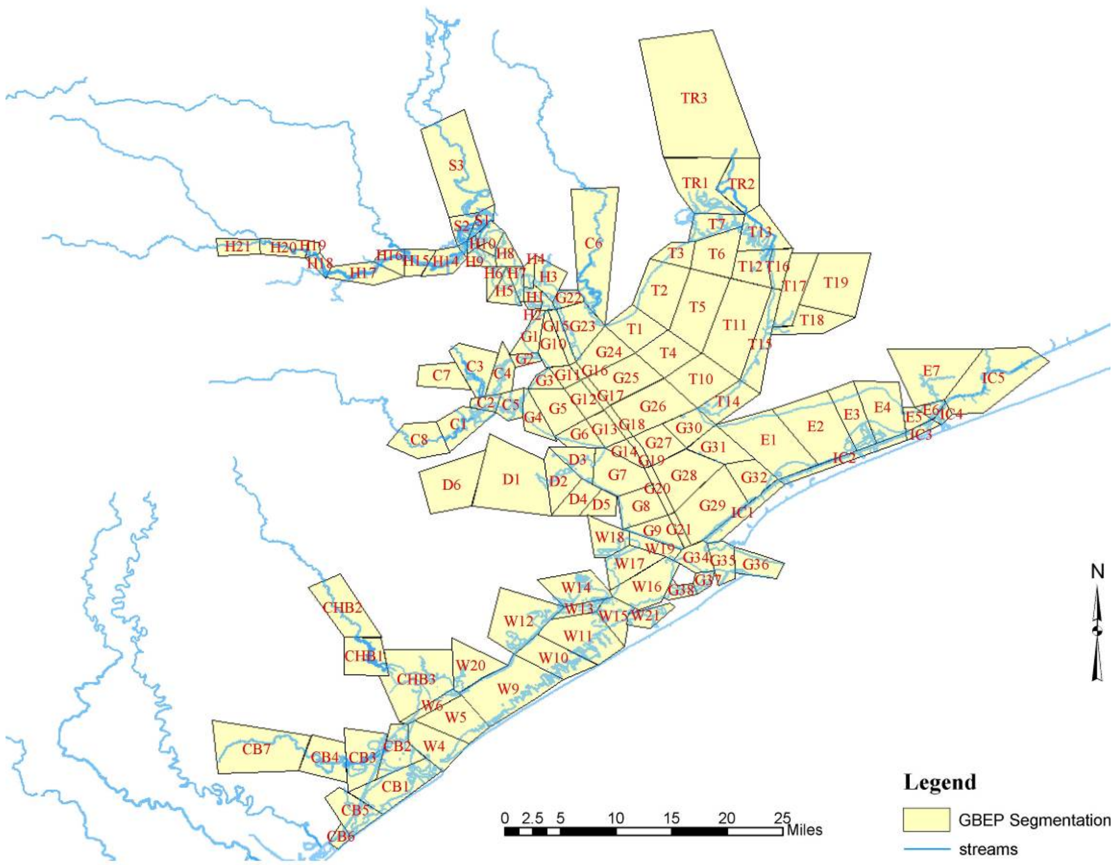

Figure 3.1.1. Tributaries and subbays of Galveston Bay per the Galveston Bay Segmentation Scheme as modified by the Status and Trends Project in 2003.

Water and sediment quality data collected in the Lower Galveston Bay watershed during the period 1999-2005 were compared to TCEQ water quality standards (TCEQ 2004) according to the methodology developed by the Galveston Bay Indicators Project (Lester 2005).

3.1.1 Recent Trends in Water and Sediment Quality (1999-2005)

Nutrients and Chlorophyll-a

Nutrients are chemical elements or compounds essential for plant and animal growth. Water quality monitoring parameters used to measure nutrients in the Lower Galveston Bay watershed include total phosphorus, ammonia, nitrate-nitrite, and chlorophyll-a (an indicator of phytoplankton biomass in the water). While the primary productivity of the bay requires adequate amounts of nutrients, high amounts are associated with over-fertilization, or eutrophication, of a water body. Low levels of nutrients can reduce growth and survival of phytoplankton at the lowest levels of the food chain, thereby limiting the biomass of animals. In freshwater systems, phosphorus is generally considered to be the critical limiting nutrient, while in salt water that function is assigned to nitrogen. In Galveston Bay, although salinity varies, nitrogen is generally considered to be the "limiting nutrient", in other words adding more nitrogen would result in more plant growth. However, it is possible that under some conditions phosphorus is also a limiting nutrient in Galveston Bay's ecosystems.

Analyses by the Galveston Bay Indicators Project in 2004 compared concentrations of nutrients (ammonia, nitrate-nitrite, total phosphorus) and chlorophyll-a in surface waters of the Lower Galveston Bay watershed to screening levels established by the TCEQ (see Table 3.1.1). Major subbays and tributaries of the bay were rated (see Table 3.1.2) based on the percentage of samples exceeding TCEQ screening limits in a given decade.

Table 3.1.1. TCEQ screening levels for nutrients in surface waters of tributaries (tidal stream screening levels) and subbays (estuarine screening levels).

Nutrient	TCEQ Tidal Stream Screening Level	TCEQ Estuarine Screening Level
Ammonia	0.58 mg/L	0.10 mg/L
Nitrate-nitrite	1.83 mg/L	0.26 mg/L
Total phosphorus	0.71 mg/L	0.22 mg/L
Chlorophyll-a	19.2 ug/L	11.5 ug/L

Table 3.1.2. Indicator rating system developed for the nutrients in surface waters indicator. Table created by the Galveston Bay Indicators Project (2004) based on screening levels from the TCEQ (2004).

Rating	% Above Screening Level
Very Good	0-5
Good	6-15
Moderate	16-30
Poor	>30

Many areas of Galveston Bay appear to have experienced an improvement in nutrient concentrations since the 1970s (Lester 2005). As seen in Table 3.1.3, one urban tributary of the bay (Buffalo Bayou) currently rates "Poor". Several areas rate "Moderate" in terms of nutrient over enrichment, including Upper and Lower Galveston Bay, Trinity Bay, the Houston Ship

Channel, and Armand Bayou. Three areas (the San Jacinto River, Dickinson Bayou/Bay, and Chocolate Bayou/Bay) rate as “Very Good”.

Table 3.1.3. Indicator describing the state of nutrients (ammonia, nitrate-nitrite, total phosphorus) and chlorophyll-a/pheophytin-a concentrations in surface waters of the Lower Galveston Bay watershed as an average proportion of TCEQ screening levels from 1999-2005.

SUBBAYS	**1999-2005**
Upper & Lower Galveston Bay	(yellow)
Trinity Bay	(yellow)
East Bay	(green)
West Bay	(green)
Christmas Bay	(green)
TRIBUTARIES	**1999-2005**
Trinity River	(green)
San Jacinto River	(blue)
Buffalo Bayou	(red)
Houston Ship Channel	(yellow)
Clear Creek	(green)
Armand Bayou	(yellow)
Dickinson Bayou/Bay	(blue)
Chocolate Bayou/Bay	(blue)
Bastrop Bayou	(green)

Nutrient data were also grouped by sampling station, rated according to the system outlined Table 3.1.2 and mapped. As with the indicator rating system stations are color coded according to the proportion of samples exceeding TCEQ screening levels. In terms of water quality, red is “poor”, yellow is “moderate”, green is “good”, and blue is “very good”. Stations denoted by white circles did not have an adequate sample size (less than 12 samples were available over the six year period).

As seen in Figure 3.1.2, areas with problematic nutrient exceedences (stations highlighted in red and yellow) include the tributaries along the urbanized, western shore of Galveston Bay. Multiple stations along the Houston Ship Channel above the Turning Basin (i.e. Buffalo Bayou) exceeded screening levels for ammonia, nitrate-nitrite, and total phosphorus. Several stations along Clear Creek and Armand Bayou exceed nitrate-nitrite and total phosphorus screening levels. Multiple stations along Clear Creek and Armand Bayou exceeded chlorophyll-a screening levels. Additionally, 12 stations in Upper Galveston and Trinity Bays rated “moderate” for chlorophyll-a exceedences; meaning that 16-20 percent of samples collected at these stations from 1999 to 2005 exceeded TCEQ’s chlorophyll-a screening levels.

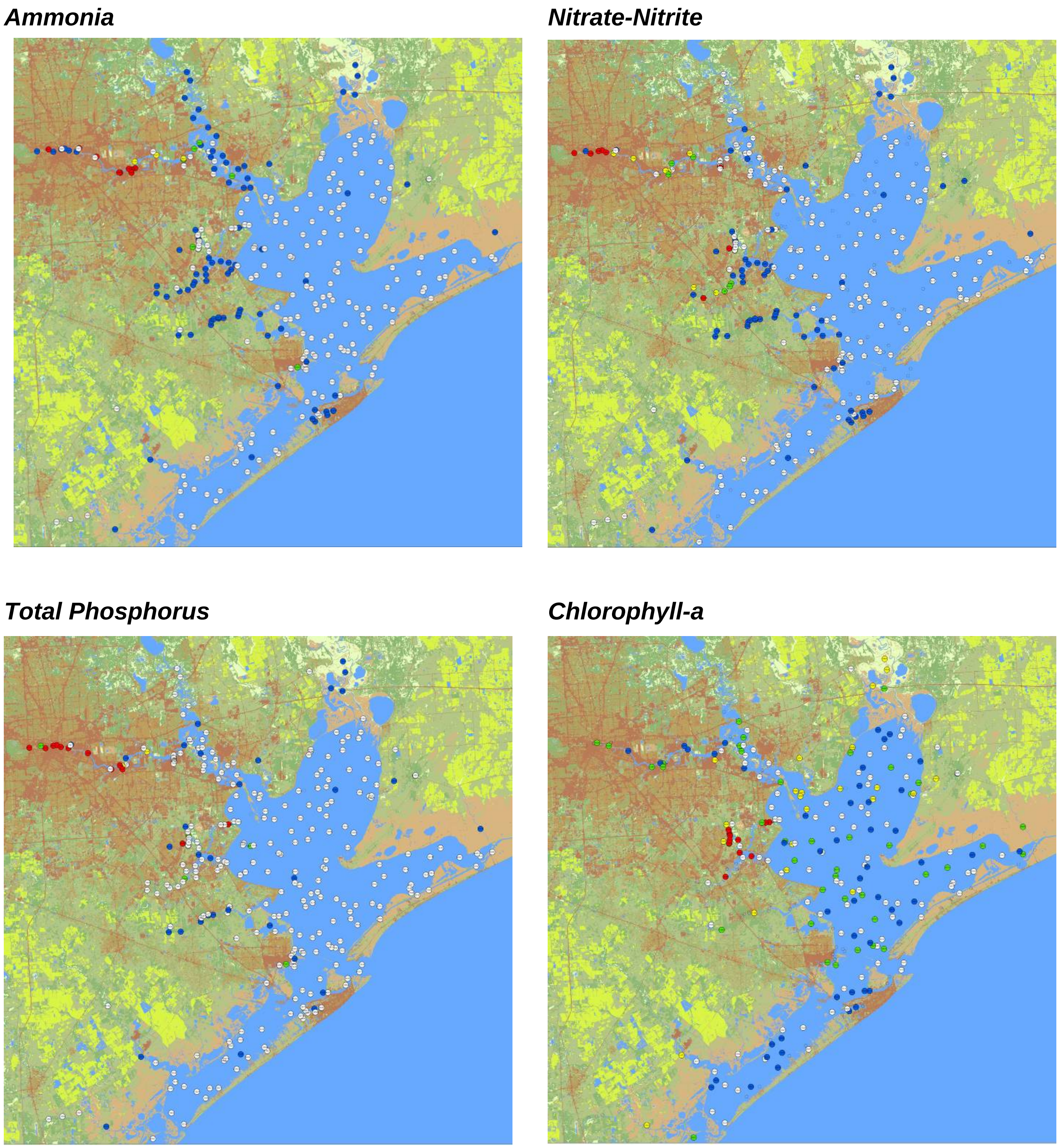

Figure 3.1.2. Stations sampled for nutrients and chlorophyll-a in surface waters of Galveston Bay 1999-2005. Stations are color-coded according to the proportion of samples exceeding TCEQ screening levels.

Dissolved Oxygen (DO)

Dissolved oxygen (DO) is a traditional indicator of aquatic health. It determines the ability of aerobic organisms to survive. In most cases, higher dissolved oxygen is better. The relationship between temperature and DO is inverse, meaning that as temperature rises, DO levels fall. As seen in Figure 3.1.3, dissolved oxygen concentrations, on average, are at their lowest in the summer months when water temperatures are high and the water flow in tributaries slows. Other important factors controlling DO include salinity, water turbulence, the presence of oxygen-demanding compounds and organisms, and photosynthesis. Of these, DO is introduced into the water column principally through simple mechanical agitation by wind and from plants, algae and bacteria as a byproduct of photosynthesis.

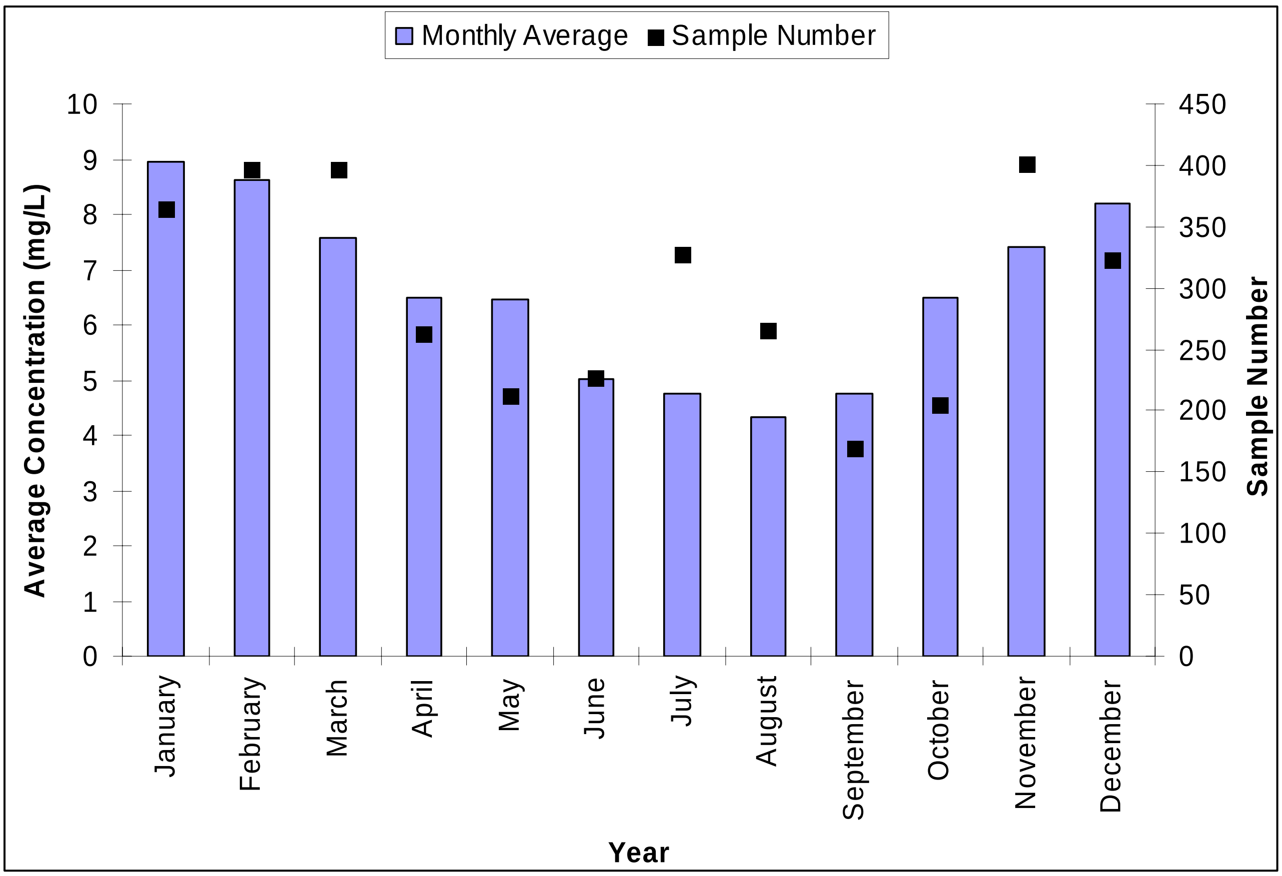

Figure 3.1.3. Monthly Average Dissolved Oxygen Concentrations in Surface Waters of Galveston Bay and Tributaries; 1969-2003. Samples were collected between 5:00 a.m. and 10:00 a.m. at 1 meter depth or less.

It is not simple to analyze the record of DO collected from the bay and its tributaries. Concentrations of oxygen vary over a daily cycle as a result of a complex interaction of the factors that produce it, use it, and affect its concentration. During daylight hours aquatic plants release oxygen into the water and raise the DO levels. At night these organisms cease photosynthesis, but continue to use oxygen causing DO levels to decline. Under other conditions, bacterial decomposition of algae causes the depletion of oxygen in the water. In high nutrient water, photosynthetic organisms can be present at densities high enough to reduce night time DO to levels too low to support fish and other aquatic animals. Low DO is the most common cause of fish kills in the Galveston Bay system. Figure 3.1.4 shows surface water quality sampling stations rated (see Table 3.1.2) according to the number of DO samples collected from 5:00 am to 10:00 am exceeding the TCEQ screening level of 2 mg/L. As seen in Figure 3.1.4, a number of sampling stations had less than 12 samples collected in the morning during the six year period (stations shaded in white). Of the stations with adequate sample sizes, many rated “good” in terms of morning dissolved oxygen levels. One station along Buffalo Bayou and two stations along Dickinson Bayou rated “poor” and “moderate”, respectively.

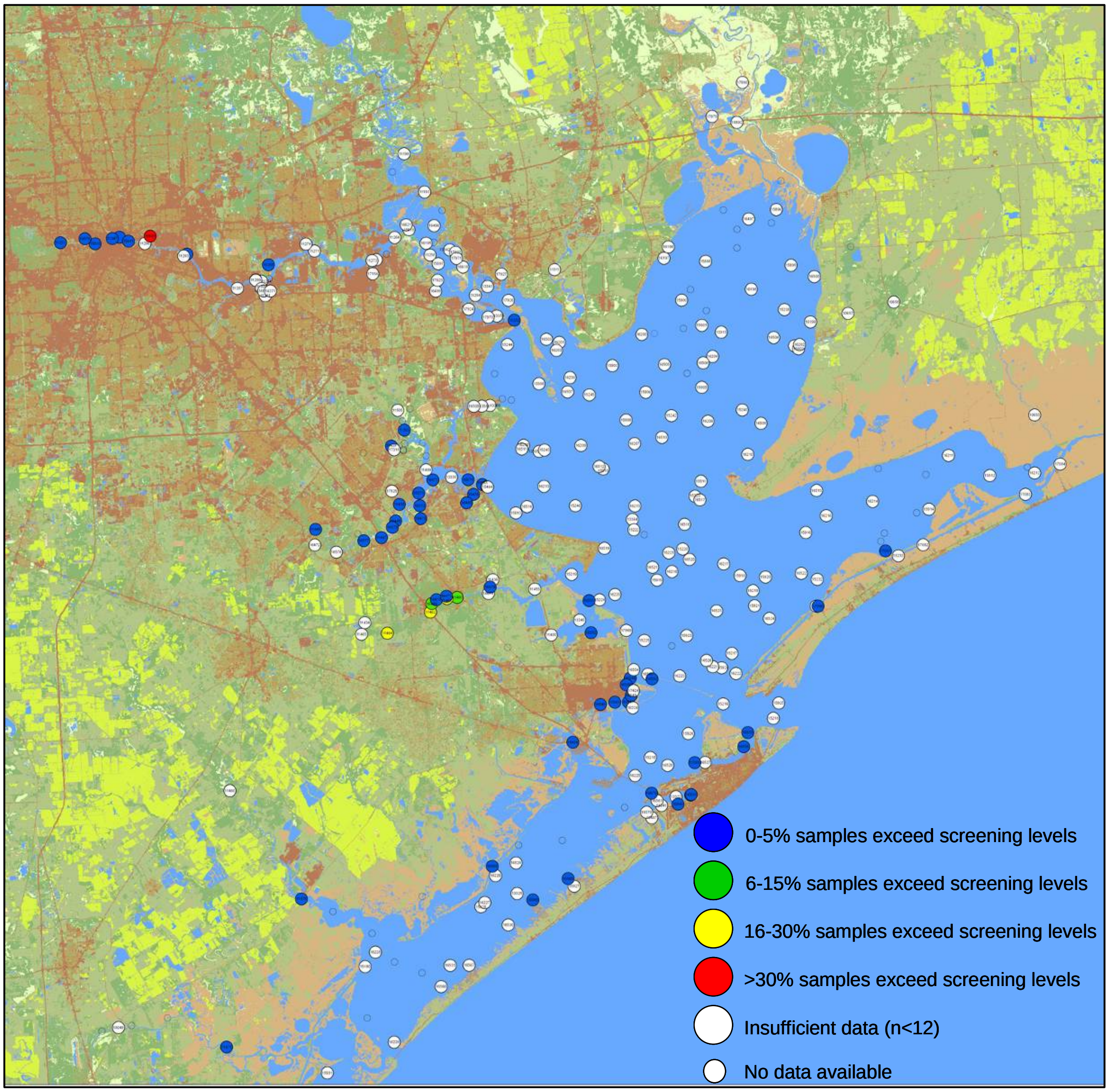

Figure 3.1.4. Stations where dissolved oxygen was collected from 5:00 am to 10:00 am in surface waters of Galveston Bay 1999-2005. Stations are color-coded according to the proportion of samples exceeding the TCEQ screening level of 2 mg/L.

Pathogens

Three parameters are used as indicators for determining whether surface water is contaminated by animal or human waste. The presence of fecal coliform bacteria, *E. coli*, or Enterococci suggests that potentially dangerous pathogens could be present. Many of the sampling stations used to assess bacterial pathogen concentrations are located in urbanized tributaries of the bay. High bacterial concentrations are typically associated with slow flowing bayous in summer months when high temperatures support the growth of the bacteria. Water samples taken from open bay waters show substantially lower bacteria concentrations.

The Galveston Bay Indicators Project in 2005 compared concentrations of fecal coliform bacteria in Galveston Bay surface waters to the fecal coliform screening level of 400 colonies per 100 mL of water established by the TCEQ for contact recreation (e.g. swimming). Major subbays and tributaries of the bay were rated based on the percentage of samples exceeding the TCEQ screening limit in a given decade (see Table 3.1.5). This methodology was applied to bacteria data collected in the Lower Galveston Bay watershed from 1999-2005.

Table 3.1.4. TCEQ screening levels for nutrients in surface waters of tributaries (tidal stream screening levels) and subbays (estuarine screening levels).

Pathogen	TCEQ Screening Level for Freshwater	TCEQ Screening Level for Saltwater
Fecal coliform	400 colonies / 100 mL	400 colonies / 100 mL
E. coli	394 MPN / 100 mL	na
Enterococci	na	89 MPN / 100 mL

Table 3.1.5. Indicator rating system developed for the bacterial pathogens in surface waters. Table created by the Galveston Bay Indicators Project (2005) based on screening levels from the TCEQ (2004).

Rating	Proportion of Samples Above Screening Level
Very Good	0% samples above the screening level
Good	1-9% samples above the screening level
Moderate	10-25% samples above the screening level
Poor	>25% samples above the screening level

As seen in Table 3.1.6, four of the five subbays are rated “Good” with nine percent or less of the samples exceeding the TCEQ bacteria screening levels. Christmas Bay is the only subbay to rate “very good” with no samples exceeding screening levels for the 1999-2005 time period. Conversely, a number of Galveston Bay tributaries are rated “poor” for bacterial contamination. They include: Buffalo Bayou, the Houston Ship Channel, Clear Creek, Armand Bayou, and Dickinson Bayou/Bay. Of those tributaries, Buffalo Bayou had an astonishing 90 percent of samples exceeding TCEQ bacteria screening levels. Three additional bay tributaries rate “moderate”. They are the San Jacinto River, Chocolate Bayou/Bay and Bastrop Bayou. Only one tributary, the Trinity River, rated “good” for bacterial concentrations.

Table 3.1.6. Indicator describing the state of bacterial pathogens in surface waters as a proportion of the TCEQ screening level.

SUBBAYS	**1999-2005**
Upper & Lower Galveston Bay	
Trinity Bay	
East Bay	
West Bay	
Christmas Bay	
TRIBUTARIES	**1999-2005**
Trinity River	
San Jacinto River	
Buffalo Bayou	
Houston Ship Channel	
Clear Creek	
Armand Bayou	
Dickinson Bayou/Bay	
Chocolate Bayou/Bay	
Bastrop Bayou	

Figure 3.1.5 shows surface water quality sampling stations rated (see Table 3.1.5) according to the number of fecal coliform, *E. coli*, and Enterococci samples exceeding the TCEQ screening levels outlined in Table 3.1.4. Although a tributary such as Bastrop Bayou may be rated as “moderate” in table 3.1.6 above. One may see numerous stations with insufficient samples (shaded in white). A station was not rated if the sample size was less than 12. However, the samples were counted for aggregated indicator rating in table 3.1.6.

Of the stations with sufficient sample size over the six year period, one can clearly see the water quality stations on the western side of Galveston Bay with elevated levels of bacteria.

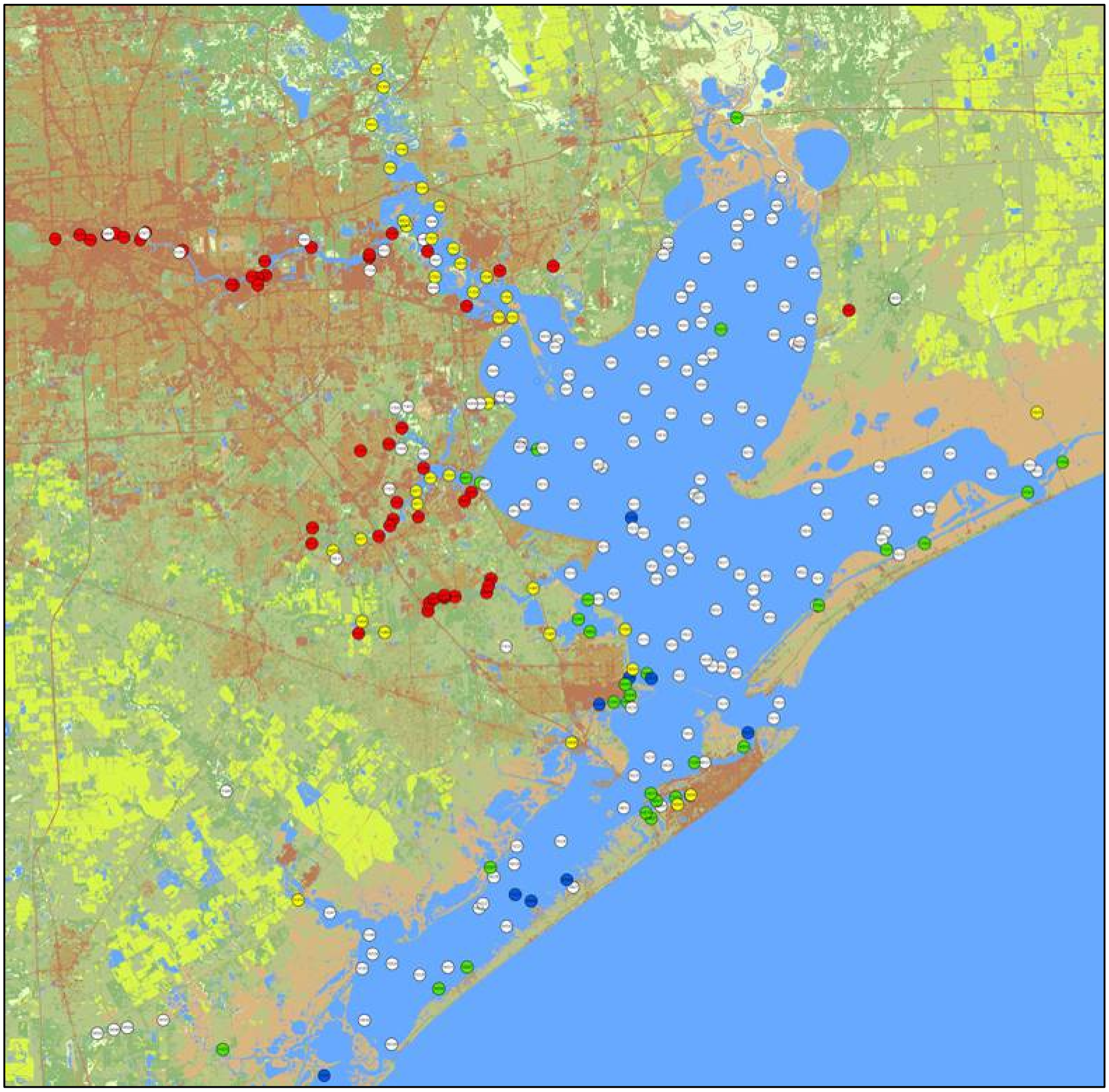

Figure 3.1.5. Stations sampled for pathogens (fecal coliform bacteria, E. coli, and Enterococci) in surface waters of Galveston Bay 1999-2005. Stations are color-coded according to the proportion of samples exceeding the TCEQ screening levels.

Elevated levels of bacterial pathogens in the tributaries of Galveston Bay continue to be the greatest water quality problem facing the Lower Galveston Bay watershed. The TCEQ has active Total Maximum Daily Load (TMDL) studies underway for Buffalo and White Oak Bayous, Clear Creek, and the Greater Houston Metropolitan Area. Elevated levels of fecal coliform contamination measured by the Texas Department of State Health Services (DSHS) have also prompted the restriction or prohibition of a large portion of Galveston Bay waters to the harvest of shellfish.

Toxics

Sediments store many contaminants. Compounds discharged in water may adsorb onto (i.e. adhere to) sediment particles. Adsorption and desorption (i.e. release) of pollutants is a function of several factors including pH, type of sediment and the type and concentration of the pollutant. Over time, if the sediment remains undisturbed and the contaminant remains adsorbed onto the sediment particles, a compound can become "locked" in the sediments. Additionally, not all contaminants in sediment are in a biologically available form. However, both natural (e.g. floods) and human (e.g. channel dredging) disturbances of the system can facilitate the release of chemical compounds from the sediment into the water column and living organisms. Sediments are also a biological habitat for benthic organisms. Sediment concentrations of contaminants can influence food web uptake of toxic pollutants.

Reaching conclusions about sediment quality is problematic. Large areas of the bay bottom remain unsampled and frequency of sediment sampling has decreased over time. In Galveston Bay sediments, metals and commonly measured organic compounds appear to follow the same general spatial distribution as do most of the other water quality parameters. Elevated concentrations occur in regions of runoff, inflow and waste discharges, and lower, relatively uniform concentrations occur in the open bay. The upper Houston Ship Channel is generally the location of maximum sediment contaminant concentrations in the system. Other areas that receive effluents from industrial facilities and ports also exhibit relatively high sediment contamination, e.g. Texas City Ship Channel.

Organic compounds and metals are primarily measured from bay sediments rather than from the water column due to the fact that heavy compounds tend to spend little time in the water before settling in the sediment. Organic pesticides refer to compounds used on agricultural fields and urban and suburban landscapes in the Lower Galveston Bay watershed. Industrial organic compounds refer to those organic substances that are used or produced by the petrochemical industry around the bay. Inorganic compounds include trace metals such as mercury, cadmium, and lead. Some trace metals such as aluminum occur naturally in the environment. However, many are introduced through human activities including industrial processing and coal combustion.

The Galveston Bay Indicators Project in 2005 developed a methodology comparing concentrations of organic compounds in Galveston Bay sediments to probable effect levels (PELs) established by the TCEQ (2004). A PEL is defined as the concentration of a contaminant above which adverse biological effects are expected to occur. Major subbays and tributaries of the bay were rated based on the percentage of sediment samples exceeding PELs in a given decade (see Table 3.1.7).

Table 3.1.7. Indicator rating system developed for toxic contaminants in sediments.

Rating	Percent of Samples Exceeding the PEL
Very Good	0%
Good	1-9%
Moderate	10-25%
Poor	>25%

While gaps in the sediment data record are evident, the data show that Upper and Lower Galveston Bay, Trinity Bay and East Bay exhibit very good sediment quality (Table 3.1.8). West Bay rates moderate for sediment quality in recent years. However, these observations occurred in one year and have not been observed again. As seen in Tables 3.1.8 and 3.1.9 below, the majority of sediment quality problems occur in the Houston Ship Channel; this is not surprising since the Houston Ship Channel is the industrial center of the Texas Gulf Coast.

Table 3.1.8. Organic pesticides and industrial organics in sediment as a proportion of Marine Probable Effects Levels (PELs) published by the TCEQ. ns = Insufficient sample size (< 12 samples).

Organic Pesticides	
SUBBAYS	**1999-2005**
Upper & Lower Galveston Bay	
Trinity Bay	
East Bay	
West Bay	
Christmas Bay	ns
Houston Ship Channel	

Industrial Organics	
SUBBAYS	**1999-2005**
Upper & Lower Galveston Bay	
Trinity Bay	
East Bay	
West Bay	
Christmas Bay	ns
Houston Ship Channel	

Greater than 25 percent of samples for twelve organic compounds have exceeded PELs since the year 1999. Oddly, there were insufficient data for polychlorinated biphenyls (PCBs) in the Houston Ship Channel. PCBs are legacy pollutants used as an electrical insulator; their manufacture, sale, and use were banned in the United States nearly thirty years ago. PCBs have been detected at high levels in some fish and are a partial cause of the seafood consumption advisories in place for the Houston Ship Channel and Upper Galveston Bay (see Figure 3.1.6).

Table 3.1.9. Detail of industrial organics in sediments of the Houston Ship Channel. ns = Insufficient sample size (< 12 samples).

Houston Ship Channel Detail	**1999-2005**
Acenaphthene	
Acenaphthylene	
Anthracene	
Benzo(a)anthracene	
Benzo(a)pyrene	
Chrysene	
1,2,4,6 Dibenzanthracene	
Fluoranthene	
Fluorene	
Naphthalene	
PCBs	ns
Phenanthrene	
Pyrene	

As with organic pesticides and industrial organics, sediments in the subbays of Galveston Bay rate "very good". The Houston Ship Channel again has issues with contaminated sediments, particularly mercury, nickel, and zinc (Tables 3.1.10 and 3.1.11).

Table 3.1.10. Heavy metals in sediment as a proportion of Marine Probable Effects Levels (PELs) published by the TCEQ (2004). ns = Insufficient sample size (< 12 samples).

Metals **SUBBAYS**	**1999-2005**
Upper & Lower Galveston Bay	
Trinity Bay	
East Bay	
West Bay	
Christmas Bay	ns
Houston Ship Channel	

Table 3.1.11. Detail of nine heavy metals in sediments of the Houston Ship Channel.

Houston Ship Channel Detail	1999-2005
Arsenic	
Cadmium	
Chromium	
Copper	
Lead	
Mercury	
Nickel	
Silver	
Zinc	

Three seafood consumption advisories for Galveston Bay and its tributaries have been issued by the Texas Department of State Health Services (DSHS) since 1990. While the majority of bay and tributary surface waters are not included in seafood consumption advisories, the DSHS advises that consumption of seafood taken from the Houston Ship Channel and portions of Upper Galveston Bay poses an increased risk of adverse human health effects. All three seafood consumption advisories in 1990, 2001, and 2005 were issued for these areas (Figure 3.1.6). Contaminants of concern include dioxin, organochlorine pesticides, and PCBs (Polychlorinated Biphenyl: a synthetic, organic chemical once widely used in electrical equipment). Species of concern include blue crab, catfish, spotted seatrout, and other species of finfish.

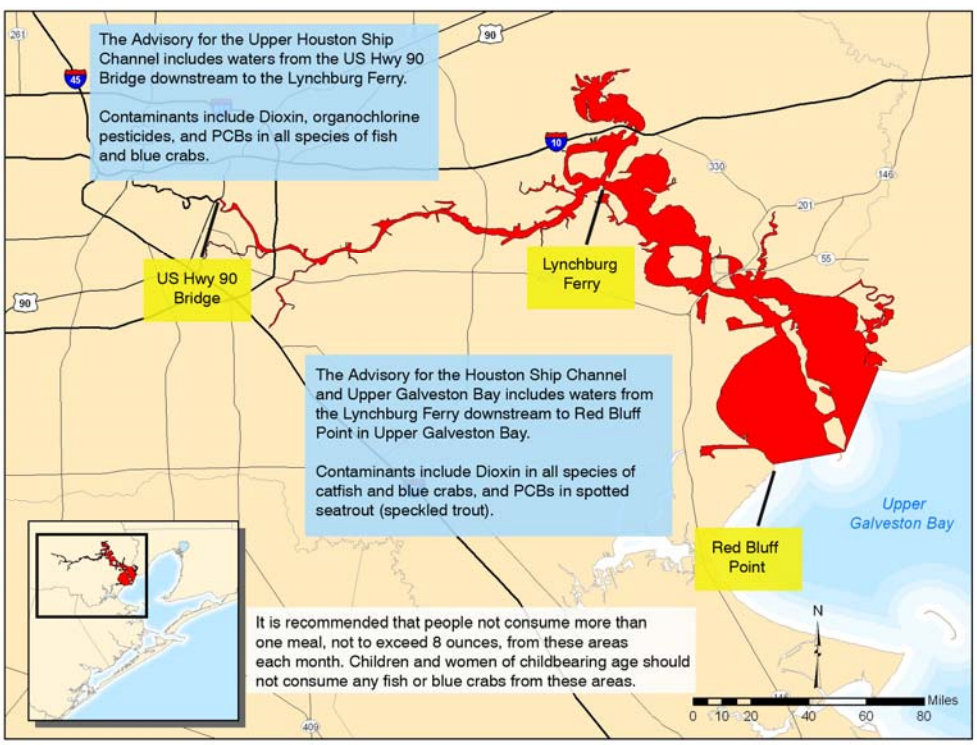

Figure 3.1.6. Description of the Area, Species, and Contaminants Included in Galveston Bay Seafood Advisories Issued by the Texas Department of State Health Services in 1990, 2201, and 2005.

3.1.2. Water Quality Gradients in Clear Creek and Clear Lake

The Status and Trends Project analyzed geographic trends in water and sediment quality for the Clear Creek/Clear Lake watershed. This area in Southeast Harris County is a heavily populated suburban area. In addition to the growing human population, the Clear Creek/Clear Lake area has industrial, commercial, recreational boating, and commercial and recreational fishing uses. The area also contains tracts of riparian habitat, estuarine and freshwater wetlands, and coastal prairie. Conversion of habitat to the built environment, invasive species, flooding, and water quality degradation are considered major issues for this watershed.

Upstream portions of Clear Creek have been listed on the Texas 303(d) List of impaired waters for total dissolved solids (TDS), chloride, chlordane, and fecal coliform bacteria. The TDS and chloride Total Maximum Daily Load studies (TMDLs) were concluded with an enforcement action against a single point source discharge. TMDLs for the legacy pollutant, chlordane, were adopted by the TCEQ in 2001. Elevated concentrations of fecal coliform bacteria remain as the subject of an active TMDL study for this watershed.

Water and sediment quality data were acquired from the Texas Commission on Environmental Quality (TCEQ) Surface Water Quality Monitoring (SWQM) Program and the Houston-Galveston Area Council (H-GAC) Clean Rivers Program (CRP). Data were geographically organized according to the most recent version of the GBEP segmentation scheme [see Figure 3.1.1 (Lester 2003)]. According to the segmentation, Clear Creek and Clear Lake (including tributaries such as Armand and Horsepen Bayous) are identified as GBEP segments C1, C2, C3, C4, C5, C7 and C8. Data collected from TCEQ SWQM and CRP water and sediment quality monitoring stations located within these segments were analyzed.

Rather than creating annual trends that analyze data through time, the Clear Creek and Clear Lake trends analyzed data geographically by sampling station and the proximity to Galveston Bay. This was done to look at water quality gradients from upstream to downstream portions of Clear Creek and Clear Lake.

35 TCEQ SWQM and CRP monitoring stations were identified in tidally influenced waters (see Figure 3.1.7 and Appendix A) and their straight-line distance to Galveston Bay was calculated in meters. The seven stations circled in red were identified as estuarine stations for which estuarine screening levels were applied for nutrient parameters. Stations were identified as estuarine if they fit at least one of two criteria: 1) they are identified by the TCEQ as a station within Basin 24 (Bays and Estuaries) or 2) they have an average salinity $\geq$ 8.0 ppt.

Station averages were calculated for 15 water quality and seven sediment quality parameters sampled over the 1999-2004 time period. Parameter concentrations were averaged by station. To ensure that adequate sample sizes were used for the trend analyses, each parameter/station average was required to be based on at least 12 water quality samples or six sediment quality samples collected during the 1999-2004 time period. Average concentrations were graphed by station according to distance to the bay in order of upstream stations to those stations closest to the confluence with Galveston Bay (see Appendix A). A linear regression trend line and R^2 value was calculated for each parameter with at least ten stations meeting the sample size requirement. Increasing or declining gradient trends were identified as those with an $R^2 \geq 0.25$.

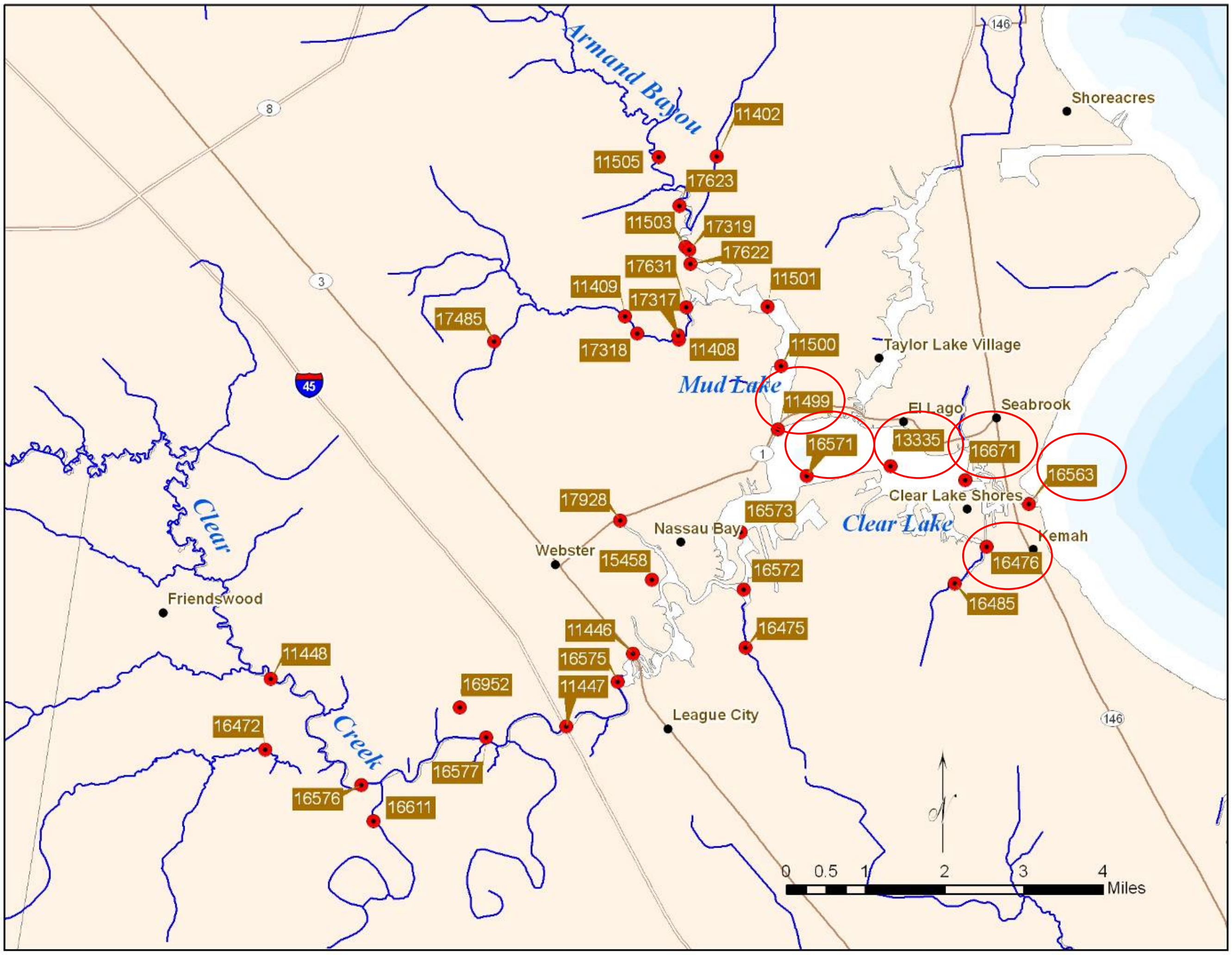

Figure 3.1.7. TCEQ Surface Water Quality Monitoring Program (SWQM) and Clean Rivers Program (CRP) monitoring stations identified in tidally influenced waters of the Clear Creek watershed. Station averages were calculated for 15 water quality and seven sediment quality parameters sampled over the 1999-2004 time period. Data were graphed according to the station's straight-line distance to Galveston Bay calculated in meters.

Conventional Parameters

Data were analyzed for eight conventional surface water quality parameters: water temperature, salinity, specific conductance, pH, biochemical oxygen demand-5 day (BOD5), total suspended solids (TSS), total organic carbon (TOC), and dissolved oxygen (samples collected between 5:00 and 10:00 a.m. only). Of the eight conventional parameters, three exhibited increasing gradient trends progressing from upstream to downstream stations. The remaining five parameters showed no gradient trends in from the upper tidal to lower tidal portions of the Clear Creek and Clear Lake.

Salinity and Specific Conductance

Salinity and specific conductance typically increase as the bayou transitions from upstream freshwater sources (rainfall runoff/stormwater and point source discharges) to the brackish waters of the bay. As one would expect, increasing gradients were found for salinity ($R^2 = 0.82$) and specific conductance ($R^2 = 0.85$). On average, salinity ranged from near zero in the upstream portions of Clear Creek and its tributaries to nearly 12 parts per thousand (ppt) near Clear Lake and the confluence with Galveston Bay. Salinity and specific conductance are measures of dissolved salts present in the water.

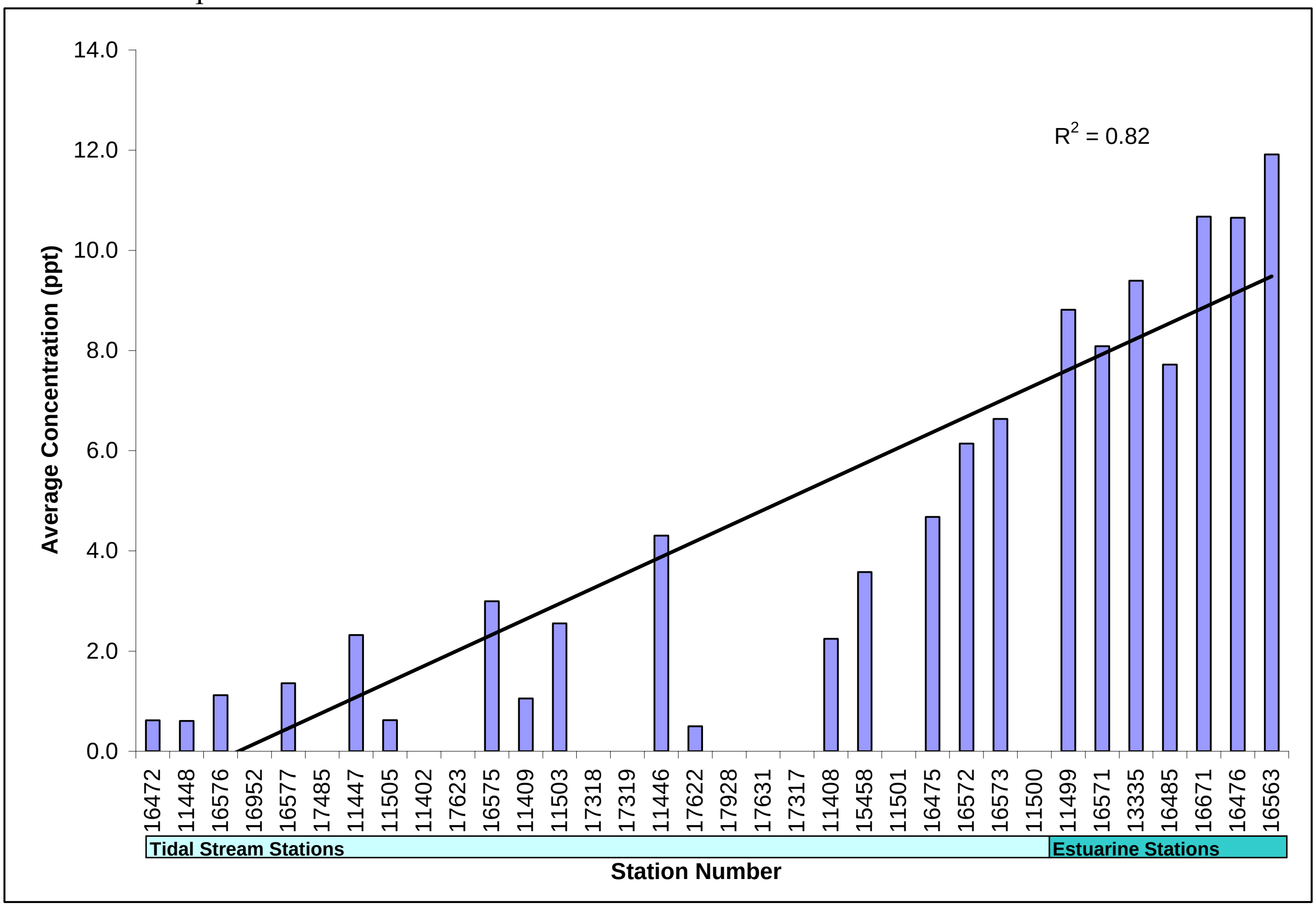

Figure 3.1.8. Average salinities by station (n ≥ 12) in surface waters of Clear Creek and Clear Lake as sampled by the TCEQ from 1999-2004. Stations are ordered by distance to Galveston Bay (upstream to downstream). Stations are also identified as a tidal stream or estuarine station. See Appendix A for station descriptions and distance to the bay.

pH

pH did not show a gradient along Clear Creek and Clear Lake and typically ranged from an average of 7.4 to 8.5 standard units. pH generally exhibits low variability in coastal environments due to the high buffering capacity of seawater.

5-Day Biochemical Oxygen Demand (BOD5)

As seen in Figure 3.1.9, an increasing gradient was found for 5-day biochemical oxygen demand (BOD5) with an $R^2 = 0.51$. BOD5 is the measure of oxygen consumed by biological processes. Elevated levels of BOD5 are typically associated with bacterial breakdown of organic matter. Decomposition of large quantities of organic matter by bacteria can severely deplete the water of oxygen and make it uninhabitable for many species.

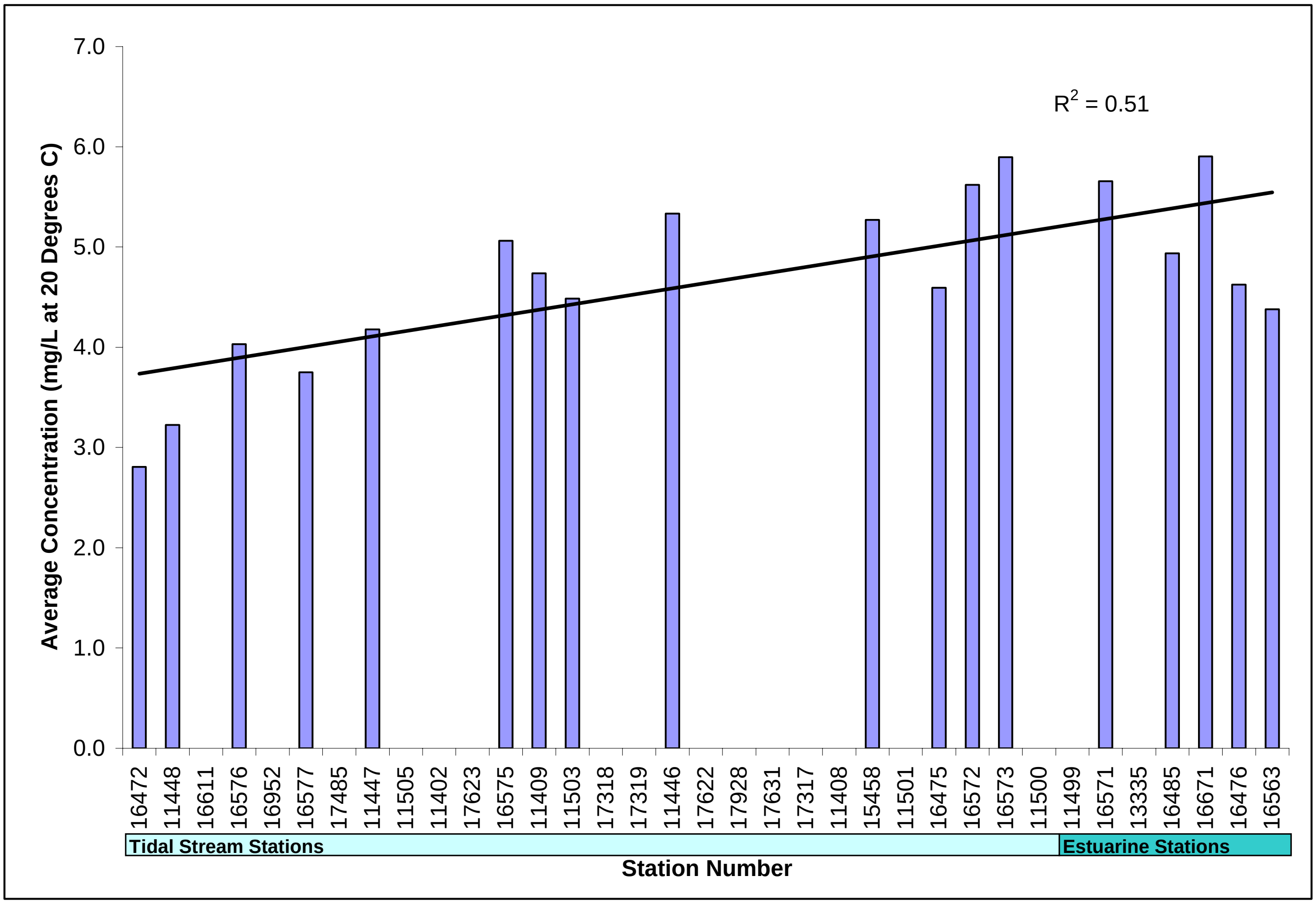

Figure 3.1.9. Average BOD5 by station (n ≥ 12) in surface waters of Clear Creek and Clear Lake as sampled by the TCEQ from 1999-2004. Stations are ordered by distance to Galveston Bay (upstream to downstream). See Appendix A for station descriptions and distance to the bay.

Dissolved Oxygen (DO)

Dissolved oxygen (DO) (only those samples collected between 5:00 and 10:00 a.m.) did not exhibit a gradient from upstream to downstream portions of Clear Creek and Clear Lake. On average, DO concentrations were well above the TCEQ screening level of 2.0 mg/L.

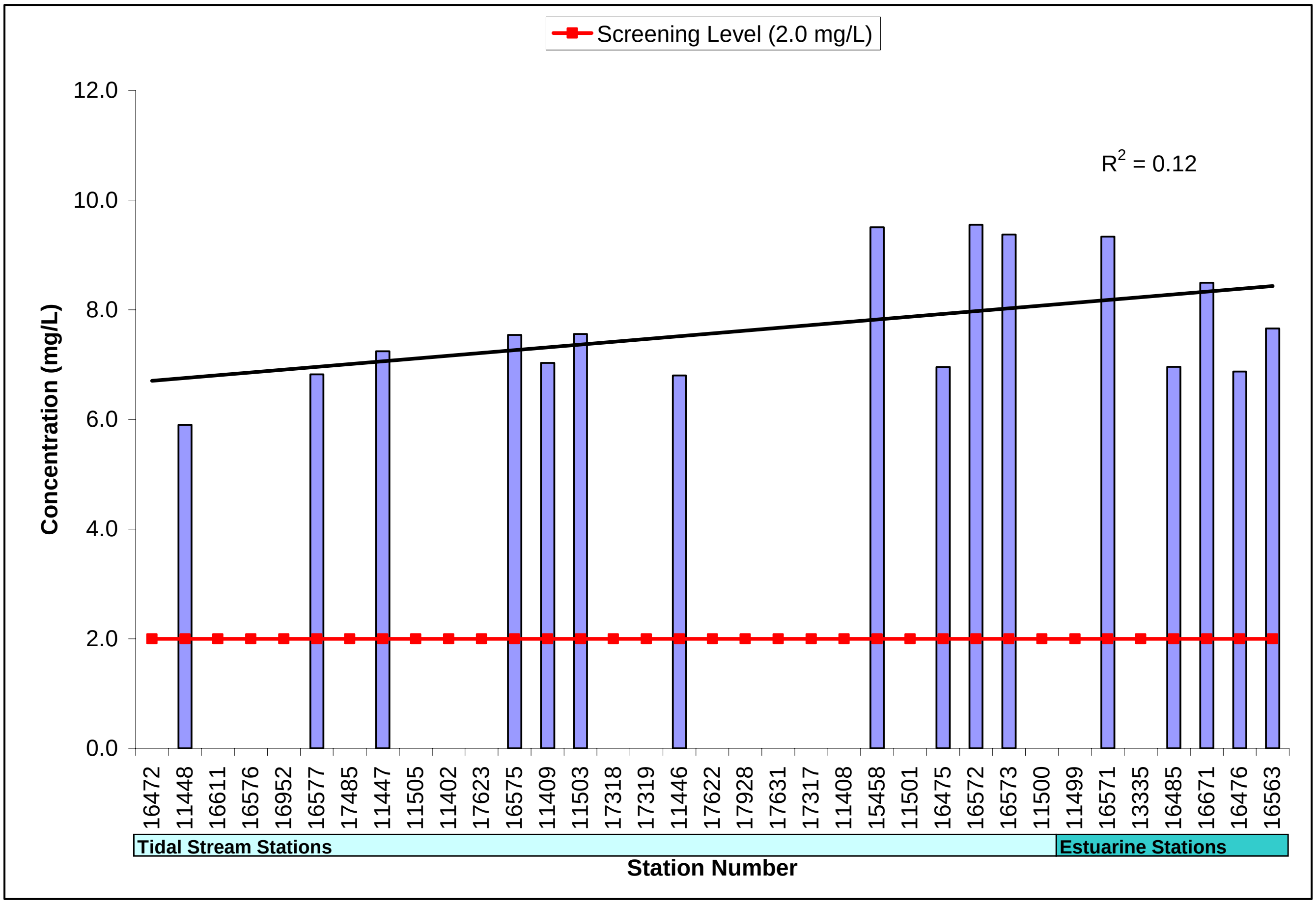

Figure 3.1.10. Average dissolved oxygen (DO) by station ($n \geq 12$) in surface waters of Clear Creek and Clear Lake as sampled by the TCEQ from 1999-2004. Stations are ordered by distance to Galveston Bay (upstream to downstream). See Appendix A for station descriptions and distance to the bay.

The remaining conventional parameters of total suspended solids (TSS) and total organic carbon (TOC) did not exhibit gradients.

<u>Nutrients and Chlorophyll-a</u>

Three surface water nutrient parameters (ammonia, nitrate-nitrite, and orthophosphate/total and dissolved phosphorus) and chlorophyll-a/pheophytin-a were analyzed for water quality gradients from upstream to downstream portions of Clear Creek and Clear Lake.

Ammonia

Average ammonia concentrations in Clear Creek and Clear Lake by station for the period 1999-2004 exhibited no gradient trend. Additionally, station averages were well below the surface water quality screening level of 0.58 mg/L.

Nitrate-Nitrite

Average nitrate-nitrite concentrations in Clear Creek and Clear Lake by station for the period 1999-2004 exhibited a declining gradient trend ($R^2 = 0.38$). Additionally, all station averages for nitrate-nitrite were below the surface water quality screening levels of 1.83 mg/L (for tidal stream stations) and 0.26 mg/L (for estuarine stations).

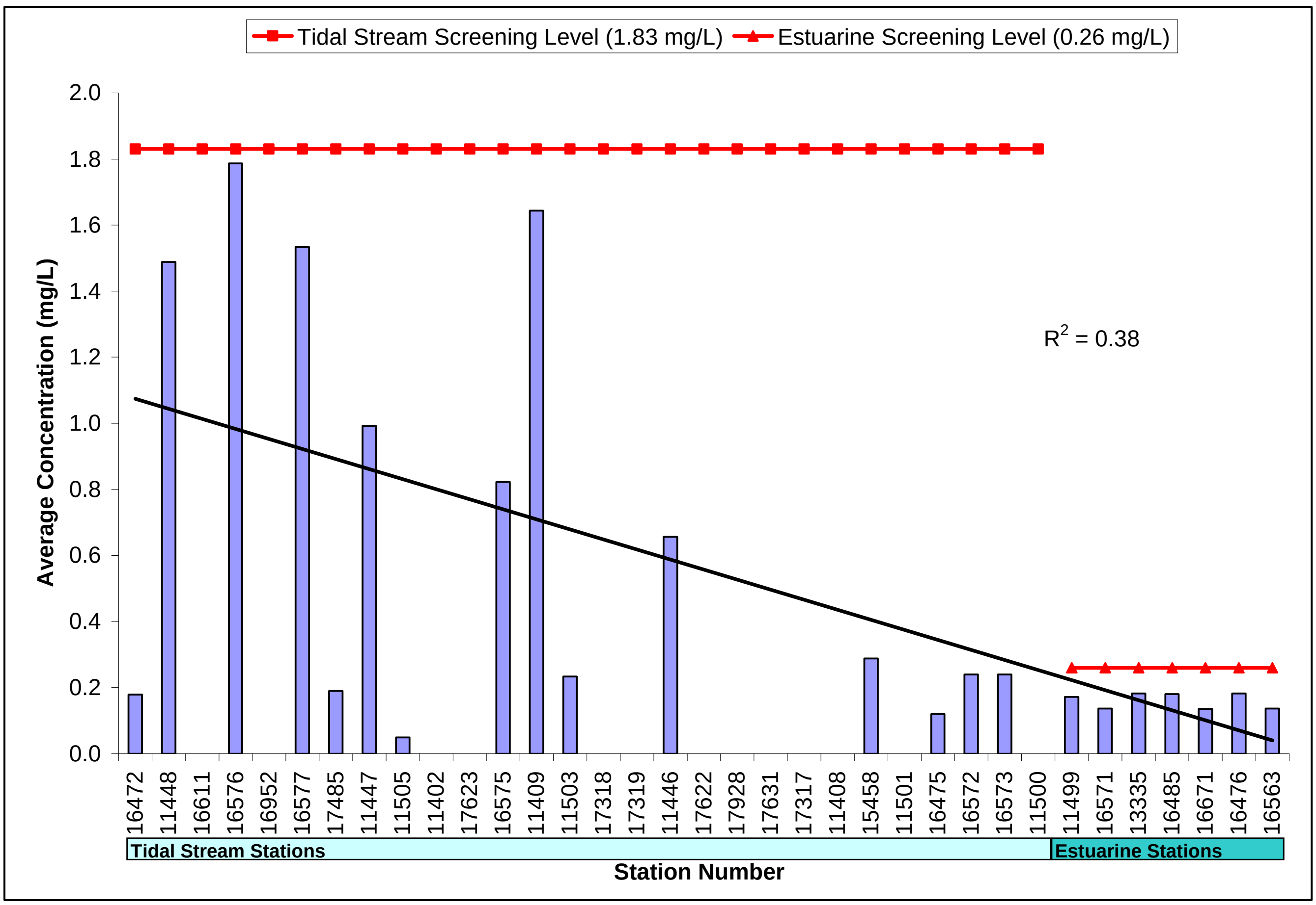

Figure 3.1.11. Average concentrations of nitrate-nitrite by station (n ≥ 12) in surface waters of Clear Creek and Clear Lake as sampled by the TCEQ from 1999-2004. Stations are ordered by distance to Galveston Bay (upstream to downstream). See Appendix A for station descriptions and distance to the bay. Tidal stream and estuarine screening levels applied as appropriate.

Phosphorus

Concentrations of total phosphorus, dissolved phosphorus, and orthophosphate sampled by the TCEQ and Clean Rivers Program in Clear Creek and Clear Lake for the period 1999-2004 were averaged together by station. Station averages of the three phosphorus parameters are graphed below in Figure 3.1.12. A linear regression trend line and R^2 value was not calculated since less than ten stations met the sample size requirement ($n \geq 12$). No stations exceeded the TCEQ tidal stream screening level for total phosphorus of 0.71 mg/L. Two stations (11499 in Armand Bayou and 13355 in Clear Lake) exceeded the estuarine screening level.

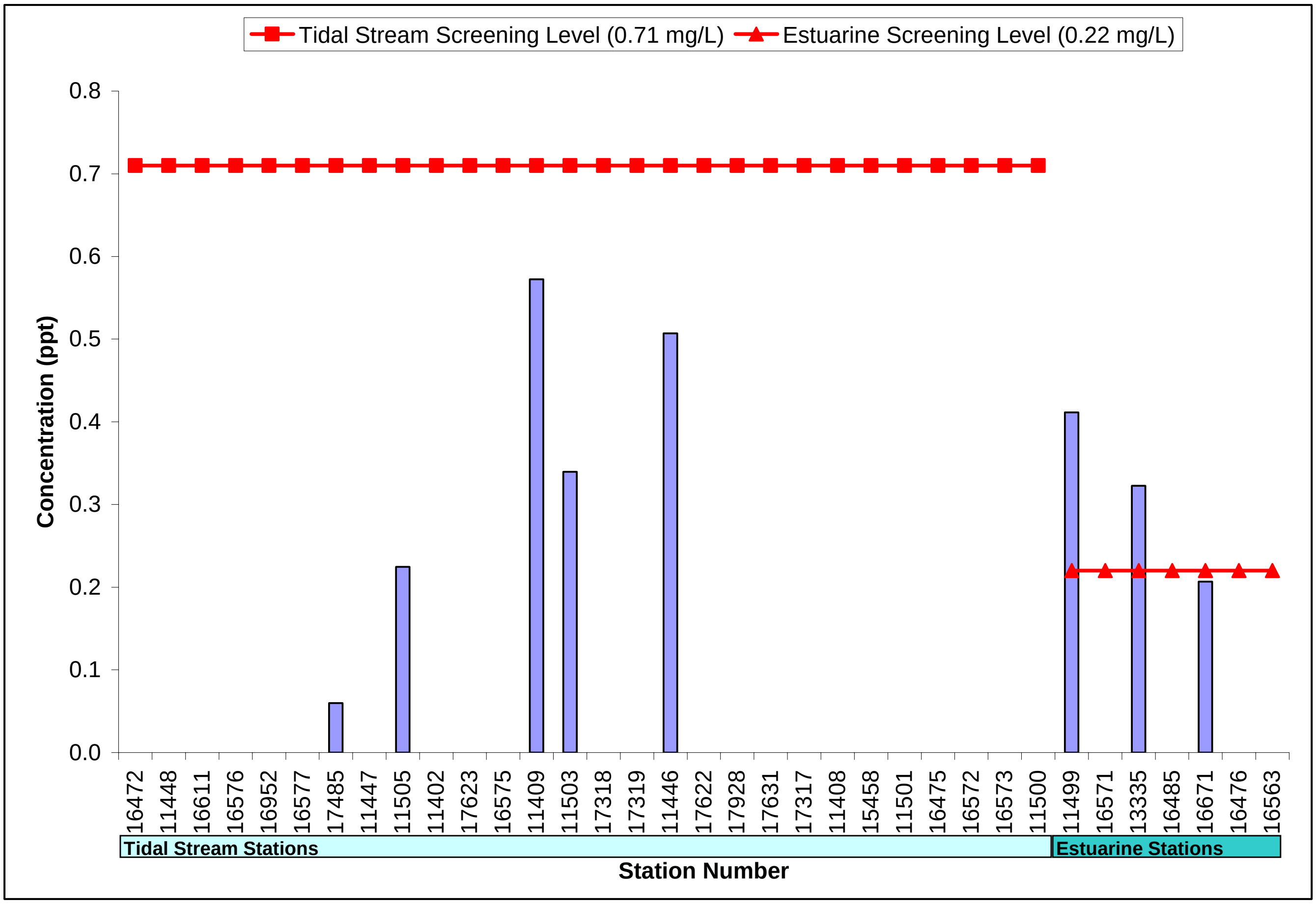

Figure 3.1.12. Average concentrations of total phosphorus, dissolved phosphorus, and orthophosphate by station ($n \geq 12$) in surface waters of Clear Creek and Clear Lake as sampled by the TCEQ from 1999-2004. Stations are ordered by distance to Galveston Bay (upstream to downstream). See Appendix A for station descriptions and distance to the bay. Tidal stream and estuarine screening levels applied as appropriate.

Chlorophyll-a

Chlorophyll-a is a photosynthetic pigment commonly found in phytoplankton and is used as an indicator of phytoplankton abundance, primary productivity and eutrophication. Pheophytin-a is a breakdown product of chlorophyll-a and is analyzed here as a water quality parameter in conjunction with chlorophyll-a due to questions regarding sample holding times prior to laboratory analysis.

Concentrations of chlorophyll-a and pheophytin-a sampled by the TCEQ SWQM and Clean Rivers Program in Clear Creek and Clear Lake for the period 1999-2004 were averaged together by station. Station averages of chlorophyll-a and pheophytin-a are graphed below in Figure 3.1.13. Average chlorophyll-a and pheophytin-a concentrations in Clear Creek and Clear Lake by station for the period 1999-2004 exhibited no gradient trend ($R^2 = 0.01$). However as seen in Table 3.1.12, of the 12 stations with sufficient sample size ($n \geq 12$); eight stations had average concentrations exceeding the TCEQ tidal stream screening level for chlorophyll-a (19.2 ug/L). Two stations exhibited average concentrations exceeding the TCEQ estuarine screening level for chlorophyll-a (11.5 ug/L).

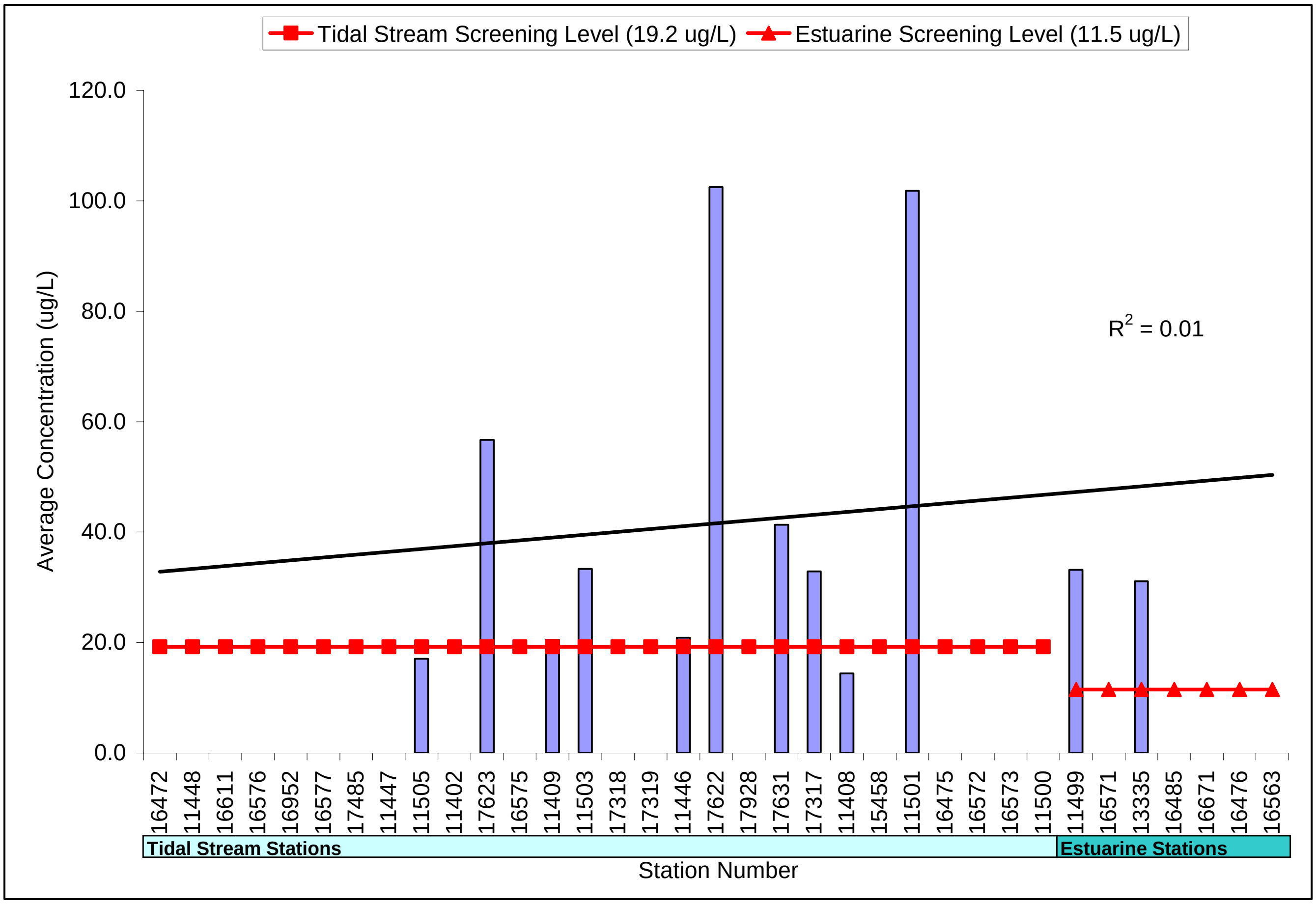

Figure 3.1.13. Average concentrations of chlorophyll-a and pheophytin-a by station (n ≥ 12) in surface waters of Clear Creek and Clear Lake as sampled by the TCEQ from 1999-2004. Stations are ordered by distance to Galveston Bay (upstream to downstream). See Appendix A for station descriptions and distance to the bay. Tidal stream and estuarine screening levels applied as appropriate.

Table 3.1.12. Average chlorophyll-a and pheophytin-a concentrations exceeded the surface water quality screening level of 19.2 ug/L at ten stations in the Clear Creek watershed during the period, 1999-2004.

Station ID	Station Type	Station Description	Average Chlorophyll-a/ Pheophytin-a Concentration (ug/L)
17623	Tidal Stream	Armand Bayou Tidal 0.75 miles upstream of Bay Area Boulevard	56.69
11409	Tidal Stream	Horsepen Bayou at Bay Area Boulevard north of NASA	20.50
11503	Tidal Stream	Armand Bayou Tidal at Bay Area Boulevard	33.32
11446	Tidal Stream	Clear Creek Tidal at Highway 3 near Webster	20.89
17622	Tidal Stream	Armand Bayou Tidal at Bay Area Park	102.49
17631	Tidal Stream	Horsepen Bayou at storm drain at Middlebrook Road	41.33
17317	Tidal Stream	Horsepen Bayou at Middlebrook Drive in Southeast Houston	32.86
11501	Tidal Stream	Armand Bayou Tidal/Upper Mud Lake	101.82
11499	Estuarine	Armand Bayou at NASA Road 1 Bridge	33.16
13335	Estuarine	Clear Lake at Channel Marker 17	31.10

Surface Water Quality: Pathogens

Fecal Coliform Bacteria

Fecal coliform bacteria are used as the traditional indicator for determining whether water is contaminated by animal or human waste. Presence of coliform bacteria suggests that potentially dangerous pathogens may also be present. As seen in Figure 3.14, average concentrations of fecal coliform bacteria in surface waters of Clear Creek and Clear Lake do not exhibit a gradient trend ($R^2 = 0.15$). However, 15 of 20 stations with a sufficient sample size ($n \geq 12$) exceeded the TCEQ screening level of 400 colonies per 100 mL.

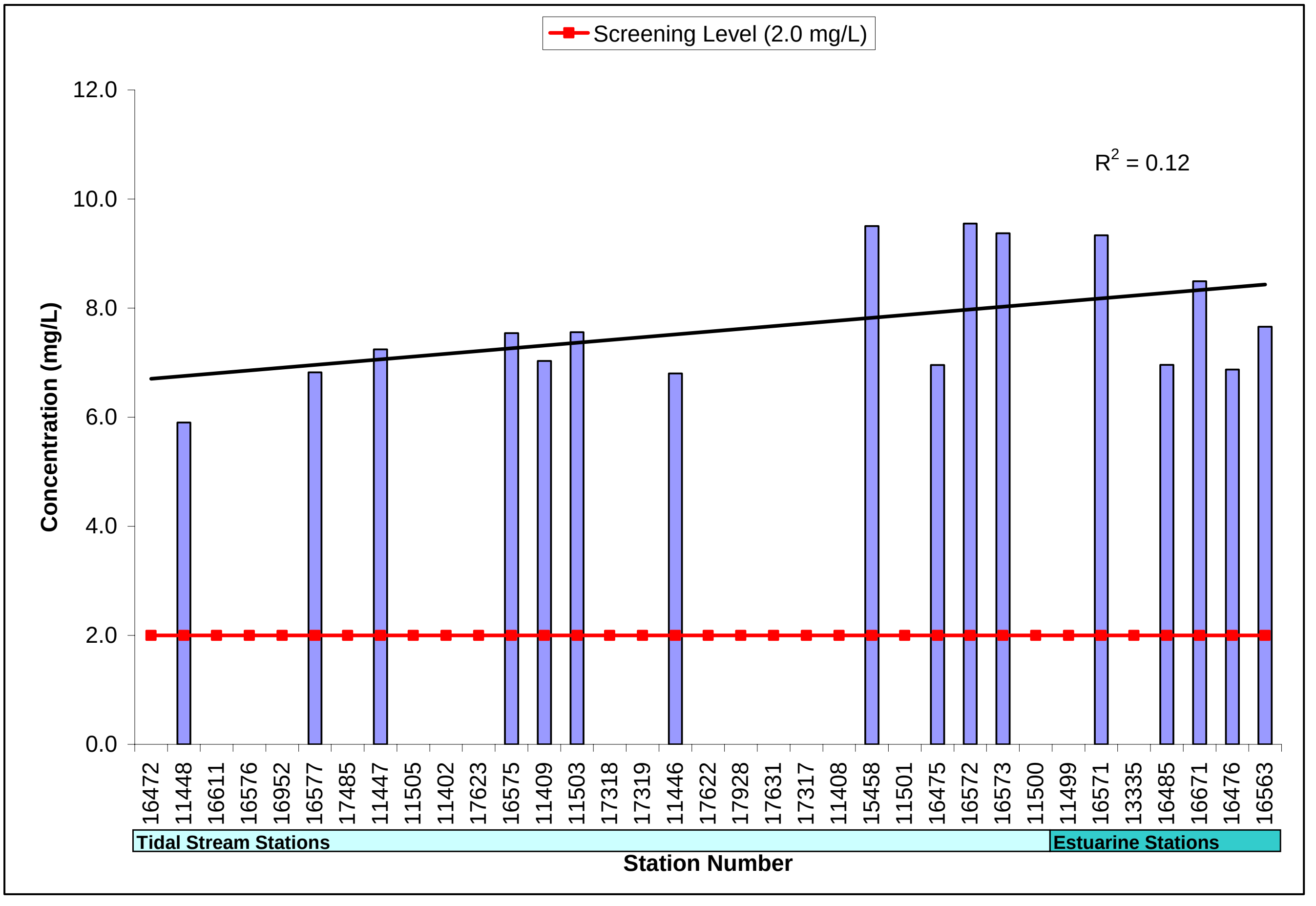

Figure 3.1.14. Average concentrations of fecal coliform bacteria by station ($n \geq 12$) in surface waters of Clear Creek and Clear Lake as sampled by the TCEQ from 1999-2004. Stations are ordered by distance to Galveston Bay (upstream to downstream). See Appendix A for station descriptions and distance to the bay.

E. coli and Enterococci

In addition to fecal coliform bacteria, *E. coli* and Enterococci serve as two additional indicators to determine if surface waters are contaminated by animal or human waste. *E. coli* is used as an indicator in freshwater and Enterococci is used as an indicator in saltwater environments. The use of *E. coli* and Enterococci as indicators of bacterial pathogens began in the year 2000 causing them to have a smaller data record than that of fecal coliform bacteria.

As seen in Figures 3.1.15 and 3.1.16, a linear regression trend line and R^2 value was not calculated for *E. coli* and Enterococci since less than ten stations met the sample size requirement (at least 12 samples collected during the 1999-2004 period). For both parameters, all four stations exceeded the TCEQ tidal stream screening level for *E. coli* (394 Most Probable Number per 100 mL) and Enterococci (89 Most Probable Number per 100 mL).

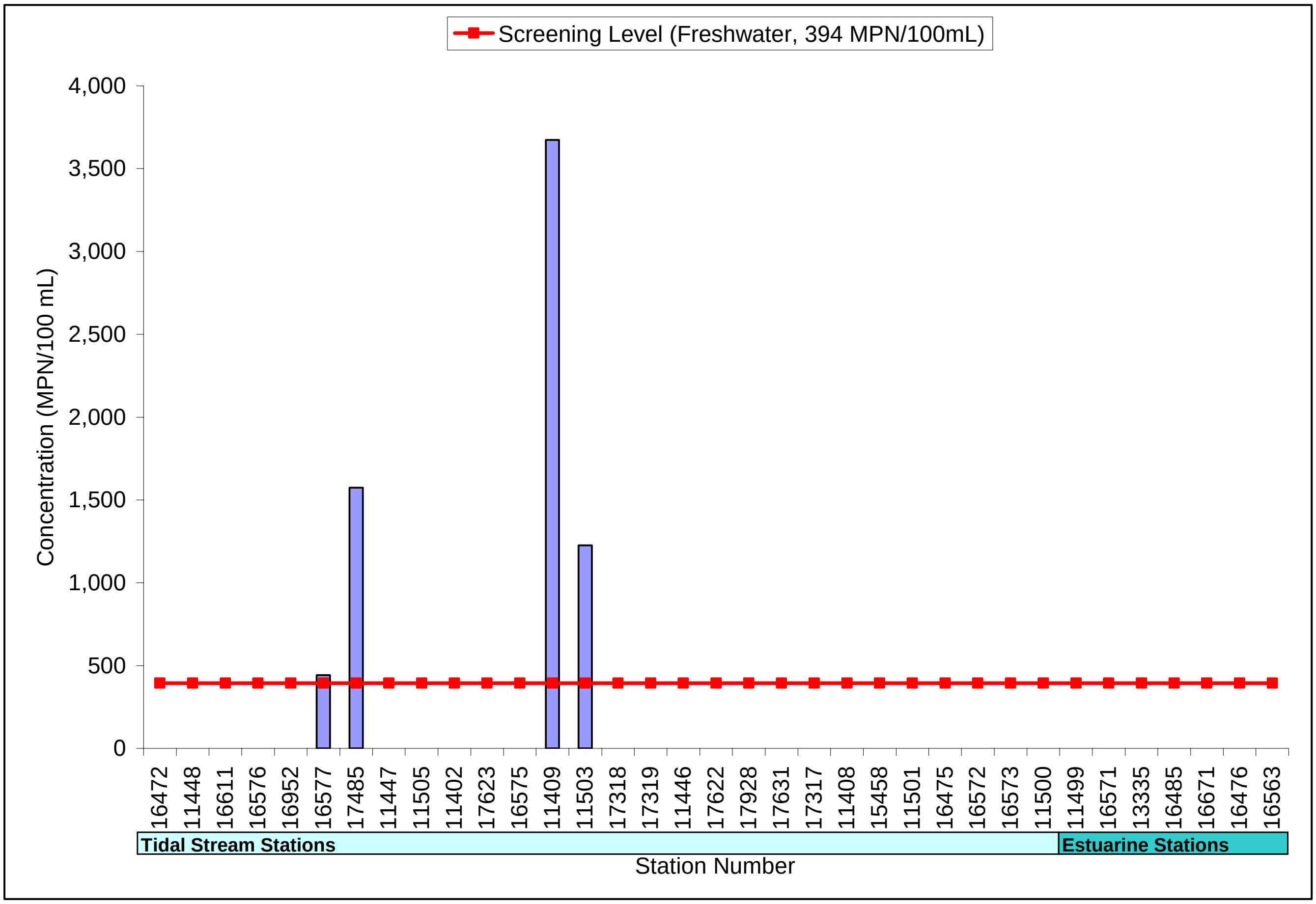

Figure 3.1.15. Average concentrations of *E. coli* by station ($n \geq 12$) in surface waters of Clear Creek and Clear Lake as sampled by the TCEQ from 1999-2004. Stations are ordered by distance to Galveston Bay (upstream to downstream). See Appendix A for station descriptions and distance to the bay.

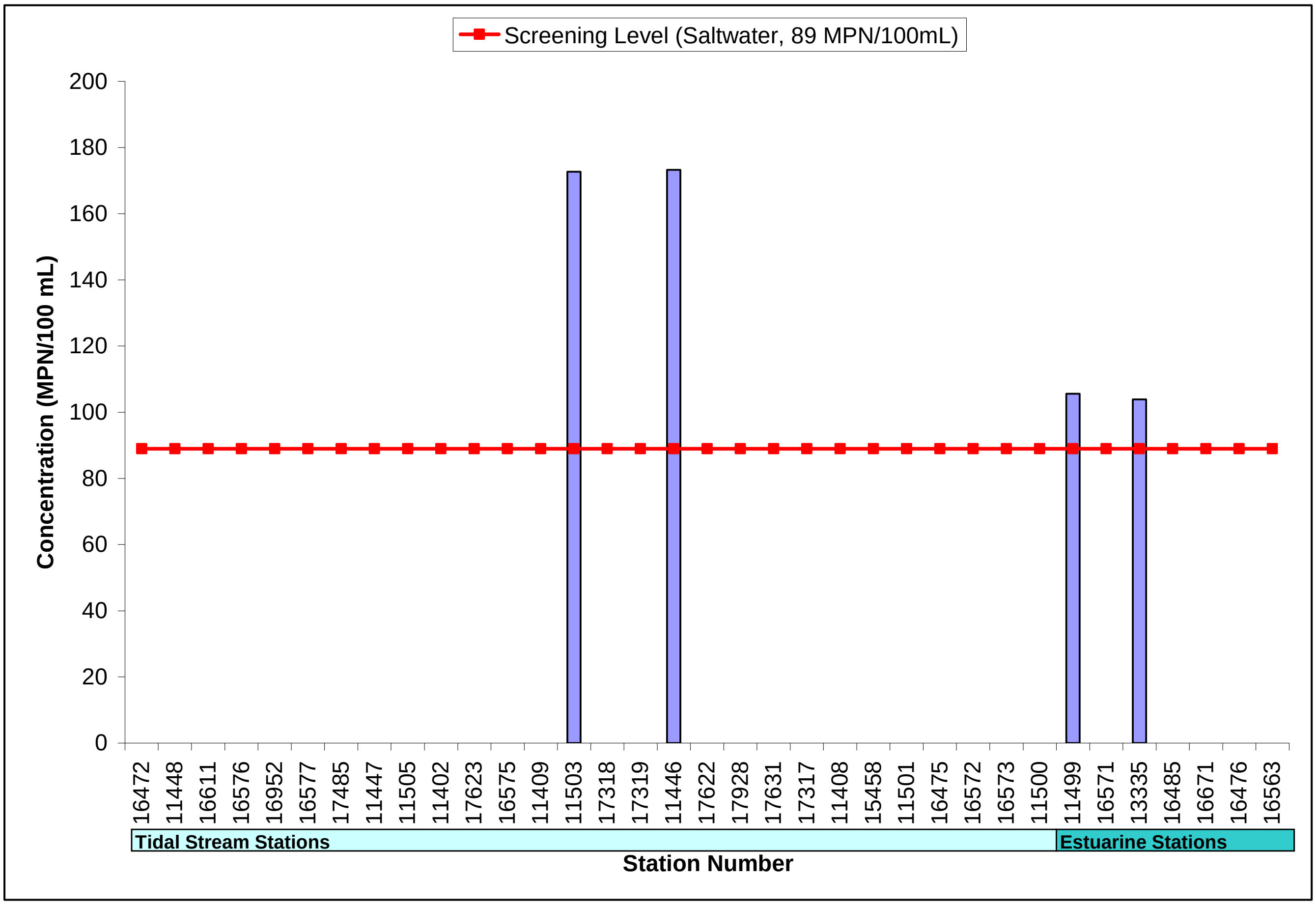

Figure 3.1.16. Average concentrations of Enterococci by station (n ≥ 12) in surface waters of Clear Creek and Clear Lake as sampled by the TCEQ from 1999-2004. Stations are ordered by distance to Galveston Bay (upstream to downstream). See Appendix A for station descriptions and distance to the bay.

Sediment Quality: Inorganic and Organic Compounds

Data were analyzed for twenty six organic and inorganic sediment quality parameters monitored by the TCEQ SWQM and Clean Rivers programs. Of the 26 parameters (listed in Table 3.1.13), none met the sample size criteria (at least ten stations with at least two samples collected during the 1999-2004 time period) and could not be analyzed using linear regression. Seven metals had five stations meeting sample size criteria, while the remaining 19 parameters had only one to two stations meeting the sample size criteria. No station averages for parameters monitored in the Clear Creek/Clear Lake watershed exceeded Marine or Freshwater Probable Effects Levels (PELs).

Table 3.1.13. Twenty-six organic and inorganic sediment quality parameters analyzed for stations in Clear Creek/Clear Lake.

Inorganic Compounds:

Metals
Arsenic
Cadmium
Chromium
Copper
Lead
Mercury
Nickel
Silver
Zinc

Organic Compounds:

Organic Pesticides
Chlordane
DDT
Dieldrin
Lindane
Industrial Organics
1,2,4,6 Dibenzanthracene
Acenaphthene
Acenaphthylene
Anthracene
Benzo(a)anthracene
Benzo(a)pyrene
Chrysene
Fluoranthene
Fluorene
Naphthalene
PCBs
Phenanthrene
Pyrene