WATER QUALITY AND BIOLOGICAL CHARACTERIZATION OF OSO CREEK & OSO BAY, CORPUS CHRISTI, TEXAS

A report of the Coastal Coordination Council pursuant to
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EXECUTIVE SUMMARY

The Texas Natural Resource Conservation Commission (TNRCC) Surface Water Quality Monitoring Program (SWQM) provides for an integrated evaluation of physical, chemical, and biological characteristics of aquatic systems in relation to human health concerns, ecological conditions, and designated uses. The TNRCC Total Maximum Daily Load (TMDL) Program is currently undertaking development and implementation of TMDL projects in Texas impaired watersheds. TMDL development and implementation is one means by which the Texas Coastal Management Program will meet state coastal non-point source pollution control requirements of §6217 of the Coastal Zone Act Reauthorization Amendments of 1990. The TNRCC initiative intends to assess pollution levels entering a water body, from both point and non-point sources, and establish pollutant limits that will restore water quality to levels suitable to support aquatic life and protect public health.

Oso Bay (Segment 2485) is an enclosed, secondary bay located on the southern shore of Corpus Christi Bay that exchanges water with Corpus Christi Bay and receives freshwater inflows from Oso Creek (unclassified). This unique urban watershed is highly productive, yet subject to both natural and anthropogenic stresses that potentially impair water quality. In support of TMDL development and implementation, it is imperative to investigate water bodies with potentially correctable problems. The scientific methods employed in the collection of the highest quality data serve to benefit the development and subsequent implementation of the TMDL program. This project provides data to confirm and document past assessments listing this segment as an impaired water body with identifiable "concerns" and "possible concerns" for various water quality standards or screening criteria.

The primary project objective was to conduct a characterization and assessment of the water quality and biota of the Oso Creek/Oso Bay Watershed System. Beginning October 1999 this project increased existing TNRCC sampling intensity in this area by sampling eight locations monthly for one year. Sampling involved the collection of routine field data and water chemistry parameters, macroinvertebrate organisms, and microbial indicator organisms. In an attempt to address depressed dissolved oxygen (DO) levels, a 24-hour monitoring program took place beginning in September 2000 at four fixed platform locations within Oso Bay and one fixed platform reference location in the Upper Laguna Madre. Additionally, collection and compilation of baseline land use data provided valuable information to aid in watershed system characterization. A secondary objective provided for sampling and data collection during and after several significant rainfall events in an attempt to assess the influence of "pulsed" inputs from potential pollutant sources to the system. The frequency and intensity of this sampling effort supplied spatial and temporal information on existing water quality conditions. Data analysis provided sufficient information for accurately assessing this water body and determining if further management measures are necessary to ensure compliance with all beneficial uses.

Based on the data collected, results suggest that significant concerns do exist for nutrient loadings, DO, and bacterial contamination within the Oso Creek/Oso Bay system. The low natural flow conditions that exist within Oso Creek allow effluent from permitted municipal

discharges to be the dominant source of flow. This source of nutrient loadings ultimately exhibits a strong influence on the water quality and aquatic life within the system.

Within Oso Creek, nutrient and chlorophyll *a* parameters exceeded TNRCC Water Quality (WQ) screening criteria in such large percentages that unfortunately, exceedance was the normal condition. Loadings ultimately affect water quality parameters, as was clearly demonstrated by the steady downstream progression in which DO and pH concentrations typically increased to a point that the last station sampled on Oso Creek (13027) exhibited such wide fluctuations it resulted in dense algal blooms and generally poor habitat conditions. Natural low gradient of the streambed and persistent low flow conditions allow nutrient containment in the system for long periods, with large amounts of suspended organic material accumulating within the sediments. Eventually periodic intense precipitation results in flooding of Oso Creek and causes the re-suspension of sediments that flush downstream and out into Oso Bay. In addition, based on the biological information gathered, supporting evidence exists for the poor water quality and habitat assessment, as often-cited indicator species such as oligochaetes and chironomids completely dominated sample collections at Oso Creek stations.

Within Oso Bay (Segment 2485), water quality was considerably better than Oso Creek, the exception being Station 13441 located below the City of Corpus Christi Oso Wastewater Treatment Plant (OWWTP). The excessive exceedance of nutrient and chlorophyll *a* screening criteria, wide fluctuations in water quality parameters, and the resultant algal blooms seen in Oso Creek did not occur in most of Oso Bay. This was likely due to the combined effect of significant amounts of Upper Laguna Madre water discharged through the CP&L-Barney Davis plant and the larger water body to absorb the inputs from Oso Creek and buffer most other influences on water quality. Biological information indicates that many species of aquatic organisms exist within Oso Bay, and except for the biological community around the OWWTP, most stations produced a high species richness and abundance. However, within all station communities there tended to be a few species that dominated collections. Most of these species are prevalent within the region, and while not necessarily indicative of poor water quality or habitat conditions, they serve as indicators of stressful environments. These stresses commonly relate to a number of varying parameters such as high or extreme fluctuations in salinity or low or extreme fluctuations in DO.

However, definite concerns do exist for non-support of aquatic life uses due to depressed DO concentrations and non-support of the Oyster Waters classification due to bacterial contamination within Oso Bay. Additional concerns definitely exist for the area surrounding the OWWTP for nutrient screening criteria exceedance.

The shallow nature of this bay system plays a large part in the naturally occurring fluctuations of DO, a vital aquatic life parameter. Data analysis revealed wide diurnal fluctuations. However, this is common and expected in such shallow, warm water, highly saline systems typical of the South Texas region. The exceptional habitat designation for Oso Bay may be justified, but it is clear that the natural hydrodynamics of this system, coupled with the nutrient loadings, may play a critical part in low DO levels occurring in this bay system. The reference DO continuous monitoring station in the Upper Laguna Madre possesses similar characteristics to Oso Bay also failed to meet the DO criteria. Listed on the 303d list as exhibiting partial or non-support of the criteria, these are natural fluctuations within the water bodies of the region and the possibility exists that the WQ criteria for exceptional habitat will never be attainable within either system based on the present fixed numerical value.

Recommendations at this time center on the concerted effort to bring all stakeholders to the table to discuss the nutrient loadings and general conditions that exist within this unique, but totally effluent dominated system. This next step is vital in meeting the TNRCC TMDL initiative of assessing pollution levels entering a water body, from both point and non-point sources, and establishing limits, standards, and criteria screening levels that accurately reflect the water body in question and that are suitable to supporting aquatic life and protecting public health. In addition, based on data collected within this and similar systems in the State of Texas, the opportunity may exist to assess whether a variable DO criteria based on the relationship between salinity and temperature may be more appropriate for assessing water quality; rather then the present fixed numerical criteria system.

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OSO CREEK/OSO BAY PROJECT

INTRODUCTION

The Texas Natural Resource Conservation Commission (TNRCC) Surface Water Quality Monitoring (SWQM) Program provides for an integrated evaluation of physical, chemical, and biological characteristics of aquatic systems in relation to human health concerns, ecological condition, and designated uses. SWQM data provide a basis for the establishment of effective TNRCC management policies that promote the protection, restoration, and wise use of Texas surface water resources. Primary statutory authority for the SWQM Program is provided under Section 26.127 of the Texas Water Code, which states, “The executive director has the responsibility for establishing a water quality sampling and monitoring program for the state. All other state agencies engaged in water quality or water pollution control activities shall coordinate those activities with the Commission.” Sections 104(b), 106, 205(j), 303(d), 305(b), 314, 319, and 604(b) of the Federal Clean Water Act of 1972 and the Water Quality Act of 1987 strongly influence the SWQM Program.

The Total Maximum Daily Load (TMDL) Legislation found in Section 303(d) mandates that “each river authority (or local governing entity) shall submit quality-assured data collected in the river basin to the commission.” “Quality-assured data” in the context of the legislation means “data that complies with commission rules for water quality monitoring programs, including rules governing the methods under which water samples are collected and analyzed and data from those samples are assessed and maintained.” This process involves the development of a Quality Assurance Project Plan (QAPP) for all projects undertaken to carry out those activities mandated by the legislation.

The purpose of the QAPP is to clearly delineate the Quality Assurance (QA) policy, management structure, and policies utilized to implement the QA requirements necessary to document the reliability and validity of environmental data. TNRCC reviews the QAPP to ensure that data generated for the purposes described above are scientifically valid and legally defensible. This process insures that all data submitted to the state-wide database have been collected and analyzed in a way that guarantees its reliability and therefore can be used in TMDL development, stream standards modifications, permit decisions, water quality assessments, and other programs deemed appropriate by the TNRCC.

The TNRCC is currently undertaking development and implementation of TMDL projects in Texas impaired watersheds. TMDL development and implementation is one means by which the Texas Coastal Management Program will meet the state coastal non-point source pollution control requirements of §6217 of the Coastal Zone Act Reauthorization Amendments of 1990. Impaired water bodies, in which specific pollutants exceed standards, remain slated for restoration to water quality standards compatible with their intended uses. This TNRCC initiative intends to assess pollution levels entering a water body, from both point and non-point sources, and establishes pollutant limits that will restore water quality to levels suitable to support aquatic life and protect public health.

Oso Bay (Segment 2485) is an enclosed, secondary bay located on the southern shore of Corpus Christi Bay that exchanges water with Corpus Christi Bay and receives freshwater inflows from Oso Creek (unclassified). This unique urban watershed is highly productive, yet subject to both natural and anthropogenic stresses that potentially impair water quality. This project will address the conclusions of the June 26, 1998 final 303(d) list and the 1996 TNRCC Regional Assessment of Water Quality in the Nueces Coastal Basins report. Both documents list this segment as an impaired water body with identifiable "concerns" and "possible concerns" for various water quality standard indicators.

The June 26, 1998 final 303(d) list included the following statement:

> "Dissolved oxygen concentrations are occasionally lower than the standard established to assure optimum habitat conditions for aquatic life in the lower portion of the bay (L/PS). Based on Texas Department of Health shellfish maps, 100% of the bay (7.2 mi^2) does not support the oyster water use (L/NS). Non-supporting areas are restricted for the growing and harvesting of shellfish for direct marketing, or prohibited due to potential microbial contamination. Studies and analyses are underway or pending".

The 1996 TNRCC Regional Assessment of Water Quality in the Nueces Coastal Basins report includes the following statement:

> "…A concern is identified in this segment for total phosphate. Possible concerns are identified for ammonia nitrogen, orthophosphorus, total phosphorus, dissolved orthophosphorus, and fecal coliform. The 1996 Surface Water Quality Inventory reports that depressed dissolved oxygen levels in the lower portion of the bay contribute to partial support of the exceptional aquatic life use. Due to elevated fecal coliform densities, the oyster waters use is not supported, and the contact recreation use is partially supported. Trend analysis shows that fecal coliform densities may be decreasing. Documented water quality problems may be due to the nine permitted wastewater discharges to this segment..."

In support of TMDL development and implementation, it is imperative to investigate water bodies with potentially correctable problems. The scientific methods employed in the collection of the highest quality data will serve to benefit the development and subsequent implementation of the TMDL program.

STUDY SITE

Overview

Oso Bay (Segment 2485) is an enclosed, secondary bay located on the southern shore of Corpus Christi Bay. It receives freshwater inflows from Oso Creek and exchanges water only with Corpus Christi Bay (Fisher 1996). Generally characterized as a soft sediment estuarine area, temperature and wind exert a strong influence on Oso Bay. The entire bay (18 km^2) is subject to tidal exchange, and significant portions are alternately exposed and submerged, depending on wind velocity and direction. Typically, average depth in Oso Bay is <1.0 m. The majority of all tidal exchange occurs through a pass located on the east side of Ward Island; with minimal exchange occurring through the small pass located to the west. A small wind-tidal flat, covering approximately 28 hectares, lies west of Ward Island. This flat, known as the Blind Oso, submerges under high tide events combined with strong southerly winds or tropical storms. During such conditions, water exchange between the Blind Oso and Corpus Christi Bay may increase through the small pass (Bowman and Jennings 1992). An annotated historical data review in Appendix I contains information on previous reports documenting water/sediment quality, and biological studies within the Oso Bay system.

Mean annual precipitation for the area averages 74 cm yr^{-1}. Mean annual evaporation rates average from 90 to 115 cm yr^{-1}, but may range as high as 150 cm yr^{-1} during time of drought. Typically, the area experiences net annual moisture losses of approximately 31 cm-yr^{-1}. Tropical storms and hurricanes arising in the Gulf of Mexico may deliver larger quantities of rainfall during late summer and early fall on an irregular basis (Armstrong 1987). Classification of the area as semi-arid and sub-tropical results from these higher than average annual moisture deficits caused by evaporation, and the hot, humid summers and mild, cool winters, respectively (Jones 1975). Summer high temperatures typically average 33.3°C, while the winter low averages 8.3°C.

Southeasterly prevailing winds are characteristic of the Texas Gulf coast for most of the year. Winds average 11.9 mph and serve as a primary source of atmospheric moisture. Strong northerly frontal passages are common in winter and may result in below freezing temperatures and extreme low tides for several days (Chabreck 1990). Tides are primarily diurnal with average amplitude of 10 cm. Astronomical tidal fluctuations typically range from 0 to 60 cm, with wind direction and velocity being the primary controlling factors influencing the duration of inundation and tidal range within the area (Wilcox and Childress 1981; White et al. 1983). Table 1 summarizes climatological conditions recorded during the twelve-month study period.

Clays and sands dominate Oso Bay sediments, with areas high in organic material found near the City of Corpus Christi Oso Wastewater Treatment Plant (OWWTP) (Oppenheimer 1972; White *et al*. 1983; Armstrong 1987). Bowman and Jennings (1992) stated that rough shell hash constituted a major bottom component present near the mouth of the bay as it empties into Corpus Christi Bay, but was not present elsewhere. Seagrass beds, mostly comprised of *Halodule beaudettei*, cover numerous areas of the bay bottom. Emergent vegetation, and a well-defined wetland area, is located adjacent to the OWWTP outfall in the area known as the Blind Oso.

TABLE 1. Local climatological data measured at Corpus Christi International Airport, for the twelve-month sampling period (NOAA 1999 and 2000).

Month	Average Air Temperature (°C)	Total Precipitation (cm)	Average Wind Speed (mph)	Resultant Wind Direction
October 1999	22.3	4.6	8.8	NE (050°)
November	19.2	1.5	9.1	ESE (100°)
December	15.1	0.6	12.0	NE (050°)
January	16.9	1.3	12.3	ESE (120°)
February	19.7	1.5	14.3	SE (140°)
March	21.8	9.3	14.5	ESE (120°)
April	22.9	2.6	12.6	ESE (120°)
May	26.6	12.2	13.1	ESE (100°)
June	27.8	6.6	11.5	SSW (200°)
July	29.4	0.0	11.9	SSE (150°)
August	29.3	2.4	9.7	S (180°)
September 2000	27.6	5.2	10.6	ESE (110°)
Average	23.2	4.0	11.7	ESE (120°)

Bowman and Jennings (1992) characterized Oso Creek as a small, effluent-dominated, low gradient stream, which enters the upper reaches of Oso Bay and creates a small estuarine area. Originating in Nueces County near the city of Robstown, about 32 km west and north of Oso Bay, the combined drainage area for the bay and creek encompasses approximately 600 km^2 (Bowman and Jennings 1992). Sediments within Oso Creek are typically comprised of soft organic mud, silts, and clays. Water depth varies from 0.20 to 0.75 m in runs, with pools up to 1.5 m deep. Vegetation is primarily sedges, grasses, shrubs, and some trees along the banks. Further downstream, banks become barren and dry during drought conditions, but vegetation can be present after rains.

The soils surrounding Oso Bay and Creek are composed of three types, Victoria Association, Orelia-Banquete Association, and Galveston-Mustang-Tidal Flats Association (USDA 1992) (Fig. 1). The Victoria Association soil is dark, calcareous, crumbly, and called blackland. These soils crack when dry and swell when wet; however, they take in water slowly.

The Orelia-Banquete Association soils are deep, dark-colored, crusty soils that contain a hardpan. The surface soil and subsoil of Orelia soils are less crumbly than those of Victoria soils are, and because the subsoil is dense, the Orelia-Banquete soils take in water even slower than the Victoria soils. Most areas surrounding Oso Creek/Bay with Orelia soils are cultivated.

The Galveston-Mustang-Tidal Flats Association exists along coastal strips of the mainland. These soils are deep, hummocky, light-colored, loose sands, and normally less than a foot thick. Runoff on these soils is very slow because practically all rain enters and moves through these soils. Therefore, surface and storm water runoff primarily to the west of Oso Creek/Bay, which is dominated by cultivated, pastured, and urban land, is fast, while runoff to the east of the creek and bay is slow (USDA 1992) (Fig. 1).

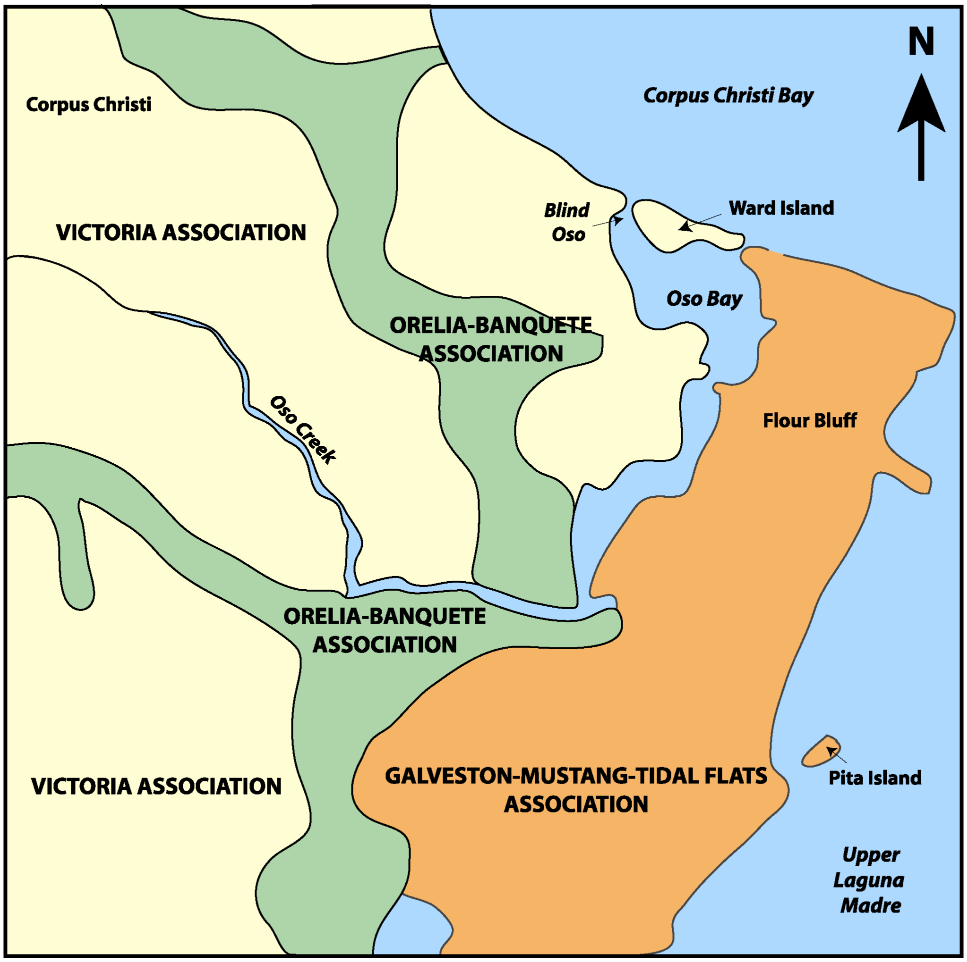

Fig. 1. Soil types surrounding Oso Creek and Oso Bay. Map adapted from USDA 1992.

The Oso Bay NE quadrangle (as determined by Texas Parks & Wildlife), used in GIS applications to determine land cover and use, encompasses nearly the entire creek and all of Oso Bay. According to Texas Parks & Wildlife (1996), the entire watershed including Oso Creek and Oso Bay is 47.3% upland, 3.3% wetlands, 0.9% transitional lands, and 48.4% water and submerged land. Of the uplands, urban development accounts for 14.8%, crop and pastureland 69.2%, prairie 4.5%, and shrub/forested land 10.7%. Much of the stormwater and runoff from these areas directly enters Oso Creek and Oso Bay. Baseline GIS land use data for this study investigated the immediate areas bordering Oso Creek and Oso Bay and produced the percent coverage information as detailed in Fig. 2.

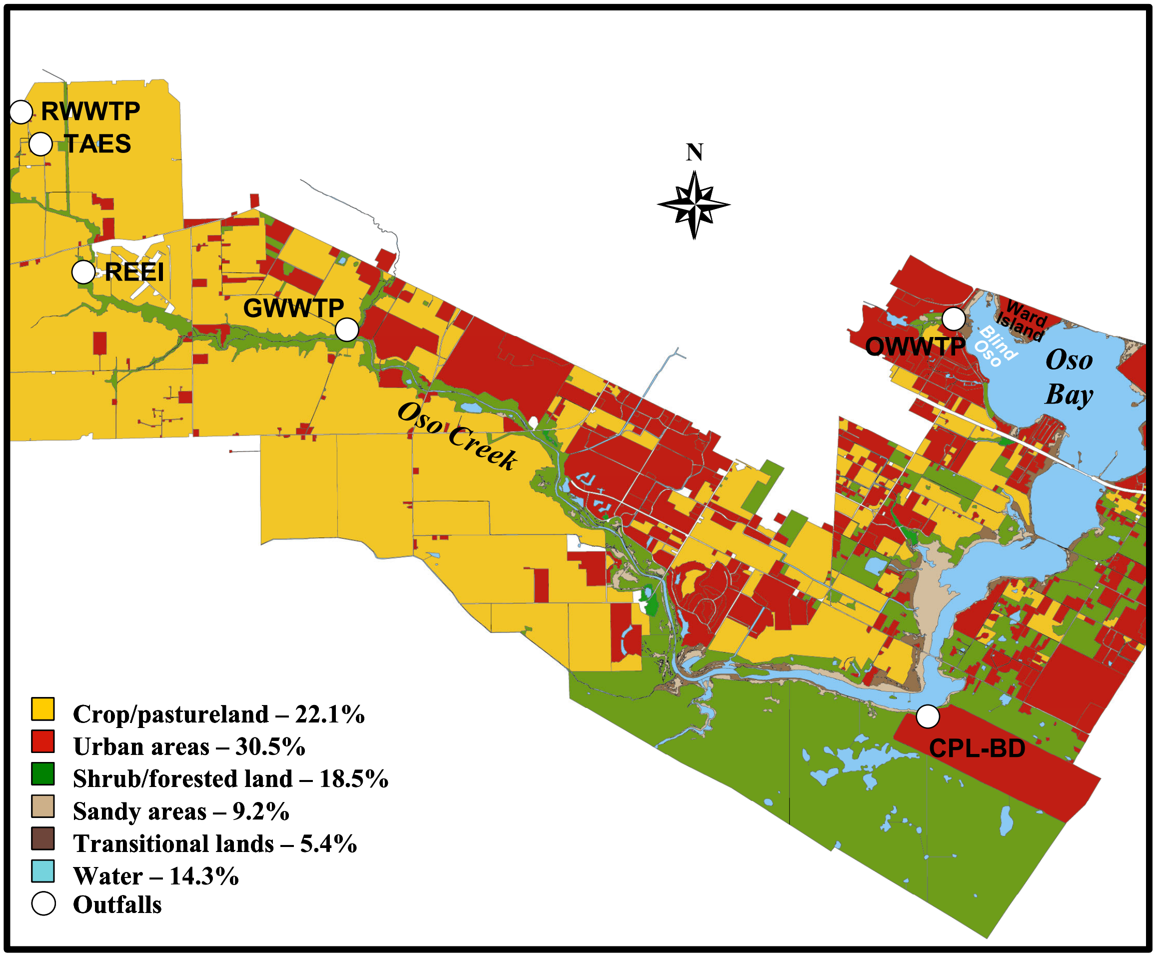

Fig. 2. Land use types and outfall locations surrounding Oso Creek and Oso Bay. RWTP (Robstown Wastewater Treatment Plant); REEI (Roloff Evangelistic Enterprises, Inc.); TAMES (Texas A&M Extension Service); GWWTP (Greenwood Wastewater Treatment Plant); CPL-BD (Central Power & Light-Barney Davis Plant); OWWTP (Oso Wastewater Treatment Plant) (GIS layers provided by the Nueces River Authority).

Under normal climatic conditions, the entire flow in Oso Creek is effluent dominated. Fisher (1996) states documented water quality problems may relate to the approximate 565 million gallons per day (MGD) discharged to Oso Creek and Oso Bay from these permitted wastewater facilities. The stream originates as treated effluent from the city of Robstown Wastewater Treatment Plant (RWWTP) (3.0 MGD). This flow moves downstream, combining with effluents from several minor domestic wastewater treatment plant outfalls: Roloff Evangelistic Enterprises, Inc. (0.02 MGD) and Texas A&M Extension Service (0.025 MGD). Approximately 15 miles downstream from the RWWTP, effluent from the City of Corpus Christi Greenwood Wastewater Treatment Plant (GWWTP) (6.0 MGD) enters Oso Creek. Additional freshwater originates from the inputs of three adjacent golf courses, storm water, agricultural, and urban runoff.

A cooling water discharge from the Central Power & Light Co., Barney Davis Electric Generating Station (CP&L-BD) (540 MGD) combines with Oso Creek at the upper end of Oso Bay (Fig. 2). Hypersaline water, drawn from the Upper Laguna Madre, passes through the plant heat-exchange system and discharges into baffled thermal equalization ponds before entering Oso Bay. This discharge remains the most significant hydrological factor in the Oso Bay/Oso Creek system, resulting in a net positive outflow into Corpus Christi Bay (Watson 1991). Near the mouth of Oso Bay, the OWWTP (16.2 MGD) discharges domestic wastewater effluent into the Oso Bay system. Although freshwater comprises only a small percentage of the total discharge it is ecologically important within the system.

In addition to diverted storm water runoff, discharges of oil field brines routinely entered Oso Creek and associated tributaries from 1939 until 1973. Spent drilling muds were often disposed of into Oso Creek and along its banks. These practices altered soil structure, enhanced erosional processes, increased sedimentation rates, and resulted in negative stream impacts along the length of the creek leading to Oso Bay (Bowman and Jennings 1992).

Bowman and Jennings (1992) stated that the widely fluctuating historical flow pattern in the Oso Creek and Oso Bay system results from the influence of infrequent, yet, large-scale rain events associated with the hurricane season. These events, interspersed with minor to severe drought conditions tend to skew the annual flow data for the system. United States Geological Survey flow data for Oso Creek for the 27-year period from 1973 through 2000 reveals a declining trend in the flow rate despite increasing urbanization and runoff diversion to Oso Creek (Fig. 3). Compared to the data reported by Bowman and Jennings (1992) for the 16-year period from 1973 through 1989 the mean flow declined approximately 7.0% from 31.6 cubic feet per second (CFS) or 22,890 acre-feet per year (Ac-Ft/Year) to 29.4 CFS, or 21,350 Ac-Ft/Year. Explanation for this trend may result from the decreasing incidents of hurricane and tropical storms coupled with the increasing number of drought periods seen during the 1990's. During the current study, Oso Creek had lower than average flow conditions. Nine months of the study period flows were <1.6CFS and only one month exceeded the mean flow rate of 29.4 CFS (Fig. 4).

Although identifiable "concerns" and "possible concerns" for water quality standards or screening criteria exist, TNRCC presently classifies Oso Bay as possessing "exceptional aquatic habitat" with an aquatic life use DO criteria of 5.0 mg l^{-1} and an Oyster Waters Fecal Coliform criteria of 14 CFU/100 ml. Oso Bay continues to provide productive nursery habitat for commercially important species, such as White and Brown shrimp (*Litopenaeus setiferus* and *Farfantepenaeus aztecus*), Blue Crabs (*Callinectes sapidus*), and assorted finfish species (Hildebrand and King 1979; TNRCC 1996). Protection of these aquatic resources to support aquatic life and protect public health is a fundamental TMDL initiative aspect.

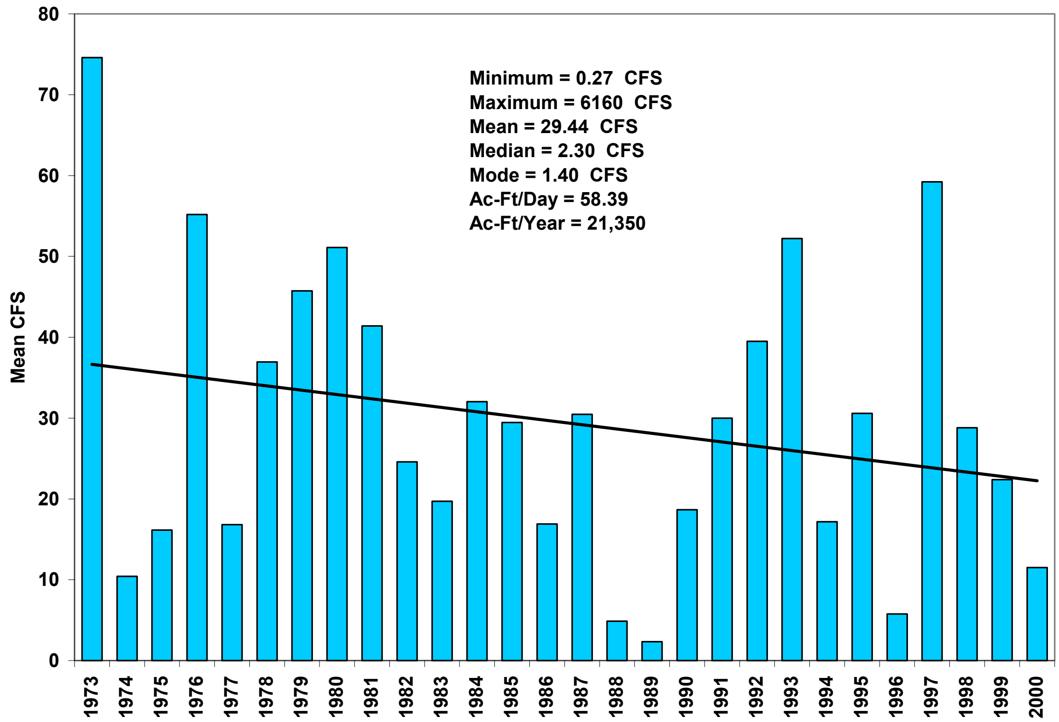

Fig. 3. Annual mean flow data for Oso Creek from the United States Geological Survey Gauge No. 08211520 located at Station 13029 at FM 763.

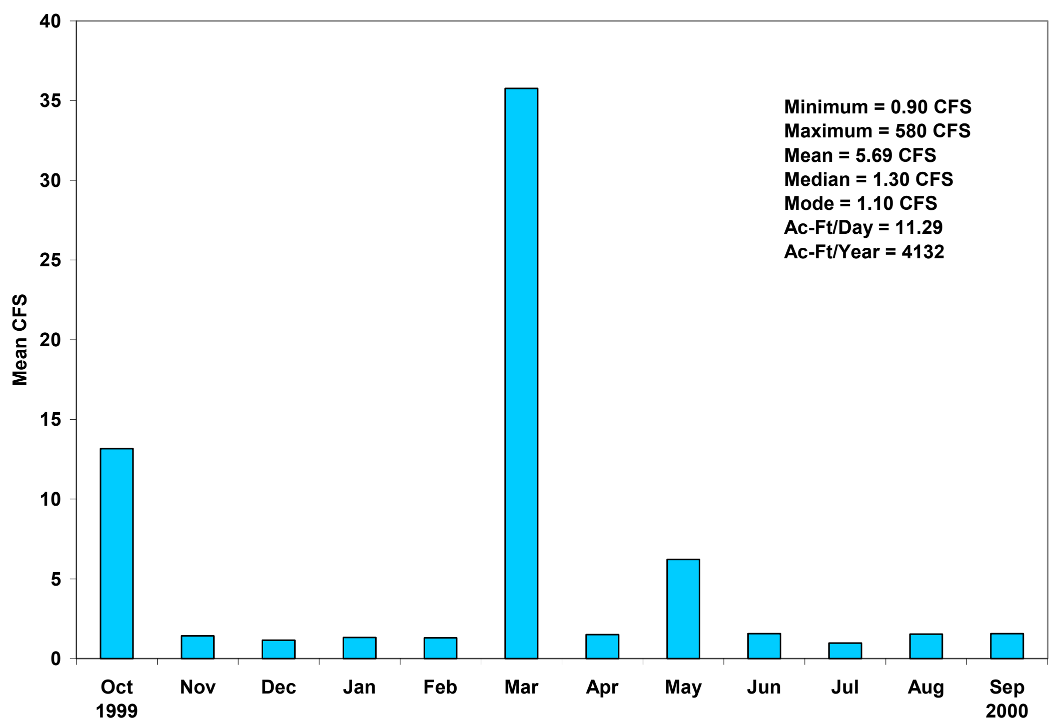

Fig. 4. Monthly mean flow data for Oso Creek from the United States Geological Survey Gauge No. 08211520 located at Station 13029 at FM 763.

Monitoring Sites

Sampling occurred monthly at eight monitoring sites (four in Oso Creek and four in Oso Bay) for water quality, microbiological, and biological parameters (Fig. 5). Seven of these sites are historical TNRCC stations and one (Station 16712) is a newly established TNRCC station within the Oso Creek/Oso Bay System. In addition, monitoring of 24-hour DO took place at four fixed platform locations within Oso Bay and one fixed platform reference location in the Upper Laguna Madre. See Table 2 on Page 19 for a list of sampling locations with Station number, location, description, and sampling parameters. Salinity gradually increases at these stations from west to east, as areas become more accessible to tidal exchange with Corpus Christi Bay. Oso Creek stations, while indicative of freshwater due to the surrounding flora and fauna, have EPA designations of Tidal Stream-Ambient while designation of Oso Bay stations (Segment 2485) is Estuarine-Ambient. Delineation of the segment boundary between Oso Creek and Oso Bay has historically been set in the shallow water reaches of Oso Creek to the west of the CP&L-BD discharge area.

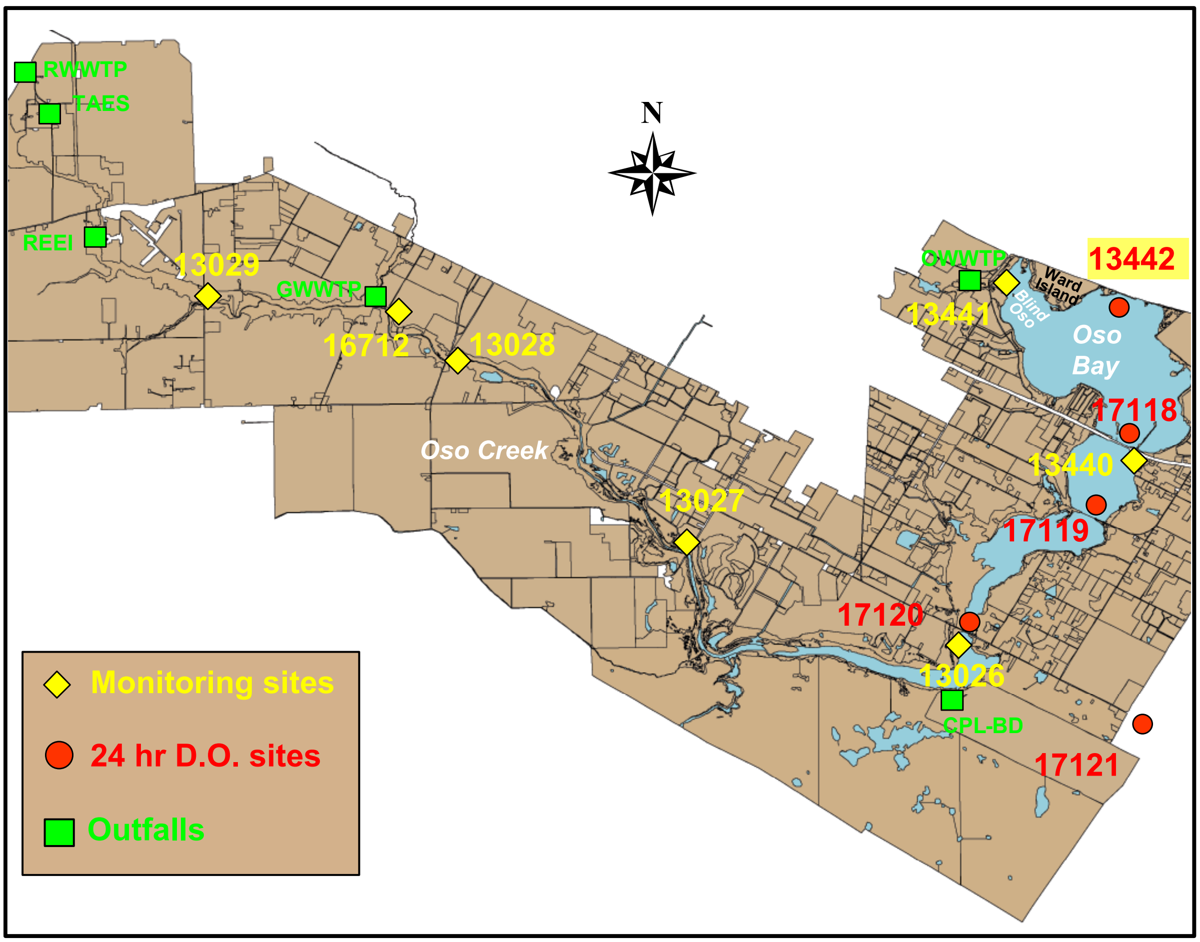

Fig. 5. Map showing monitoring locations along Oso Creek and Oso Bay.

Station 13029

Located where FM 763 crosses Oso Creek, this is the farthest upstream station. Vegetation surrounding the station is mostly shrub, with some mesquite, hackberry, and Chinese tallow trees. Shading exists and vegetation grows down to the streambed (Fig. 6). The stream is approximately 3-6 m wide and sampling location is approximately 30 m upstream from the FM 763 Bridge. Water depth in the sample area is approximately 0.5 m. Bottom sediments are a clay/sand substrate interspersed with gravel deposited during bridge construction.

Fig. 6. View of Station 13029 - Oso Creek at FM 763

Station 16712

This newly created station is located at the southwestern boundary of the City of Corpus Christi's Elliot Landfill. Vegetation surrounding the station is similar to Station 13029. Shading exists along the shoreline and vegetation grows down to the streambed (Fig. 7). Stream is approximately 30 m wide and sampling location is approximately 100 m downstream of the GWWTP discharge, which enters Oso Creek by way of La Viola creek. Water depth in the sample area ranges from 0.3 to 0.8 m with some areas greater than 1.0 m. Bottom sediments are clay, covered by a substantial soft organic mud layer.

Fig. 7. View of Station 16712 - Oso Creek at Elliot Landfill.

Station 13028

Station location is approximately 50 m downstream of where State Highway 286 or Ayers Road crosses Oso Creek. The vegetation mentioned above is present, however estuarine emergent vegetation (*Sueda linearis, Salicornia sp, Batis maritima, and Distichlis spicata*) is present, as well as California bulrush (*Scirpus* sp.) (Fig. 8). Water depth in the sample area ranges from 0.5 to 1.0 m with some areas greater than 1.5 m. Bottom sediments are clay, covered by a substantial soft organic mud layer. Some gravel exists closer to the bridge. An open ditch to the southwest, and a storm drain on the east side of the bridge, delivers runoff to this area. This area serves as a constant dumping ground for debris. During the study, numerous items such as building materials (sheetrock, lumber, roofing shingles, etc.), household items (mattresses, chairs, garbage, etc.), dead animals, and general litter (Styrofoam cups, cans, plastic bottles and bags, paper, cardboard, etc.) ended up discarded by, or within, the creek.

Fig. 8. View of Station 13028 - Oso Creek at State Highway 286 (Ayers Road).

Station 13027

Station location is where FM 2444 or Staples Street crosses Oso Creek. Vegetation characteristics are similar to Station 13028. While vegetation grows down to the streambed, urban development of the surrounding areas resulted in the clearing of most trees and much of the shrub such that relatively little streambed shading exists within the area (Fig. 9). The sampling location is adjacent and downstream of the bridge and water depth in the sample area ranges from 0.15 to 0.70 m. Bottom sediments are clay, covered by a substantial soft organic mud layer. A storm drain on the northeast side of the bridge, delivers runoff from the residential area to the creek. Although not as excessive, like Station 13028, this area also serves as a constant dumping ground for debris.

Fig. 9. View of Station 13027 - Oso Creek at State Highway 2444 (Staples Street).

Station 13026

Located where the Yorktown Road Bridge crosses Oso Bay, this station is approximately 1000 m downstream of the CP&L-BD cooling ponds outfall (Fig. 10). Clearing of vegetation for the construction of the adjacent bridge resulted in the shoreline being bare or covered in riprap to control erosion. Location of the CP&L-BD outfall exerts a substantial influence on the substrate characteristics of the location. A scoured channel exists, with an approximate depth of 2.5 m, in the middle of the bay. This area is composed of a hard clay substrate often impenetrable by the benthic coring device used in this study. Nearer the shore, the substrate transitions to a finer clay and silt composition mixed with patches of sand. Patches of the seagrass, *Halodule beaudettei* exists in this location.

The sampling area is adjacent and upstream of the bridge and water depth in the sample area ranges from 0.20 to 1.3 m. A large amount of tidal flat area exists and due to easy access to the water, numerous anglers use the bridge and surrounding area heavily, often driving vehicles across the tidal flats. This often results in a large amount of debris deposited on the shoreline near the bridge.

Fig. 10. View of Station 13026 - Oso Creek at Yorktown Road.

Station 13440

Located where State Highway 358 (South Padre Island Drive) crosses Oso Bay, this station is located at mid-bay. As with Station 13026 the clearing of vegetation during the construction of the adjacent bridge resulted in the shoreline being bare or covered in riprap to control erosion (Fig. 11). The sampling area is adjacent and downstream of the bridge and bottom sediments are primarily a soft clay/sand composition. Water depth within the sampling area ranged from 0.30 to 0.80 m with some areas greater than 1.0 m. Seagrass beds composed of *Halodule beaudettei* exist on the northern portion of the location. Prevailing southeasterly winds provide for constant mixing of the water within this area of Oso Bay. Easy access to the water also makes this an attractive spot for anglers and as seen at other stations this often results in debris deposited on the shoreline in the immediate area.

Fig. 11. View of Station 13440 - Oso Creek at State Highway 358 (South Padre Island Drive).

Station 13441

Located west of Ward Island at the Hans Suter Wildlife Refuge, which is adjacent to the OWWTP, this station is unique. Treated wastewater released from the OWWTP creates a freshwater wetland with such plant species as cattail, transcending to the bay and adjacent areas which are surrounded by low, mid, and high marsh vegetation. This station is located approximately 200 m from the OWWTP outflow; at the end of the discharge channel (Fig. 12. The sampling location is approximately 50 m from the end of the discharge channel and in front of the viewing platform used by visitors to the refuge.

While considered a low energy environment, there is potential for considerable mixing from the prevailing southeasterly winds when water levels are high. While the permit defines the mixing zone as a being within a 50-foot radius from the outflow pipe, typically the low water levels at this location result in a visible dominant plume of freshwater that flows out and mixes with the higher saline waters of Oso Bay. Due to these low water levels, and extended periods of the tidal flats being emergent, it is often necessary to walk extended distances to obtain enough water for representative water chemistry samples. Bottom substrate tended to be hard clay overlaid with silt and/or a layer of black organic material.

Fig. 12. View of Station 13441 - Oso Creek at Hans Suter Park below OWWTP outfall.

Station 13442

Located East of Ward Island, where Oso Bay connects with Corpus Christi Bay (Segment 2484) and flows under Ocean Drive, this area experiences significant wash and scour effects due to high rates of tidal exchange (Fig. 13). Under usual conditions, all water exchange with Oso Bay occurs through this area. The sampling area is adjacent and upstream of the bridge and bottom sediments include broken shell and sand over clay substrate. Water depth within the sampling area ranged from 0.30 to 0.50 m with areas greater than 1.5 m located in the channel under the bridge. Seagrass beds composed of *Halodule beaudettei* exist on the southern portion of the sampling area. As with Station 13026 and 13440 the clearing of vegetation during the construction of the adjacent bridge resulted in the shoreline being bare or covered in riprap to control erosion. Easy access to the water also makes this an attractive spot for anglers and as seen at other stations this often results in debris deposited on the shoreline in the immediate area.

Fig. 13. View of Station 13442 - Oso Creek at Ocean Drive.

METHODS AND MATERIALS

Project Objectives and Research Plan

The primary objective was to conduct a characterization and assessment of the water quality and biota of the Oso Creek/Oso Bay System. From October 1999 through September 2000, this project increased existing TNRCC sampling intensity in this area by sampling eight locations monthly for routine field data and water chemistry parameters, macroinvertebrate organisms, and microbial indicator organisms (Table 2).

Additionally, collection and compilation of baseline land use data provided valuable information to aid in watershed system characterization. As an accurate assessment of the watershed for potential water quality problems was important, a secondary objective provided for sampling and data collection during and after several significant rainfall events in an attempt to assess the influence of "pulsed" inputs from potential pollutant sources to the system. Examples of inputs include, but are not limited to, agricultural non-point source runoff, municipal point source discharges, and residential non-point source runoff.

Furthermore, in an attempt to address the depressed DO levels, a 24-hour DO monitoring program occurred at four fixed platform locations within Oso Bay and one fixed platform reference location in the Upper Laguna Madre. Please note that the original sampling plan called for conducting the 24-hour DO program concurrently with the main portion of the study. Delays in contract negotiations, adjustment in funding budgets, and subsequent time line constraints resulted in the 24-hour DO program beginning in August 2000. The project managers continued this sampling for duration of one year, concluding in August 2001, thereby capturing 24-hr DO data within the index period (March 15^{th} through October 15^{th}) over two years and within the critical phase of the index period (July 1 through October 15^{th}) for one year.

The frequency and intensity of the sampling effort supplied spatial and temporal information on existing water quality conditions within the Oso Creek/Oso Bay system by providing basic water quality, biological community composition, and land use data. Data analysis provided sufficient information for preliminary assessment of this water body and determination of whether further management measures are required to ensure compliance with the beneficial uses currently assigned to this segment.

Field Sampling Procedures

Standard operating sampling procedures were consistent with those documented in the TNRCC *Surface Water Quality Monitoring Procedures Manual* 1999, Texas Watch *Volunteer Environmental Monitoring Manual*, or other methods approved through the TNRCC and documented in the *Oso Creek/Oso Bay Watershed System Study Quality Assurance Project Plan - Revision 4.* Additional aspects outlined below reflect specific requirements for sampling parameters and/or provide additional clarification.

TABLE 2. Sampling locations with Station number, location, description, and sampling parameters (B=Benthic Cores, D=Dip/Kick Net, FD=Field Data, M=Microbiological, N=Nekton Sled, WC=Water Chemistry, *24DO* = 24 Hour DO).

Stations	Location	Description	Sampling Parameters
13029	Oso Creek @ FM 763	Tidal Creek	B, D, FD, M, WC
16712	Oso Creek @ Elliot Landfill	Tidal Creek	B, FD, M, N, WC
13028	Oso Creek @ SH 286 (Ayers Road)	Tidal Creek	B, FD, M, N, WC
13027	Oso Creek @ FM 2444 (Staples Street)	Tidal Creek	B, FD, M, N, WC
13026 *17120*	Oso Bay @ Yorktown Road	Open Bay-Estuarine	B, FD, M, N, WC, *24DO*
13440 *17118*	Oso Bay @ SH 358 (South Padre Island Drive)	Open Bay-Estuarine	B, FD, M, N, WC, *24DO*
13441	Oso Bay @ Hans Suter Wildlife Refuge	Open Bay-Estuarine	B, FD, M, N, WC
13442	Oso Bay @ Ocean Drive	Open Bay-Estuarine	B, FD, M, N, WC, *24DO*
17119	Oso Bay @ Holly Road RR tracks	Open Bay-Estuarine	*24DO*
17121	Laguna Madre 0.7 km Southeast of Yorktown Road	Open Bay-Estuarine	*24DO*

Field Data

In addition to routine field observations, to assess the progression and effects of flows through the ecosystem, monthly water quality measurements (water temperature, DO, percent saturation, pH, conductivity, and salinity) took place at all locations using a portable Hydrolab Surveyor 4a.

24-hour Dissolved Oxygen Monitoring

Consultation with TNRCC resulted in the selection of the four platform stations in Oso Bay and one reference station in the Upper Laguna Madre (Fig. 5) as being representative of Oso Bay and the Upper Laguna Madre systems. Monitoring took place from August 2000 thorough October 2001 resulting in data collection for a portion of the 2000 index period (August 17 through October 15) and for all of the 2001 index period (March 15 through October 15). Appendix II contains all 24-hour DO data values used for analysis.

The Conrad Blucher Institute-Division of Nearshore Research (CBI-DNR) utilized the following standard operating procedures for the 24-Hr DO data collection. Complete QA/QC information is contained in the QAPP on file with TNRCC.

Each platform contained a radio transmitter set at 453.5 MHz, a terminal node controller (TNC), associated wires and cables, and a 24 or 40 amp-hour gel-cell battery, enclosed in a weatherproof NEMA4X fiberglass enclosure. External to the enclosure was a radio antenna and a Hydrolab H_2O DataSonde unit. All Hydrolab units located in Oso Bay and Upper Laguna Madre were in water depths representative of the Oso Bay system (0.6 m to 1.2 m deep). This allowed for suspension of DO probes at a minimum of 0.3 meters in the water column while recording 24-hour DO data. The request for data was issued from the computers at CBI on the half-hour and data was transmitted to CBI with each transmission consisting of 5 instantaneous readings from the Hydrolab, data were received via radio/TNC at CBI, stored as raw files, and imported into the CBI Environmental Database for analysis.

Station servicing took place every 7 days. Weekly service was critical, particularly in the warm water months (March-November). Excessive barnacle and algal growth occurs during this period, so efforts took place to keep instruments as clean as possible, as often as possible. Freshly calibrated Hydrolab units were exchanged with existing units during station servicing. Retrieved units went back to CBI for post-calibration/cleaning in the CBI Wet-lab.

Water Chemistry

Collection of water samples for routine chemical analysis conformed to methods defined in the QAPP, and prescribed in the TNRCC *Surface Water Quality Monitoring Procedures Manual* 1999, at all monitoring sites for each monthly and significant rainfall sampling event. Generally, sampling at each station involved three grab samples collected, placed on ice, and returned to the CCS lab for preservation and shipment on ice to the TNRCC Houston Laboratory for analysis. Appendix III provides additional information concerning parameters analyzed, matrix, container types, preservation, sample volume, and holding times.

Microbiological Indicators

Sample analysis for fecal coliform, enterococci, and *E. coli* concentrations occurred after membrane filtration (American Public Health Association 1995). Sampling consisted of collecting two replicate (field) samples per station for analysis. Differences in resulting data represent variability introduced during sampling, field handling, and transport back to the lab. Filtration of three different volumes took place for each replicate sample. Conducting a duplicate test, on one of the field samples from one site, served as a quality control measure.

Francy and Darner (1998) suggest that comparative results of replicate samples may aid in design of future monitoring projects. The objective was to filter a sample volume that resulted in the optimum number (20 to 60) colonies on the filter, thus the volumes filtered depended on the sample source and clarity of water sampled. The more turbid or contaminated the sample, the smaller the volume filtered. Following filtration, the membrane filter containing the bacterial cells was transferred, using sterilized forceps, to a prepared petri dish (50 x 9 mm, with tight fitting lids) containing a selected medium and incubated at the appropriate temperature. Colonies resulting after incubation were counted and calculated according to Standard Methods Sections 9215 A8 and 9222 B6 or the TAMUCC Microbiology Research Laboratory Colony Counting Rules (unpublished) when counts were zero, one, or too numerous to count (TNTC). Recording of final counts (average of two replicates) will be a whole number to two significant figures.

Fecal coliform

Filtration of samples follows procedures outlined in the TNRCC *Surface Water Quality Monitoring Procedures Manual* 1999 and *Standard Methods for the Analysis of Water and Wastewater*, 20^{th} ed., 1998, Section 9222D. Incubation consists of fecal coliform media, with addition of agar and rosalic acid, and the petri dishes containing the filters, incubated in whirl-pak bags in a fecal coliform water bath at 44.5°C for 24 hours. After 24 hours, counting consists of recording the number of blue colonies (larger than pinpoint size) and reporting them as number of colony forming units (CFU) per 100 ml of water.

Escherichia coli

Determination of *E. coli* employed Standard Methods Section 9213 D-3 (APHA 1998). Two-step incubation consisted of placement of membrane filters on mTEC agar plates, a selective and differential medium, for two hours at 35°C, before transfer to a 44.5°C incubator for 22 hours. Transfer of membrane filters showing colony growth to a filter pad saturated with urea substrate followed incubation. After 15 minutes, *E. coli* colonies recorded consisted of counting the number of all yellow or yellow-brown colonies.

Enterococci

As recommended by the USEPA, determination of enterococci employed Method 1600: Membrane Filter Test Method for Enterococci in Water EPA-821-R-97-004 (USEPA 1997; Messer and Dufour 1998; Schaub 1998). Placement of the membrane containing the bacterial cells on a selective medium, mEI agar, and incubated for 24 hours at 41°C allows determination of enterococci colonies by recording all colonies with a blue halo, regardless of colony color.

Quality Control

Sterility checks – consisting of 100 ml sterile rinse water—occurred at the beginning, middle, and end of each filtration series for all replicate field samples. Performance testing of each media batch utilized raw influent from the City of Corpus Christi Oso Wastewater Treatment Plant as a "positive control". Conducting the positive control consisted of filling the funnel, with filter in place, to a depth of approximately 5 cm with sterile water, with the insertion of a sterile inoculation loop into the raw influent then brushed through the sterile water in the funnel. Performance of indicator verification tests adhered to Standard Methods 9222 G-1 (APHA 1998) for of *E. coli*, Standard Methods 9020B-8 (APHA 1998) for fecal coliform, and Method 1600 (USEPA 1986) for enterococci. In addition, throughout the study period we also followed the microbiological analysis quality control recommendations listed in Standard Methods Section 9020 B (APHA 1998).

Benthic Macroinfaunal Community

Monthly sampling, to determine species density, diversity, and community composition occurred at all eight stations. A PVC cylindrical benthic core, 5.08 cm diameter, ($20.27 cm^2$) sampled benthic infauna to a depth of 10 cm. Sampling consisted of five replicate samples, each containing five sub-samples, taken at each station, placed into 0.5 mm (500 F) mesh Biobags, and fixed in a 10% formalin/ambient water mixture containing the protein stain

Rose Bengal. Sample transfer to 45% isopropyl alcohol took place approximately seven days later. Laboratory analysis consisted of washing samples through nested sieves (minimum mesh = 0.5 mm), with organisms sorted, counted, and identified to the lowest possible taxon. Benthic analysis did not include epifauna or nekton incidentally collected with core samples.

Epifaunal Invertebrates and Nektonic Community

Monthly sampling to determine species density, diversity, and community composition occurred at all eight stations. Sampling of epibenthic invertebrates and nekton utilized a benthic marsh sled. Sled construction consists of a 1.1 mm mesh collecting bag secured to an aluminum frame with Velcro strips. The frame is 100 cm (wide) by 20 cm (tall) and the bag is 60 cm (deep). Sampling involves pulling the sled once at each station, at approximately 0.3 m/sec, for a distance of 25 m. Specimen preservation in 10% buffered formalin/ambient water with Rose Bengal followed sampling, with samples placed into Nalgene containers and transported back to the CCS lab. Sample transfer to 45% isopropyl alcohol took place approximately seven days later. Laboratory analysis consisted of washing samples through nested sieves (minimum mesh = 0.5 mm), with organisms sorted, counted, and identified to the lowest possible taxon. Analysis did not include benthic macrofaunal species incidentally collected with net samples. Due to unacceptable stream conditions (primarily underwater debris) at Station 13029, sampling utilized a kick-net and followed sampling methods prescribed in the TNRCC *Surface Water Quality Monitoring Procedures Manual* 1999.

Significant Rainfall Monitoring

Monitoring of significant rainfall events followed procedures as detailed in the previous field data, water chemistry, and microbiological indicator sections. No biological sampling took place during these events. Project plans called for four monitoring events, during and after significant rainfall, over the one-year study period. The determinations of when to sample required that rainfall occur at all station locations and that rainfall was significant enough to produce appreciable runoff within Oso Creek and Oso Bay. Significant rainfall event monitoring data appears in Appendix IV of this document.

Land Use GIS Data Collection and File Creation

The Nueces River Authority (NRA) utilized the following steps for the land use GIS data collection and file creation portion of this project. Where applicable, the NRA adhered to QA/QC requirements as documented in the QAPP.

Step 1. Obtained recent aerial photography or satellite imagery of the study area.

Step 2. Collect GPS coordinates using a TNRCC approved GPS unit as defined in the Geographic Information Systems Positional Data Policy (Policy). The points were collected in accordance with the GPS Data Collection Standards and Minimum Data Elements as defined in the Policy. These points were used to establish reference points in order to digitize the photographs. A minimum of four points per photograph were collected to define the area.

Step 3. Digitized the photographs to create a land use/land cover polygon coverage using a change in the surface characteristics to initially define the polygon boundaries. The photographs were digitized using Arc View 3.1 and exported to Arc/Info 7.1.2. A land use/land cover attribute was added to the coverage.

Step 4. Conducted field surveys (where the property was accessible) to:

a. Determine the land use/land cover. The classifications and codes were consistent with the ones used by the Texas Natural Resources Information System.

b. Verified/corrected polygon boundaries.

Step 5. Assigned the land use/land cover attribute codes to the polygon coverage based on field observations and photo analysis.

Step 6. The final GIS included line coverages of the creeks, roads, and shoreline, and point coverages of the surface water quality monitoring stations and wastewater outfalls. These coverages were clipped from existing coverages used by the NRA. All coverages were in Geographic projection and used the NAVD88 Datum.

Analysis

To facilitate data interpretation, presentation of graphical and tabular station data followed the numbering convention of stations listed in an upstream to downstream sequence (except for Brays-Curtis dendograms), starting with Oso Creek stations (13029, 16712, 13028, 13027) followed by Oso Bay stations (13026, 13440, 13441, 13442). Data analysis utilized the statistical programs SPSS 8.0 and BioDiversity Professional 2.0. One-way ANOVAs provided faunal density and biomass analysis after Log_{10} (y + 1) data transformation. Statistical tests were significant at $P \leq 0.05$ level. Appropriate separation tests or contrasts analyzed statistically significant differences between means. Shannon's Diversity Index provided comparisons between sites based on species richness and the evenness of the individual's distribution among the different species collected. Cluster analysis of species employed Brays-Curtis similarity matrices to define species assemblages by utilizing the components of species richness and abundance of individual species collected. This allows for creation of an association index describing similarity between ecological communities with similarity increasing as the index approaches 100%.

RESULTS AND DISCUSSION

Field Data

Water Temperature

In Oso Creek, mean water temperature was lowest at Station 13029 (farthest upstream station), highest at Station 16712 (below GWWTP) and Station 13027, and ranged from 14.5°C in December 1999 to 30.6°C in July 2000. Range was lowest over the twelve-month period at Station 16712 and highest at Station 13029 (Table 3). No statistically significant differences existed between the four Oso Creek stations (Table 4).

In Oso Bay, mean water temperature was lowest at Station 13440, highest at Station 13441 (below OWWTP), ranging from 13.5 in December 1999 to 31.0°C in August 2000. Range was greatest over the twelve-month period at Station 13441 and lowest at Station 13026 (Table 3). No statistically significant differences existed between the four Oso Bay stations (Table 4). In addition, Station 13026 located below the CP&L-BD heat exchange discharge, while yielding the second highest mean water temperature had the smallest water temperature range (Table 3). Minimum values recorded at this location remained above 20.0°C during the winter months and is indicative of the hydrological influence this constant supply of warmer water has on the upper portion of Oso Bay. The area directly below the discharge point has provided ideal habitat conditions for the seagrass, *Halodule beaudette*i, with full meadows and numerous patches of this seagrass encountered at many locations within the area.

While the majority of sampling occurred between 0830 and 1400 hours, and may not reflect the actual high values for the sampling day in question, water temperatures recorded were typical of the Coastal Bend region. The routinely higher summer time temperatures experienced in this area are all key components in depressing DO levels, through the increased breakdown of organic matter by microbial organisms and the fact that warmer, high salinity waters hold less DO.

Conductivity (Salinity)

In Oso Creek, mean conductivity (salinity) was lowest at Station 16712 (below GWWTP) and highest at Station 13027, and ranged from 1682 Fmho/cm (0.9 ppt) in June 2000 to 7736 Fmho/cm (4.3 ppt) in November 1999 (Table 3). Range was lowest over the twelve-month period at Station 13028 and highest at Station 13027, with no statistically significant differences found between the four Oso Creek stations (Table 4).

In Oso Bay, mean conductivity (salinity) was lowest at Station 13441 (below OWWTP), highest at Station 13440, and ranged from 1991 Fmho/cm (1.1 ppt) to 74,805 Fmho/cm (51.4 ppt) in August 2000. Range was lowest over the twelve-month period at Station 13442 and greatest at Station 13441 below the OWWTP (Table 3). Data analysis showed statistically significant differences existed between the four Oso Bay stations (Table 4).

Field conductivity (salinity) values recorded were typical of the area. In Oso Creek, mean values recorded were representative of other effluent dominated locations within the area, such as the diversion ponds at the Allison Wastewater Effluent Demonstration Diversion

Project in the Nueces River Delta. Lack of significant rainfall, due to the prolonged drought experienced over the last few years, may also influence increased values recorded within Oso Creek. Within Oso Bay, stations 13026 and 13440 exceeded the maximum TNRCC values for data reporting of conductivity/salinity (70,000 Fmho/cm / 45.0 ppt) several times. While lack of significant precipitation during the year, and the general climatic conditions of the region, these values most likely result from the hypersaline waters of the Upper Laguna Madre passed through and discharged from the CP&L-BD plant into Oso Bay.

Dissolved Oxygen (mg l^{-1}) Grab Samples

In Oso Creek, mean DO as obtained by one time grab samples was lowest at Station 13029, highest at Station 13027, and ranged from 4.1 mg l^{-1} in August 2000 to >20.0 mg l^{-1} in January and February 2000. Values greater than 20.0 mg l^{-1} exceed the maximum TNRCC value for data reporting of 19.0 mg l^{-1}. Readings were most likely higher, as the Hydrolab instrument utilized in this study will not report values in excess of 20.0 mg l^{-1}. Range was lowest over the twelve-month period at Station 13029, and highest at Station 13027. Maximum, range, and mean values increased from upstream to downstream (Table 3) and statistically significant differences did exist between the four Oso Creek stations (Table 4).

In Oso Bay, mean DO was lowest at Stations 13026 and 13440, highest at Stations 13441 (below OWWTP) and 13442 (entrance to Corpus Christi Bay), and ranged from 2.1 mg l^{-1} in August 2000 to 15.0 mg l^{-1} in June 2000. Range was lowest over the twelve-month period at Station 13026 and greatest at Station 13441 (below OWWTP) (Table 3). No statistically significant differences existed between the four Oso Bay stations (Table 4).

Dissolved Oxygen (% Saturation) Grab Samples

In Oso Creek, mean DO percent saturation (%) as obtained by one time grab samples was lowest at Station 13029, highest at Station 13027, and ranged from 55.2% in August 2000 to >200.0% in January and February 2000 (Table 3). Readings were most likely higher, as the Hydrolab instrument utilized in this study will not report values in excess of 200.0%. Range was lowest over the twelve-month period at Station 13029, highest at Station 13027, and statistically significant differences did exist between the four Oso Creek stations (Table 4).

In Oso Bay, mean DO percent saturation (%) as obtained by one time grab samples was lowest at Station 13440, highest at Station 13442, and ranged from 38.3% in August 2000 to >200.0% in June 2000. Range was lowest over the twelve-month period at Station 13026 and greatest at Station 13441 (Table 3). No statistically significant differences existed between the four Oso Bay stations (Table 4).

pH

In Oso Creek, mean pH was lowest at Station 13029, highest at Station 13027, and ranged from 7.5 during various months to 9.9 in February 2000. Range was lowest over the twelve-month period at Station 13029, highest at Station 13027, and values increased from upstream to downstream (Table 3). Statistically significant differences did exist between the four Oso Creek stations (Table 4) and mean pH levels were slightly higher at Oso Creek than Oso Bay stations.

In Oso Bay, mean pH was lowest at Station 13441, highest at Station 13442 (entrance to Corpus Christi Bay), and ranged from 7.3 in January 2000 to 8.5 in November 1999 and June 2000. Range was lowest over the twelve-month period at Station 13026 and greatest at Station 13441 (Table 3) and statistically significant differences existed for pH between the four Oso Bay stations (Table 4).

While pH levels recorded during this study were typical of the area, the high maximum, wide range, and elevated mean values recorded at Station 13027 indicated other influences. The elevated pH and DO levels coincided with the intense algal blooms seen at this location and strongly indicate the increased biological activity occurring during this episode.

Exceedance of Dissolved Oxygen Water Quality Screening Criteria – Grab Samples

The upper four stations (13029, 16712, 13028, and 13027) are within the "unclassified" segment of Oso Creek, which carries a high aquatic life use and a 4.0 mg l^{-1} DO criterion. Based on this criterion the Oso Creek stations remained above 4.0 mg l^{-1} 100.0% of the time sampled. However, intense algal blooms seen at Station 13027 in January and February 2000 raised DO levels above the maximum data reporting value of 20 mg l^{-1} for 16.6% of the time and DO levels remained >10 mg l^{-1} for 75.0% of the time sampling took place at this station. In addition, DO % saturation levels exceeded 100.0% saturation for 0.0%, 50.0%, 66.6%, and 75.0% of the time sampled at stations 13029, 16712, 13028, and 13027, respectively.

Within the "classified" segment of Oso Bay, routinely collected instantaneous grab sample DO data revealed a markedly different picture concerning the designated exceptional aquatic life use and 5.0 mg l^{-1} criterion, with 15 measurements recorded below the criterion. Stations 13026 and 13440 remained below 5.0 mg l^{-1} for 41.6% of the time sampled, while stations 13441 and 13442 remained below the criterion for 33.3% and 8.3% of the time sampled, respectively. DO % saturation levels exceeded 100.0% at stations 13026, 13440, 13441, and 13442 for 16.6%, 25.0%, 33.3%, and 50.0% of the times sampled, respectively.

Routinely collected instantaneous DO measurements recorded were extremely reflective of daily and yearly cycles experienced in this shallow, effluent dominated system. However, based on data obtained, depressed DO levels remain a concern for Oso Bay. Based on water quality standards three stations (13026, 13440, and 13441) do not support the aquatic life criteria. Taken collectively, the aquatic life use is not supported in Oso Bay, as DO levels fell below the criterion 31.3% of the time sampling occurred at all stations.

As stated earlier, warmer temperatures, high salinity, and increased biological activity through the breakdown of natural organic matter from point and non-point sources, all contribute to the depletion of DO. High emphasis remains on the fact that the hydro and geomorphology of this relatively shallow, warm water, high salinity bay exerts a strong influence, and that collectively all these factors produce water quality conditions leading to depressed DO levels such as seen during this study.

TABLE 3. Field data descriptive statistics for October 1999 through September 2000 (= *Lowest value*, = **Highest value**).

Water Temperature (°C)

Area	Station	Minimum	Maximum	Range	Mean
OC	13029	*14.5*	29.7	**14.7**	*22.4*
OC	16712	18.9	30.1	*11.2*	**24.8**
OC	13028	16.5	**30.6**	14.1	24.3
OC	13027	16.7	30.2	13.5	**24.8**
OB	13026	20.4	29.8	*9.5*	25.3
OB	13440	*13.5*	28.1	14.6	*23.2*
OB	13441	15.9	**31.0**	**15.1**	**26.4**
OB	13442	15.7	30.5	14.8	24.1

Conductivity (Fmho/cm)

Area	Station	Minimum	Maximum	Range	Mean
OC	13029	1723	7450	5727	4681
OC	16712	1780	6436	4656	*4453*
OC	13028	2382	6209	*3827*	4614
OC	13027	*1682*	**7736**	**6054**	**5354**
OB	13026	50,451	72,347	21,896	57,426
OB	13440	51,790	**74,805**	23,015	**59,883**
OB	13441	*1991*	50,895	**48,904**	*13,316*
OB	13442	48,780	64,451	*15,671*	54,663

Salinity (ppt)

Area	Station	Minimum	Maximum	Range	Mean
OC	13029	*0.9*	4.1	3.2	2.6
OC	16712	1.0	3.5	2.5	*2.5*
OC	13028	1.3	3.4	*2.1*	*2.5*
OC	13027	*0.9*	**4.3**	**3.4**	**2.9**
OB	13026	33.1	49.5	16.4	38.4
OB	13440	34.3	**51.4**	17.1	**40.2**
OB	13441	*1.1*	33.5	**32.4**	*8.7*
OB	13442	32.0	43.6	*11.6*	36.2

TABLE 3 (continued).

Dissolved Oxygen (mg l^{-1}) Grab Samples

Area	Station	Minimum	Maximum	Range	Mean
OC	13029	*4.1*	8.9	*4.8*	*6.5*
OC	16712	5.2	12.8	7.6	8.5
OC	13028	4.6	14.0	9.4	9.0
OC	13027	4.5	**>20.0**	**15.5**	**11.7**
OB	13026	3.6	8.4	*4.8*	*5.4*
OB	13440	*2.1*	8.4	6.3	*5.4*
OB	13441	3.6	**15.0**	**11.4**	**7.3**
OB	13442	4.1	12.3	8.2	**7.3**

Dissolved Oxygen (% Saturation) Grab Samples

Area	Station	Minimum	Maximum	Range	Mean
OC	13029	*55.2*	91.2	*36.0*	*75.3*
OC	16712	70.0	151.1	81.1	103.8
OC	13028	58.4	178.9	120.4	108.5
OC	13027	60.3	**>200.0**	**139.7**	**135.4**
OB	13026	61.6	115.8	*54.2*	82.1
OB	13440	*38.3*	119.0	80.7	*78.7*
OB	13441	47.8	**>200.0**	**152.2**	95.6
OB	13442	67.5	180.0	112.5	**108.1**

pH (s.u.)

Area	Station	Minimum	Maximum	Range	Mean
OC	13029	*7.5*	8.1	*0.6*	*7.7*
OC	16712	7.7	8.5	0.8	8.0
OC	13028	*7.5*	8.8	1.3	8.1
OC	13027	8.0	**9.9**	**1.9**	**8.8**
OB	13026	7.8	8.3	*0.5*	8.0
OB	13440	7.5	8.3	0.8	8.0
OB	13441	*7.3*	**8.5**	**1.2**	*7.7*
OB	13442	7.8	**8.5**	0.7	**8.1**

TABLE 4. *P*-values for one-way ANOVA comparing Field Data parameters from October 1999 through September 2000 (**Bold** = significant values).

Parameter	4 Oso Creek Stations	4 Oso Bay Stations
Water Temperature (°C)	.536	.270
Dissolved Oxygen (mg l^{-1})	**.002**	.055
Dissolved Oxygen (% Sat)	**.000**	.096
Conductivity (Fmho/cm)	.445	**.000**
Salinity (ppt)	.454	**.000**
pH (s.u.)	**.000**	**.003**

24-hour Dissolved Oxygen Monitoring

Data collected by CBI-DNR at the four fixed platform stations in Oso Bay and the one Upper Laguna Madre reference station (Fig. 5), proved very representative of the typical hydrologic conditions found in shallow depth, warm water, high salinity South Texas estuaries. Radio communication problems, coupled with installation difficulties inherent in establishing this type of data collection platform, yielded several data gaps, but overall the dataset proved useful in documenting DO conditions prevalent in these two shallow water systems. While excessive barnacle and algal growth is often the cause for discarding much of long-term DO data collected, the first 48 and sometimes 72 hours after servicing presented reasonably reliable data from which to make preliminary assessments. However, in keeping with TNRCC guidance, this report only documents the first 24 hours following weekly servicing.

Data analysis clearly reveals depressed DO levels occur at these locations. For measurements taken during both index periods, reference Station 17121 in the Upper Laguna Madre failed to meet the DO criteria of 5.0 mg l^{-1} 52.4% of the time (Fig. 14). Within Oso Bay, Station 17120 (Oso Bay at Yorktown Road) and Station 17119 (Oso Bay at Holly Road Railroad Tracks) produced the greatest number of values below the criteria, each failing to meet the criteria for 60.0% of the time. Station 17118 (Oso Bay at SPID) and Station 13442 (Oso Bay at Ocean Drive) failed to meet the criteria 50.0% and 25% of the time, respectively (Fig. 14). Combining all four Oso Bay stations produces DO measurements that fall below the criteria 38.3% of the time. These low values clearly indicate DO concentrations are often lower than the criterion to provide optimum aquatic life conditions, resulting in a Non-Support classification based on an exceptional habitat designation. For measurements taken over the entire period (index and non-index), while percentages are lower, data still produces Non-Support of the criteria for all stations except Station 13442 (Fig. 15). However, if a reclassification of the segment from exceptional to high aquatic habitat occurred, the resulting reduction in the DO criteria from 5.0 mg l^{-1} to 4.0 mg l^{-1}, would reveal all stations supporting the designation within the index period (Fig. 16) and for measurements taken over the entire period (index and non-index) (Fig. 17).

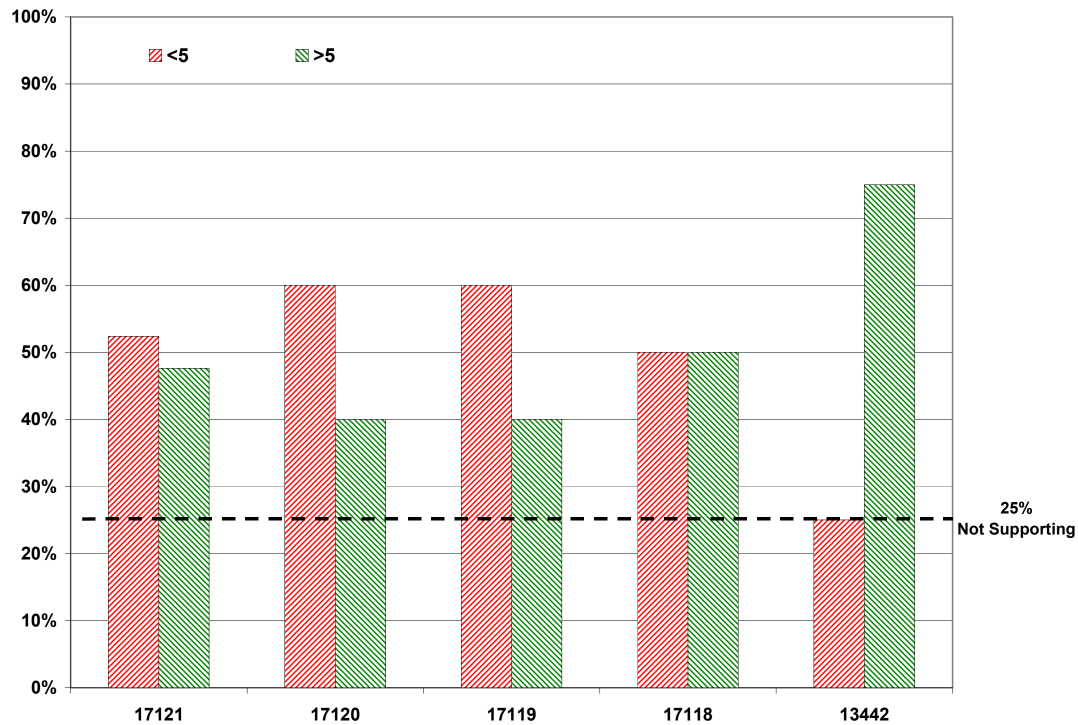

Fig. 14. Percentages that 24-hour mean DO concentrations exceed the 5.0 mg l^{-1} criterion during both index periods, August 2000 through October 2001.

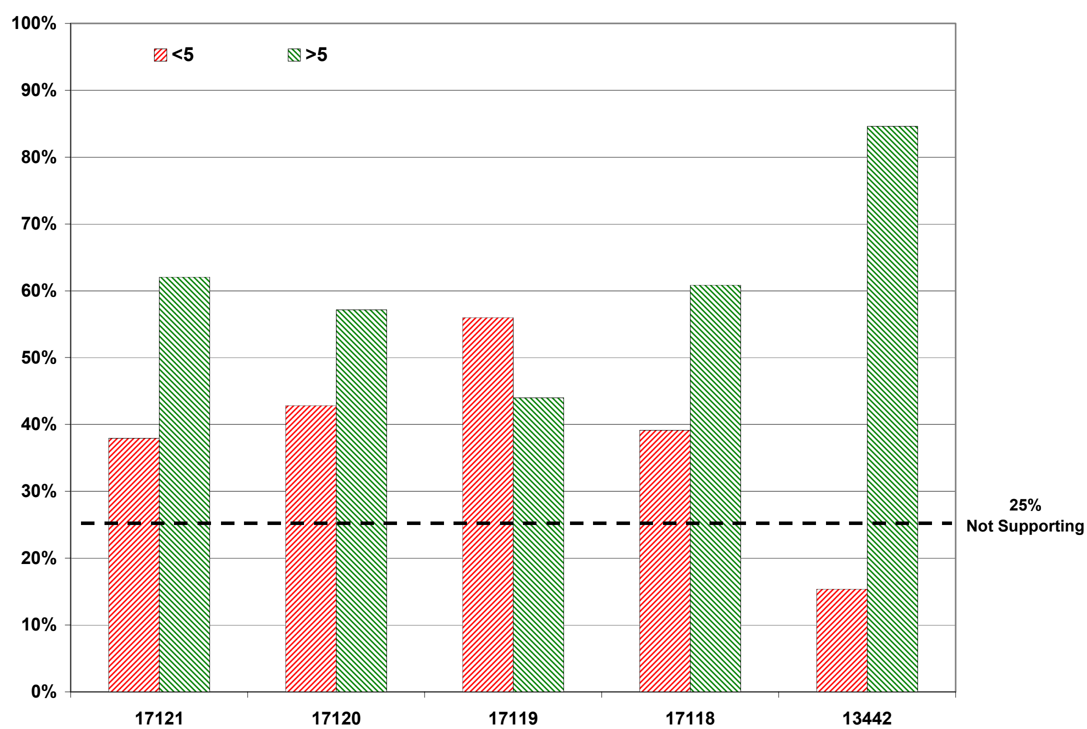

Fig. 15. Percentages that 24-hour mean DO concentrations exceed the 5.0 mg l^{-1} criterion for all values recorded from August 2000 through October 2001.

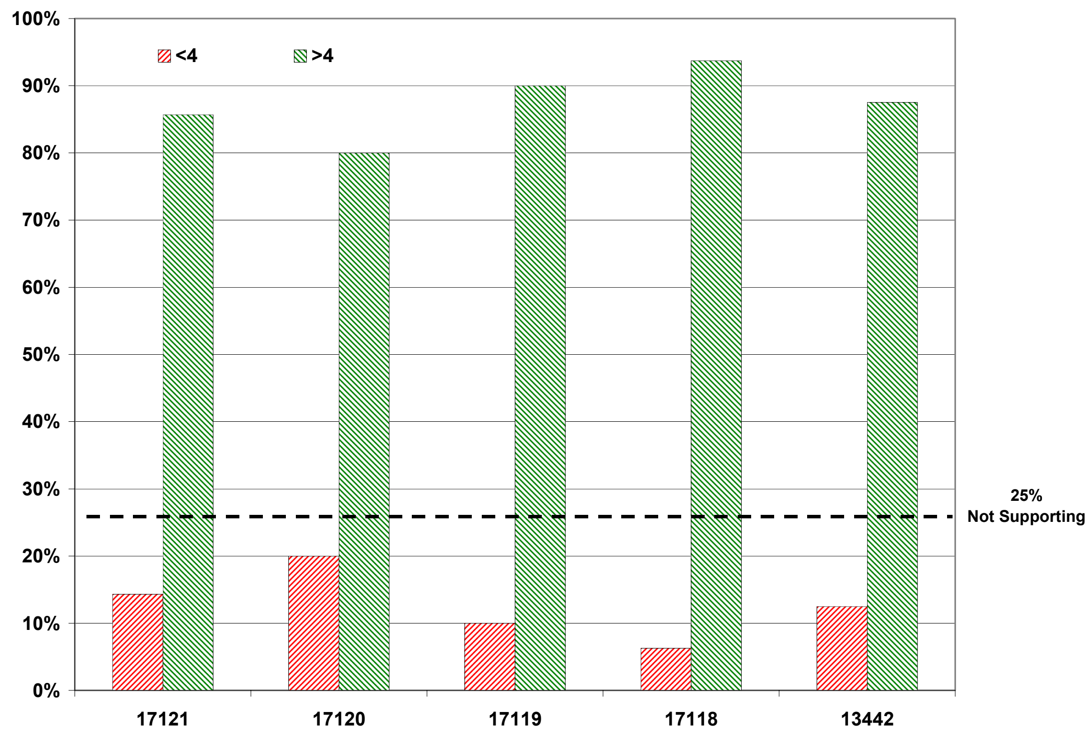

Fig. 16. Percentages that 24-hour mean DO concentrations exceed a 4.0 mg l^{-1} criterion during both index periods, August 2000 through October 2001.

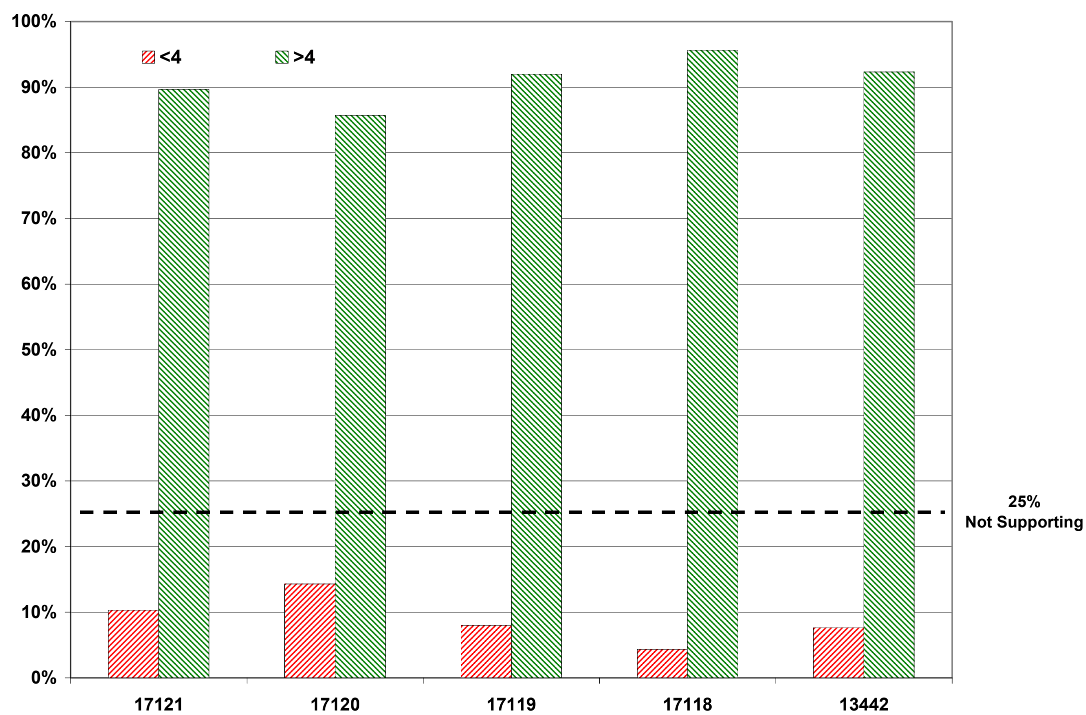

Fig. 17. Percentages that 24-hour mean DO concentrations exceed a 4.0 mg l^{-1} criterion for all values recorded from August 2000 through October 2001.

Water Chemistry

Adoption of Texas Surface Water Quality Standards (TSWQS) allows TNRCC to direct water quality programs that protect, maintain, and restore the state waters of Texas. The quantitative basis for evaluating use support, and management of point and non-point surface water loadings within Texas, are derived from numerical concentrations, or criteria, established in the TSWQS. Utilization of these criteria as maximum or minimum concentrations that may result from permitted discharges, or originate from non-point sources within the receiving stream, allows for detailed assessments. Screening levels established for selected nutrients (ammonia, nitrate + nitrite, total phosphorus, ortho-phosphorus), and chlorophyll *a*, allow the TNRCC to determine concerns for aquatic life within a water body based on percent exceedance derived from long-term SWQM Program data, while bacterial indicators are used for determining concerns for contact recreation and oyster water use. The following discussion centers on those nutrients, with screening levels, and presents an opportunity to aid in those determinations. Additional parameters collected can further serve in assessing the water body through interpretation of the individual constituents analyzed.

Ammonia-Nitrogen (mg l^{-1})

In Oso Creek, mean levels were lowest at Station 13027 (0.06 mg l^{-1}) and highest at Station 16712 (0.18 mg l^{-1}) located below the GWWTP. Monthly values ranged from <0.05 mg l^{-1} to 1.00 mg l^{-1} (Fig. 18). The elevated value of 1.0 mg l^{-1} at Station 16712 in October 1999 exceeded tidal stream screening levels (0.44 mg l^{-1}). Typically, most values recorded were <0.20 mg l^{-1}. Range was lowest at Station 13029 and highest at Station 16712. No statistically significant differences existed between the Oso Creek stations (Table 5).

In Oso Bay, mean levels were lowest at Stations 13026 and 13440 (0.06 mg l^{-1}) and highest at Station 13441 (5.89 mg l^{-1}) located below the OWWTP, with monthly values ranging from <0.05 mg l^{-1} to 12.4 mg l^{-1} (Fig. 19). Station 13441 exceeded estuarine nutrient screening levels (0.12 mg l^{-1}) 100.0% of the time sampled. Range was lowest at Station 13440 and greatest at Station 13441. Ammonia levels were higher in Oso Bay than Oso Creek and statistically significant differences existed between the Oso Bay stations (Table 5) due to high levels recorded at Station 13441.

As a nutrient, ammonia is essential for life, but high levels may harm aquatic organisms. Excessive amounts may produce altered metabolism or increase body pH. Slightly elevated levels may affect hatching success, reduce growth rate, and impair morphological development in fish. Typical transport modes to a surface water body are overland flow following rainfall or irrigation events, direct industry or municipal source discharges, or airborne particulate deposition. Primarily, water quality managers must be concerned with the toxicity of ammonia to aquatic life. Water temperature, pH, DO, carbon dioxide concentrations, toxic compound existence, and prior acclimation to ammonia may directly affect ammonia toxicity (USEPA 1991). Typically, experiments show that a variety of fish species suffers lethal effects when ammonia ranges from 0.2 to 2.0 mg l^{-1} (USEPA 1987). The data collected for this study clearly demonstrates that there are definite concerns for ammonia within portions of western Oso Bay within proximity of the OWWTP.

Ammonia Nitrogen

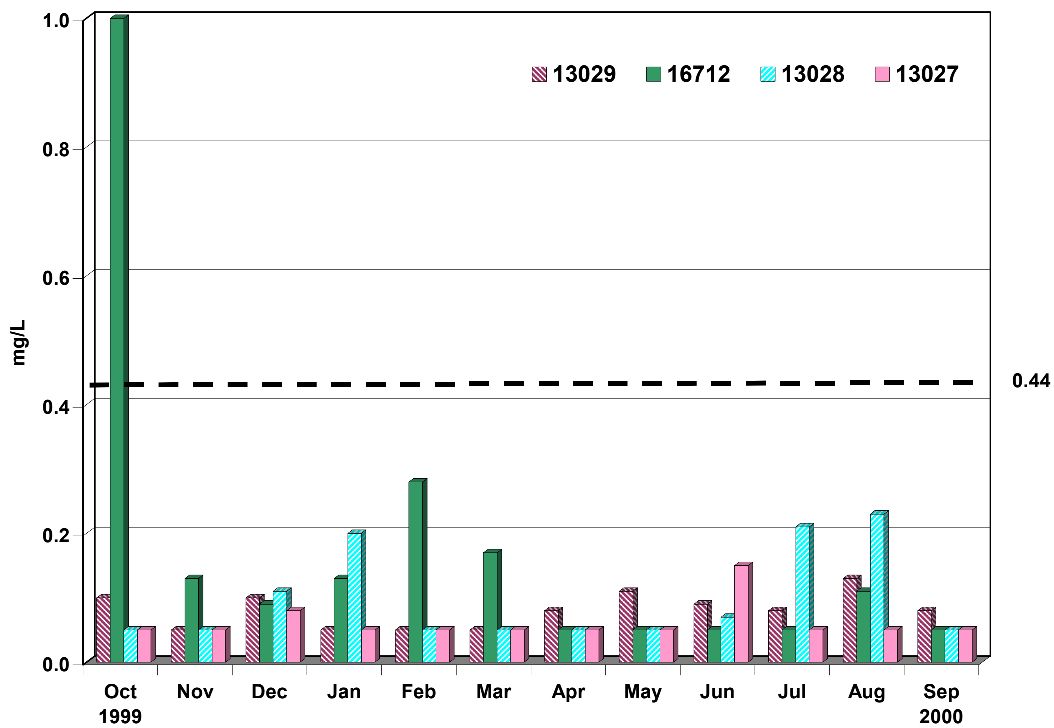

Fig. 18. Comparison of Ammonia Nitrogen concentrations at Oso Creek stations.

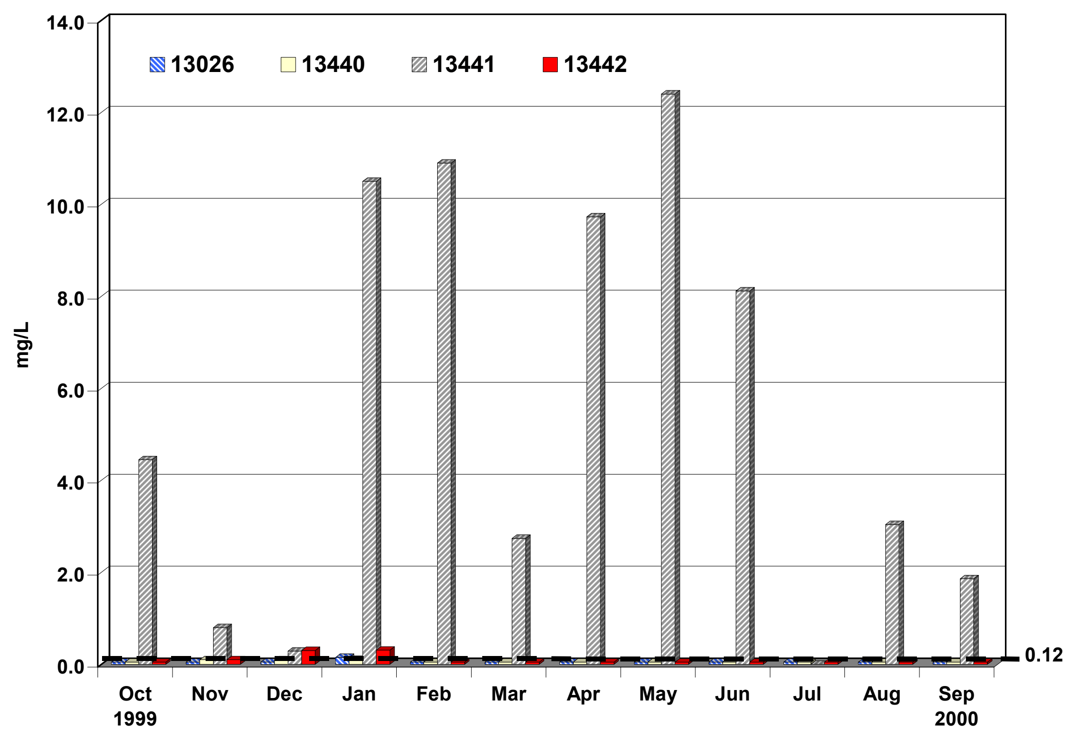

Fig. 19. Comparison of Ammonia Nitrogen concentrations at Oso Bay stations.

TABLE 5. *P*-values for one-way ANOVA comparing water chemistry parameters at Oso Creek and Oso Bay sampling locations from October 1999 through September 2000 (**Bold** = significant values).

Parameter	**4 Oso Creek Stations**	**4 Oso Bay Stations**
Ammonia Nitrogen	.185	**.000**
Nitrate & Nitrite, Nitrogen	.083	**.000**
Total Kjeldahl Nitrogen	**.000**	**.000**
Total Organic Carbon	**.000**	**.000**
Total Phosphorus	**.000**	**.000**
Ortho-Phosphate	**.000**	.812
Chlorophyll *a*	**.001**	.234
Pheophytin *a*	.117	.630
Chloride	.149	**.000**
Sulfate	.204	**.000**
Total Alkalinity	**.000**	.200
Total Dissolved Solids	.092	**.000**
Total Suspended Solids	**.005**	.708
Volatile Suspended Solids	**.000**	.690

Nitrate + Nitrite, Nitrogen (mg l^{-1})

In Oso Creek, mean nitrate + nitrite levels were lowest at Station 13027 (2.71 mg l^{-1}), highest at Station 16712 (7.85 mg l^{-1}) below the GWWTP, and values ranged from <0.05 mg l^{-1} to 17.5 mg l^{-1} (Fig. 20). All stations in Oso Creek exceeded tidal stream nutrient screening levels (2.34 mg l^{-1}) from 25% to 83.3% of the times sampled. Over the study period, 50% of values were >4.0 mg l^{-1} and 27.0% were >8.0 mg l^{-1}. Range was lowest at Station 13029 and highest at Station 16712. No statistically significant differences existed between the four Oso Creek stations (Table 5). Mean levels were noticeably higher in Oso Creek compared to Oso Bay stations. "Flagged" data points in May and October represent samples that exceeded holding times due to instrument failure but were re-analyzed in an attempt to provide data.

In Oso Bay, mean nitrate + nitrite levels were low at Stations 13026 and 13440 (0.22 mg l^{-1}), and highest at Station 13441 (1.59 mg l^{-1}) located below the OWWTP with values ranging from <0.05 mg l^{-1} 3.75 mg l^{-1} (Fig. 21). Stations 13026, 13440, and 13442 reported many values just below the estuarine nutrient screening level (0.26 mg l^{-1}) while Station 13441 exceeded the levels 75.5% of the time sampled. Range was lowest over the study at Stations 13026 and 13440 and greatest at Station 13441. Statistically significant differences existed between the four Oso Bay stations due to the extremely high levels recorded at Station 13441 (Table 5).

Extremely high nitrate + nitrite levels are definitely a concern in Oso Creek and at Station 13441 in Oso Bay within proximity of the OWWTP. Ammonia entering aquatic systems is readily converted to nitrate + nitrite in the nitrification process by bacterial oxidation, and then subsequently assimilated by algae or other aquatic plants. A clear demonstration of this process occurred at Station 13027 (Fig. 20). Increasing levels of nitrate + nitrite for that station reached a maximum in December 1999 before falling in January and February during the event of the two algal blooms observed at this location by CCS field personnel. Low levels persisted and were nonexistent by summer as aquatic plants assimilated this resource.

A primary limiting nutrient in estuarine systems, nitrogen levels control rates of primary production, with high input levels often producing significant increases in phytoplankton and macrophyte production. A picture of this exists in recent aerial photographs of the area surrounding Station 13441 clearly showing the presence of a large vegetative mat that was not there the previous year. As the discharge from the OWWTP has been occurring for many years, this constant source of freshwater may not be the only source available to sustain this algal growth. Some limits suggested for avoiding algal blooms and for maintaining designated aquatic life uses in estuaries range between 0.1 mg l^{-1} for maximum diversity to 1.0 mg l^{-1} for moderate diversity (NOAA/EPA 1988; AWWA 1990).

These increased inputs of nitrogen further cause depressed DO concentrations within this system as increases in aquatic vegetation result in increased plant respiration at night. In addition, dead macrophyte and phytoplankton serve to stimulate decomposer organisms and microbial breakdown of organic matter requiring oxygen. Additional problems result in the aesthetic interpretation of the water body as decaying algal mats and other vegetation can produce noxious odors and discoloration of the water. While these processes also occur regularly in nature, data highly suggests an anthropogenic influence.

Nitrate + Nitrite Nitrogen

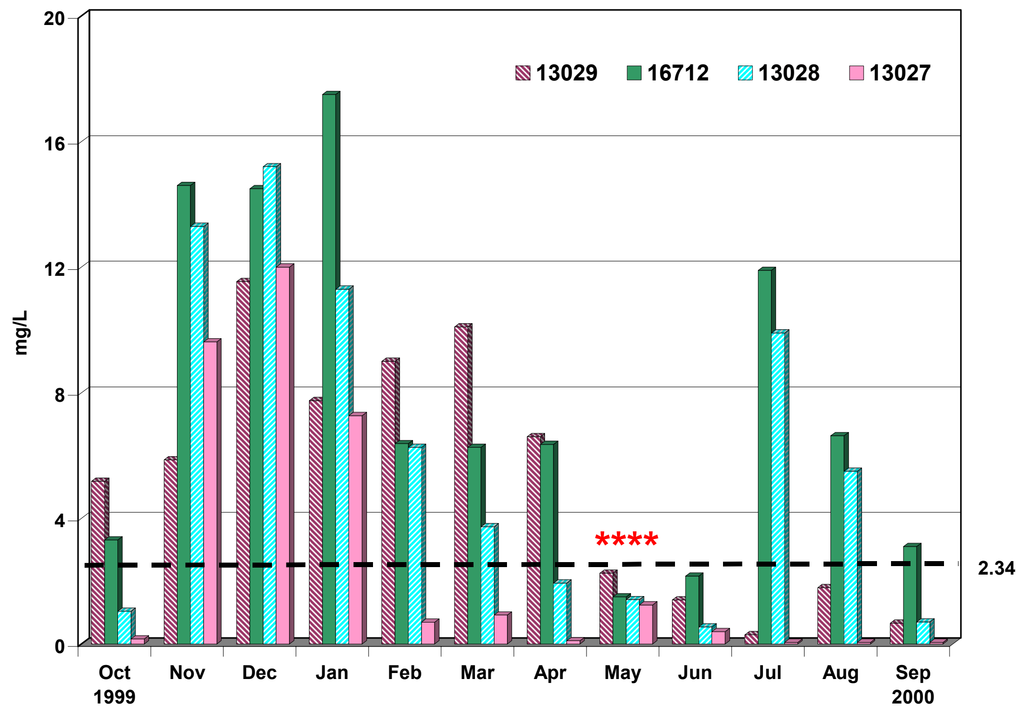

Fig. 20. Comparison of Nitrate + Nitrite Nitrogen concentrations at Oso Creek stations (* = Flagged data point).

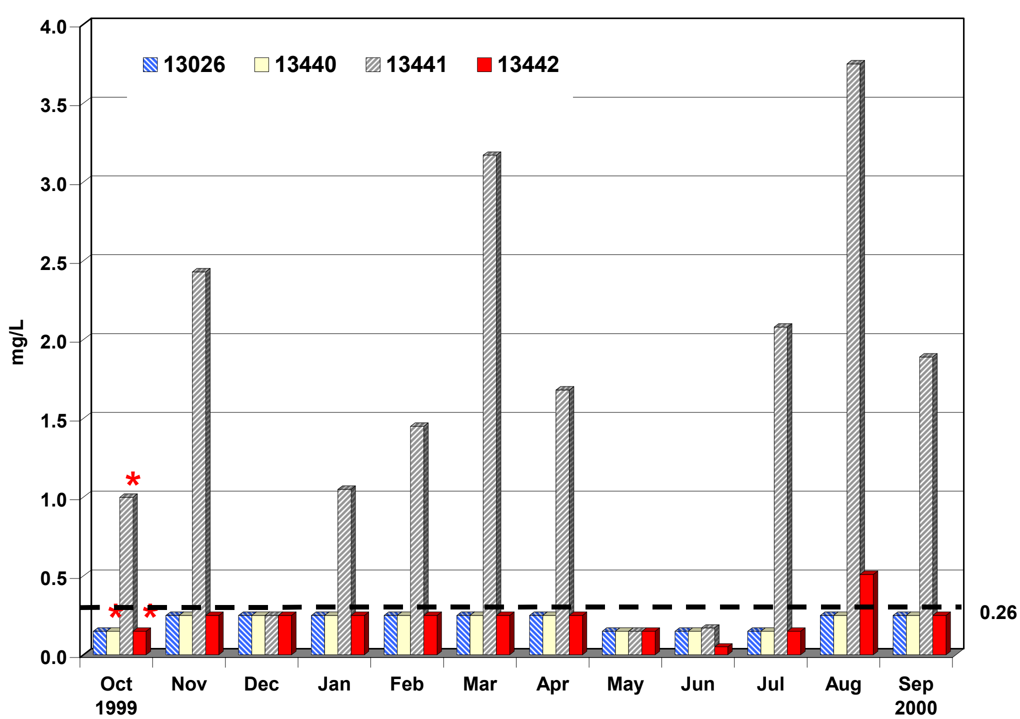

Fig. 21. Comparison of Nitrate + Nitrite Nitrogen concentrations at Oso Bay stations (* = Flagged data point).

Total Phosphorus (mg l^{-1})

In Oso Creek, mean levels were lowest at Station 13027 (0.63 mg l^{-1}), highest at Station 13029 (1.62 mg l^{-1}), and monthly values ranged from 0.20 mg l^{-1} to 2.50 mg l^{-1} (Fig. 22). Highest levels tended to occur at Station 13029, exceeding the tidal stream screening level of (1.10 mg l^{-1}) 91.6% of the times sampled. The remaining three stations exceeded screening levels from 16.6% to 50% of the times sampled. Lowest ranges occurred at Station 13027, highest at Station 16712, and statistically significant differences existed between the four Oso Creek stations (Table 5). Mean phosphorus levels were routinely higher in Oso Creek.

In Oso Bay, mean levels were lowest at Station 13442 (0.11 mg l^{-1}) and highest at Station 13441 (0.63 mg l^{-1}). Generally, higher levels occurred at Station 13441; exceeding estuarine screening levels (0.23 mg l^{-1}) 83.3% of the times sampled. Monthly values ranged from <0.01 mg l^{-1} to 1.04 mg l^{-1} (Fig. 23). Range was lowest over the twelve-month period at Station 13026 and greatest at Station 13441. Statistically significant differences existed between the four Oso Bay stations (Table 5).

Ortho-Phosphate (mg l^{-1})

A significant amount of data remains questionable for Oso Bay stations due to high chloride interference encountered during analysis. TNRCC laboratory personnel indicated this is a common problem when dealing with samples from high saline waters. Values often reported as <0.30 mg l^{-1} register above the estuarine screening level of 0.18 mg l^{-1} making total phosphorus a better indicator of phosphorus levels within Oso Bay.

In Oso Creek, mean levels were lowest at Station 13027 (0.24 mg l^{-1}), highest at Station 13029 (1.34 mg l^{-1}), and values ranged from <0.06 mg l^{-1} to 2.16 mg l^{-1} (Fig. 24). Highest levels typically occurred at Station 13029; exceeding screening levels (0.90 mg l^{-1}) 75.0% of the times sampled. Station 16712 exceeded screening levels 50.0% of the times sampled. Range was lowest at Station 13027, highest at Station 13029, and statistically significant differences existed between the four Oso Creek stations (Table 5). Mean levels were higher in Oso Creek stations than Oso Bay. “Flagged” data points for May represent samples which exceeded holding times due to instrument failure but were re-analyzed in an attempt to provide data. In Oso Bay, mean levels were lowest at Station 13441 (0.24 mg l^{-1}) and equally high at the other stations (0.26 mg l^{-1}). Monthly values typically exceeded estuarine screening levels (0.18 mg l^{-1}) but questions remain as to the validity of this data. Monthly values ranged from <0.12 mg l^{-1} 0.34 mg l^{-1} (Fig. 25). Range was greatest at Station 13441 below OWWTP. No statistically significant differences existed between stations (Table 5).

Phosphorus inputs to freshwater and estuarine systems come from either agricultural and/or urban-residential runoff, and from treatment or lack of sewage treatment. Analysis shows concerns for phosphorus in both Oso Creek and Oso Bay as several of these influences possibly exist within this system. As with nitrogen, phosphorus stimulates macrophyte and phytoplankton growth. Typically, phosphorus is a limiting nutrient in freshwater systems but may become limited in estuarine systems where nitrogen concentrations are elevated and N:P>16:1 (Jawaorski 1981). Recommended levels of phosphorus to avoid algal blooms is 0.01 mg l^{-1} to 0.1 mg l^{-1} or a 10:1 N:P ratio (NOAA/EPA 1988). Earlier comments, concerning deleterious effects stated for nitrogen, apply equally to phosphorus.

Total Phosphorus

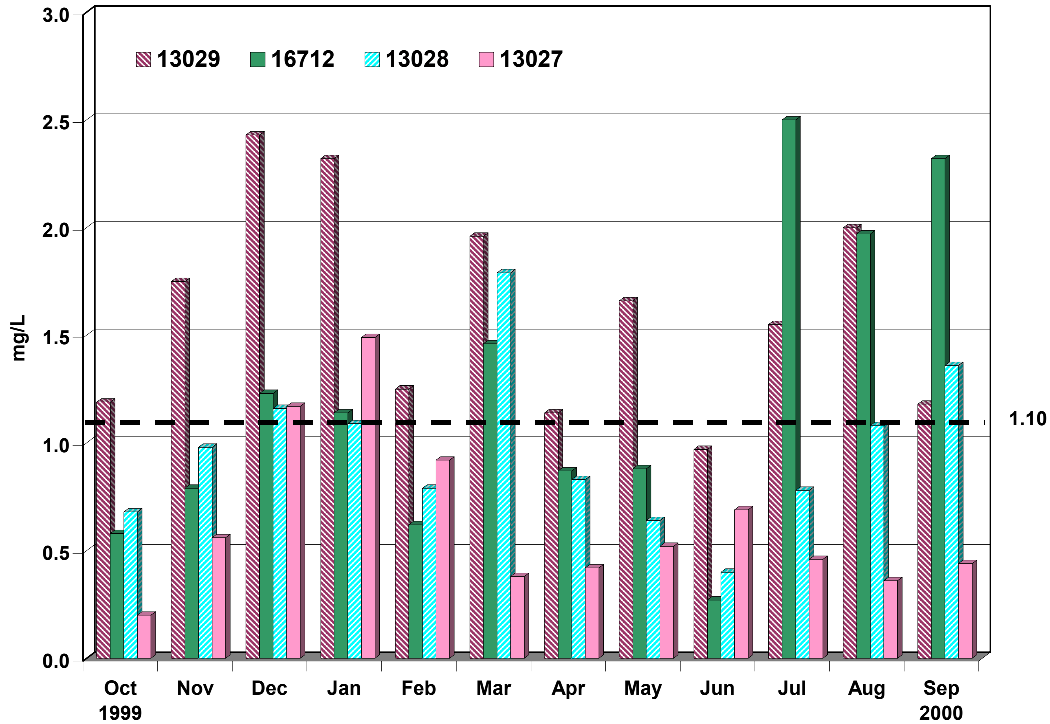

Fig. 22. Comparison of Total Phosphorus concentrations at Oso Creek stations.

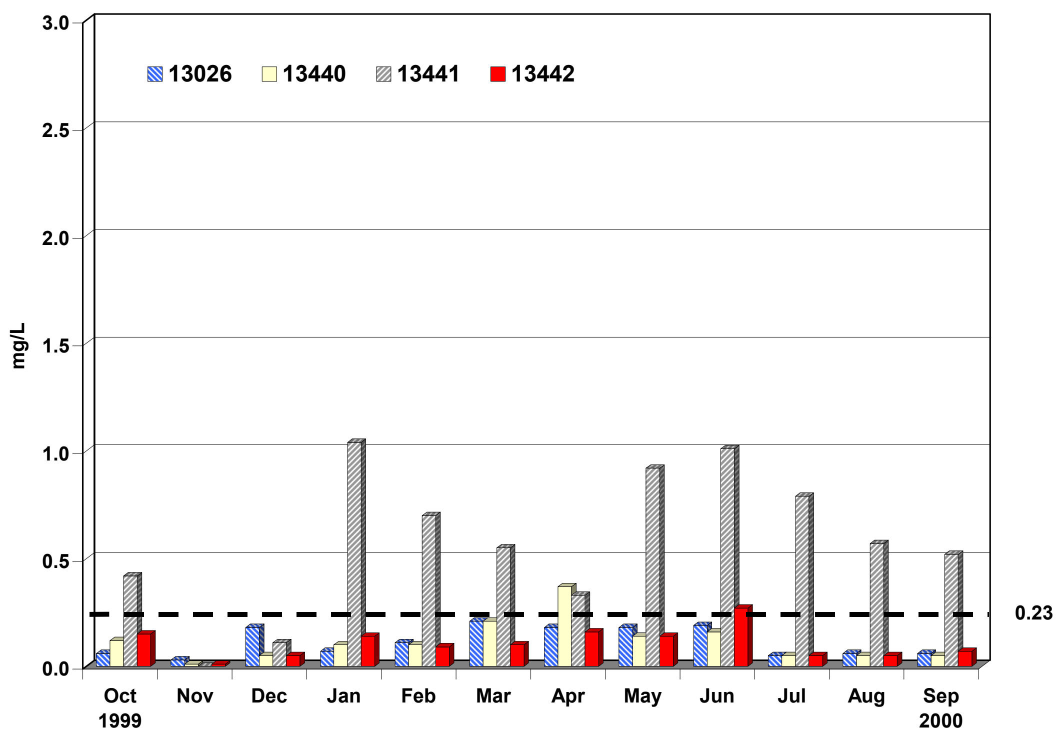

Fig. 23. Comparison of Total Phosphorus concentrations at Oso Bay stations

Ortho-Phosphate

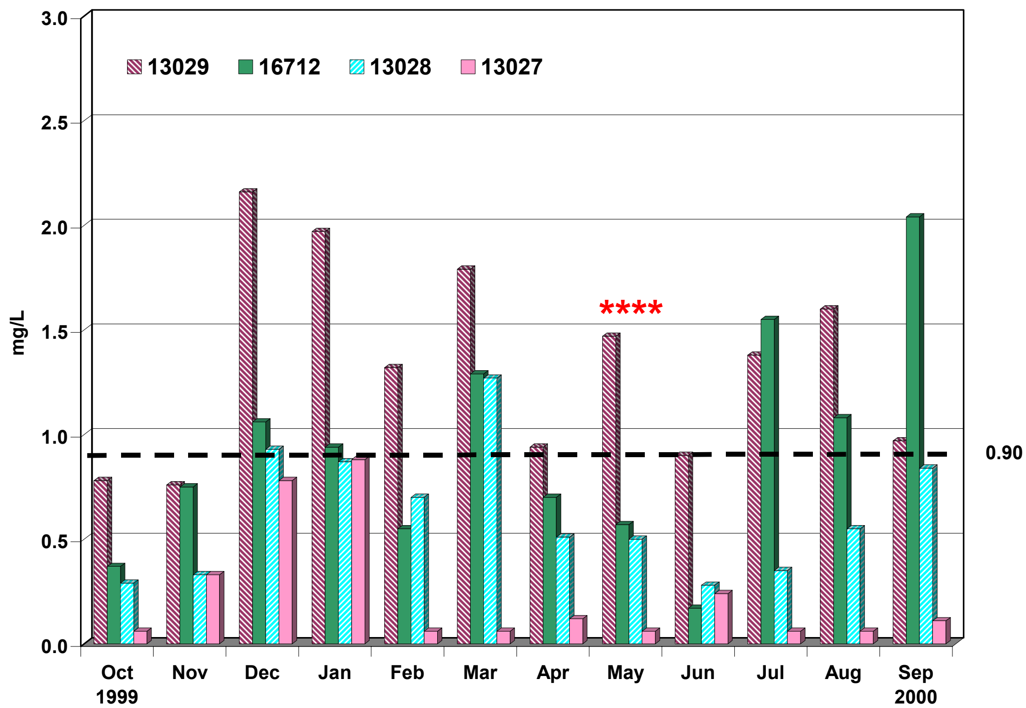

Fig. 24. Comparison of Ortho-Phosphate concentrations at Oso Creek stations (* = Flagged data point).

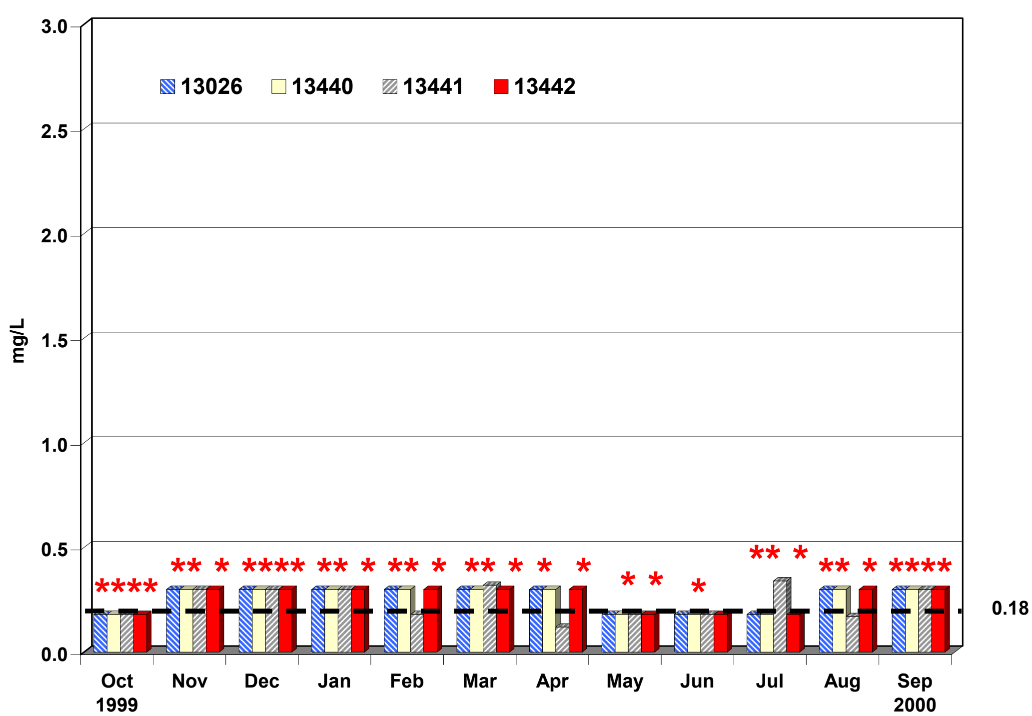

Fig. 25. Comparison of Ortho-Phosphate concentrations at Oso Bay stations (* = Flagged data point).

Chlorophyll a (Fg l^{-1})

In Oso Creek, mean chlorophyll *a* levels were lowest at Station 13029 (4.83 Fg l^{-1}), highest at Station 13027 (76.62 Fg l^{-1}), and monthly values ranged from <1.00 Fg l^{-1} to 305.00 Fg l^{-1} (Fig. 26). Typically, levels increased from upstream to downstream stations within the segment. Stations 16712, 13028, and 13027 exceeded the chlorophyll *a* tidal stream screening levels (23.0 Fg l^{-1}) 33.3%, 50.0% and 83.3% of the times sampled, respectively. Range was lowest over the twelve-month period at Station 13029, highest at Station 13027, and statistically significant differences existed between the four Oso Creek stations (Table 5). Mean levels were higher at Oso Creek than Oso Bay stations.

In Oso Bay, mean chlorophyll *a* levels were lowest at Station 13440 (2.17 Fg l^{-1}) and highest at Station 13441 (13.22 Fg l^{-1}) below the OWWTP. Station 13441 exceeded chlorophyll *a* estuarine screening levels (14.6 Fg l^{-1}) 25.0% of the times sampled and monthly values ranged from <1.00 Fg l^{-1} to 92.50 Fg l^{-1} (Fig. 27). Range was lowest over the twelve-month period at Station 13440 and greatest at Station 13441. No statistically significant differences existed between the four Oso Bay stations (Table 5).

Analysis of chlorophyll *a* data reinforces the nutrient data previously discussed. Exceedance of screening levels within Oso Creek and primarily at Station 13441 in Oso Bay point to increased phytoplankton biomass (see Station 13027 in Fig. 20) within the water column directly related to increased nutrient loading. All the inputs mentioned have far reaching effects on DO levels and the habitat quality of the water body as a whole.

Pheophytin a (Fg l^{-1})

In Oso Creek, mean pheophytin *a* levels were lowest at Station 13029 (5.17 Fg l^{-1}), highest at Station 13027 (20.12 Fg l^{-1}), and monthly values ranged from <1.00 Fg l^{-1} to 84.80 Fg l^{-1} (Fig. 28). Highest levels tended to occur at Stations 13028 and 13027. Range was lowest over the twelve-month period at Station 13029 and highest at Station 13027. No statistically significant differences existed between the four Oso Creek stations (Table 5) and mean levels recorded were higher in Oso Creek than Oso Bay sampling locations.

In Oso Bay, mean pheophytin *a* levels were lowest at Station 13442 (4.26 Fg l^{-1}) and highest at Station 13440 (11.01 Fg l^{-1}). Monthly values ranged from <1.00 Fg l^{-1} to 59.60 Fg l^{-1} (Fig. 29). Range was lowest over the twelve-month period at Station 13442 and greatest at Station 13440. No statistically significant differences existed between the four Oso Bay stations (Table 5).

Chlorophyll *a*

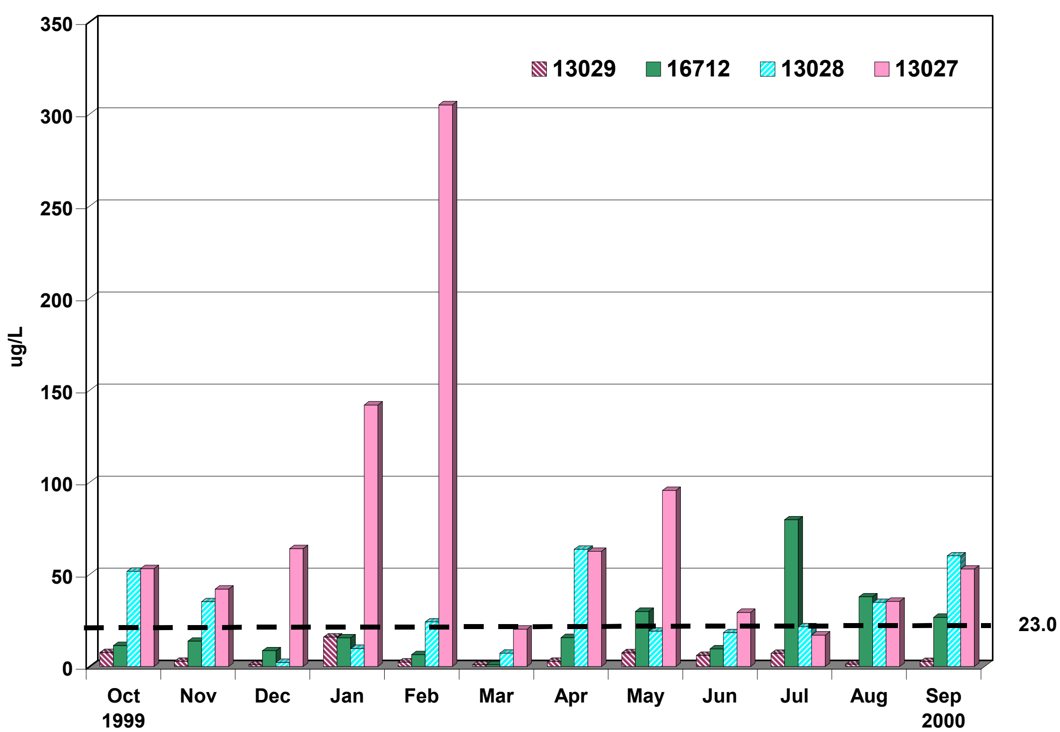

Fig. 26. Comparison of Chlorophyll *a* concentrations at Oso Creek stations.

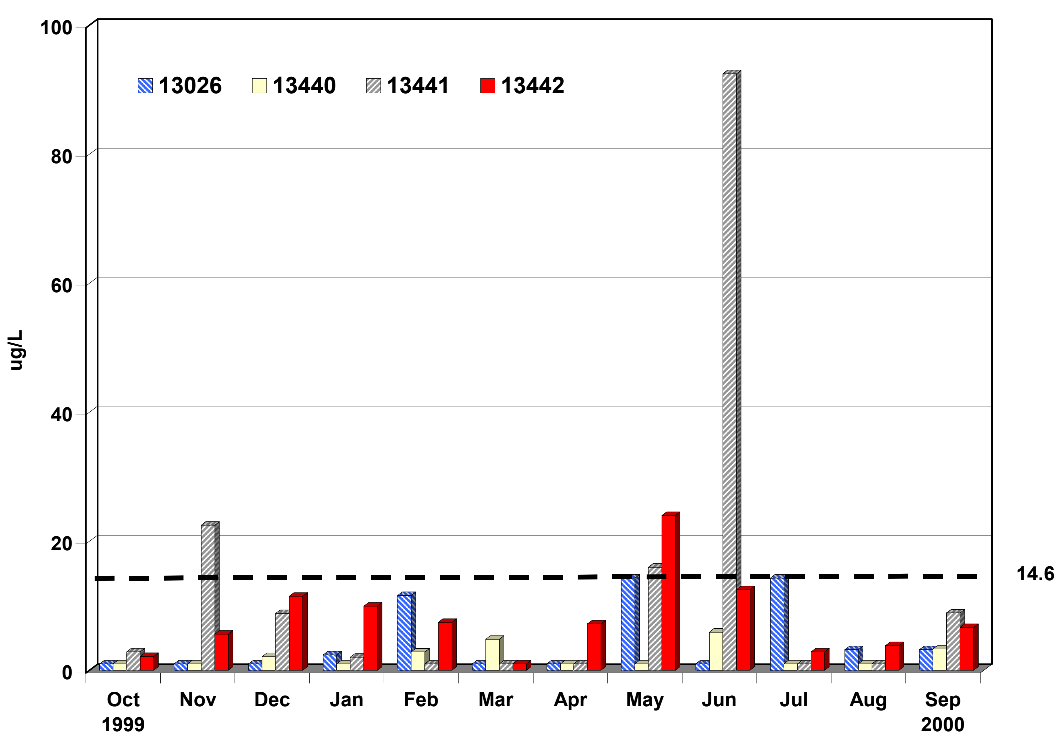

Fig. 27. Comparison of Chlorophyll *a* concentrations at Oso Bay stations.

Pheophytin *a*

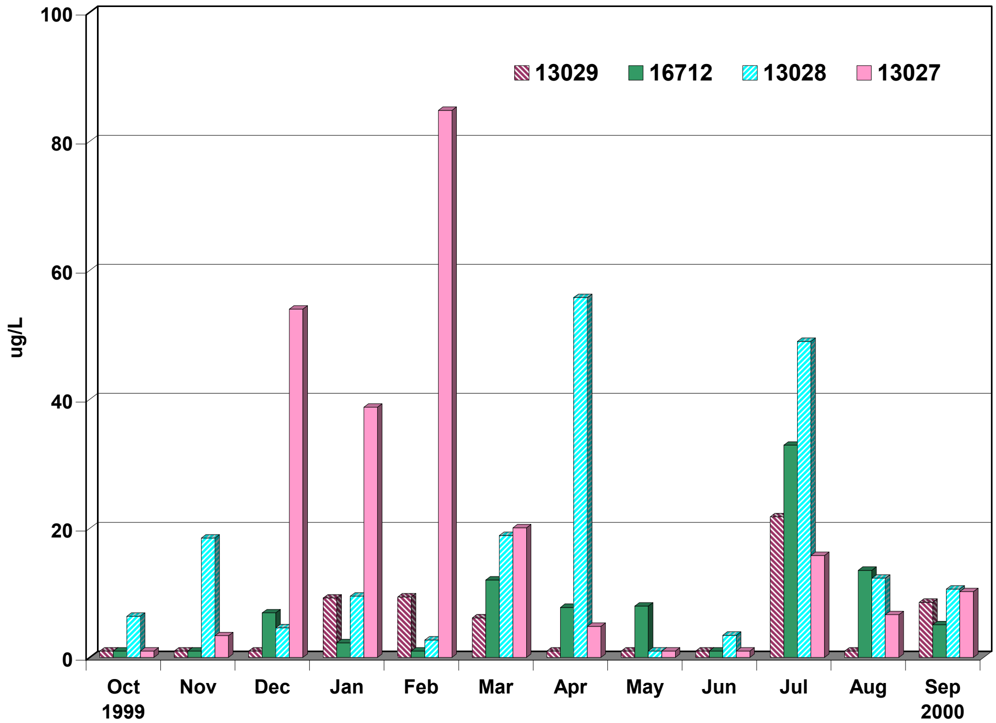

Fig. 28. Comparison of Pheophytin *a* concentrations at Oso Creek stations.

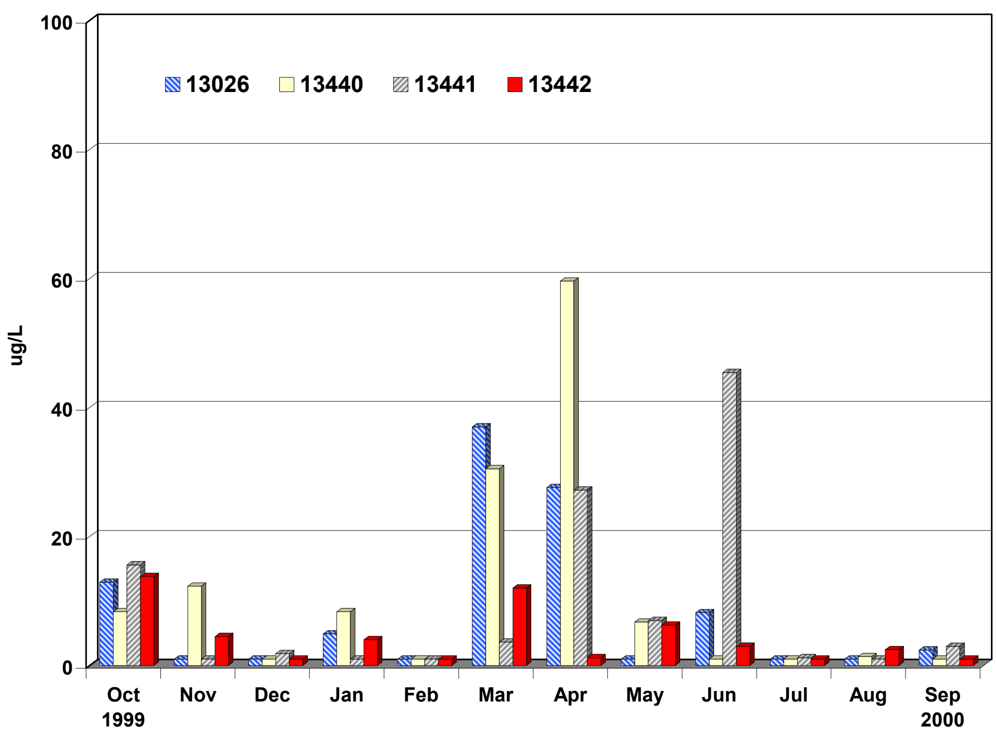

Fig. 29. Comparison of Pheophytin *a* concentrations at Oso Bay stations.

Total Kjeldahl Nitrogen (mg l^{-1})

In Oso Creek, mean TKN levels were lowest at Station 13029 (1.19 mg l^{-1}), highest at Station 13027 (2.67 mg l^{-1}), and monthly values ranged from 0.14 mg l^{-1} to 5.47 mg l^{-1} (Fig. 30). Levels were higher at Station 13027 for all but the August 2000 sampling event. Range was lowest over the study at Station 16712 and highest at Station 13027 and statistically significant differences existed between the four Oso Creek stations (Table 5). “Flagged” data points for October, January, and April represent samples that exceeded holding times, due to instrument failure, but were re-analyzed in an attempt to provide data. In Oso Bay, mean TKN levels were lowest at Station 13442 (1.40 mg l^{-1}), and highest at Station 13441 (7.98 mg l^{-1}) below the OWWTP. Higher levels occurred at Station 13441 for 11 of the 12 months. Monthly values ranged from 0.82 mg l^{-1} 13.70 mg l^{-1} (Fig. 31). Range was lowest over the twelve-month period at Station 13442 and greatest at Station 13441. Statistically significant differences existed between the four Oso Bay stations (Table 5) and TKN levels tended to be higher at Oso Bay than Oso Creek stations.

Total Organic Carbon (mg l^{-1})

In Oso Creek, mean TOC levels were lowest at Station 16712 (9.17 mg l^{-1}), highest at Station 13027 (14.33 mg l^{-1}), and monthly values recorded ranged from 7.00 mg l^{-1} to 20.00 mg l^{-1} (Fig. 32). Highest levels occurred at Station 13027 for all but two sampling events. Range was lowest over the study at Station 16712 and highest at Station 13027 and statistically significant differences existed between the four Oso Creek stations (Table 5). Mean TOC levels were higher in Oso Creek than Oso Bay. In Oso Bay, mean TOC levels were lowest at Station 13442 (3.42 mg l^{-1}) and highest at Station 13441 (10.08 mg l^{-1}). Higher levels occurred at Station 13441 for nine of the twelve months sampling took place. Monthly TOC values ranged from <1.00 mg l^{-1} to 18.00 mg l^{-1} (Fig. 33). Range was lowest over the twelve-month period at Station 13442 and greatest at Station 13441. Statistically significant differences existed between the four Oso Bay stations (Table 5).

Chloride (mg l^{-1})

In Oso Creek, mean chloride levels were lowest at Station 16712 (1093 mg l^{-1}), highest at Station 13027 (1519 mg l^{-1}), and monthly values ranged from 374 mg l^{-1} to 2300 mg l^{-1} (Fig. 34). Typically, the inputs from the GWWTP, located above Station 16712, diluted the higher levels from upstream station 13029, but levels steadily rose at the two downstream stations (13028 and 13027). Range was lowest over the twelve-month period at Station 13028 and highest at Station 13029. No statistically significant differences existed between the four Oso Creek stations (Table 5). Within Oso Bay, lowest mean chloride levels occurred at Station 13441 (5679 mg l^{-1}) due to the inputs from the OWWTP and highest levels occurred at Station 13440 (23,825 mg l^{-1}). Individual monthly values ranged from 409 mg l^{-1} to 31,200 mg l^{-1} (Fig. 35). Range was lowest over the twelve-month period at Station 13442 and greatest at Station 13441 and statistically significant differences existed between the four Oso Bay stations (Table 5). Mean levels were understandably higher in the estuarine waters of Oso Bay.

Total Kjeldahl Nitrogen

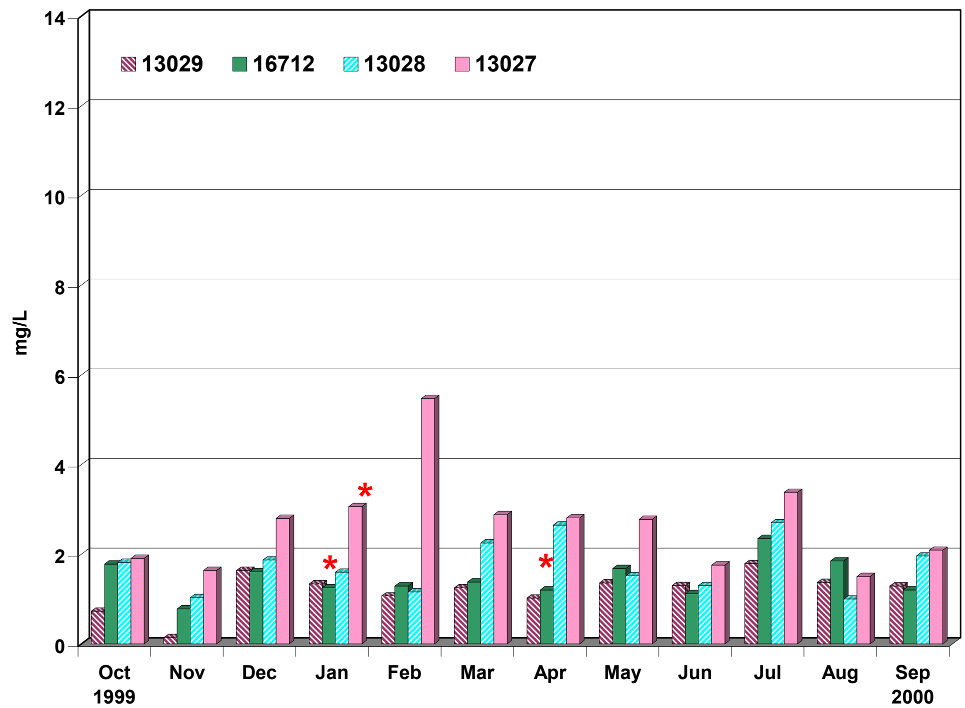

Fig. 30. Comparison of Total Kjeldahl Nitrogen concentrations at Oso Creek stations (* = Flagged data point).

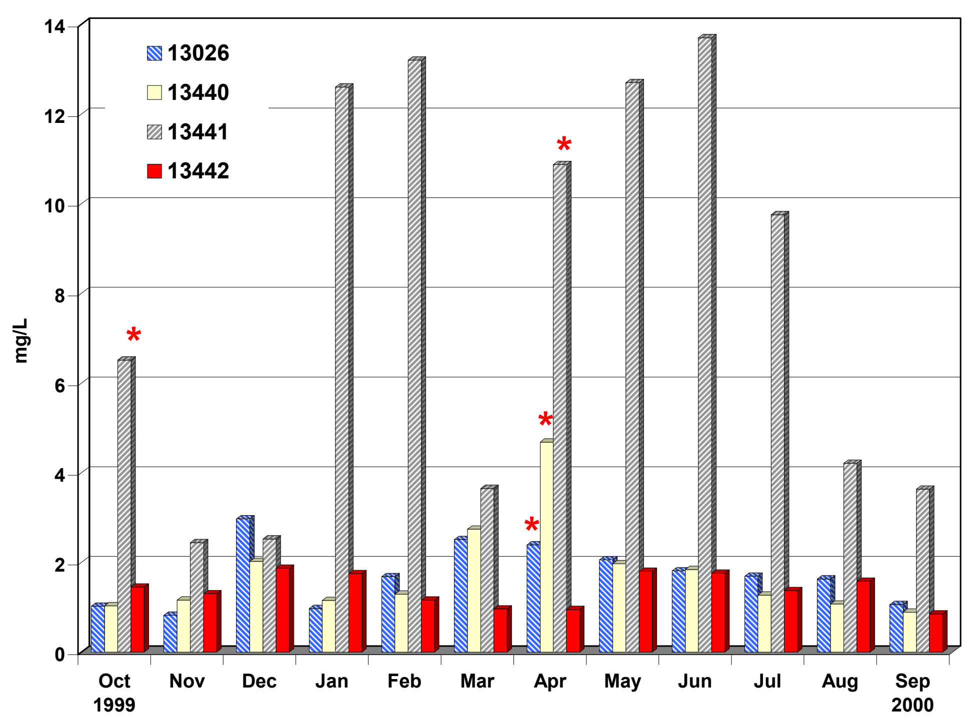

Fig. 31. Comparison of Total Kjeldahl Nitrogen concentrations at Oso Bay stations (* = Flagged data point).

Total Organic Carbon

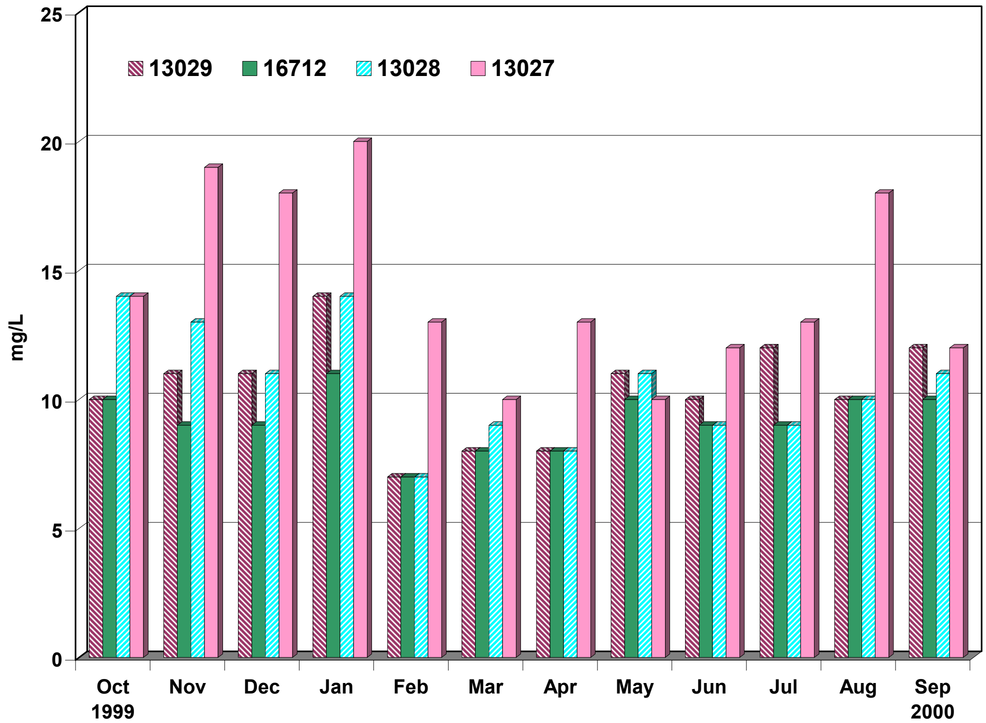

Fig. 32. Comparison of Total Organic Carbon concentrations at Oso Creek stations.

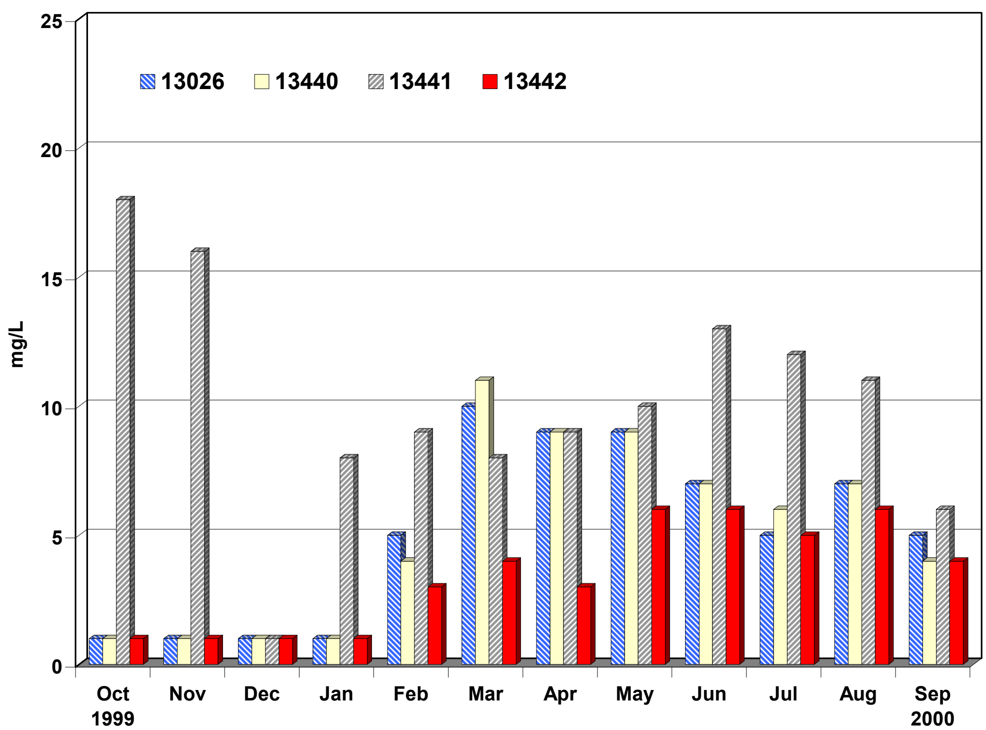

Fig. 33. Comparison of Total Organic Carbon concentrations at Oso Bay stations.

Chloride

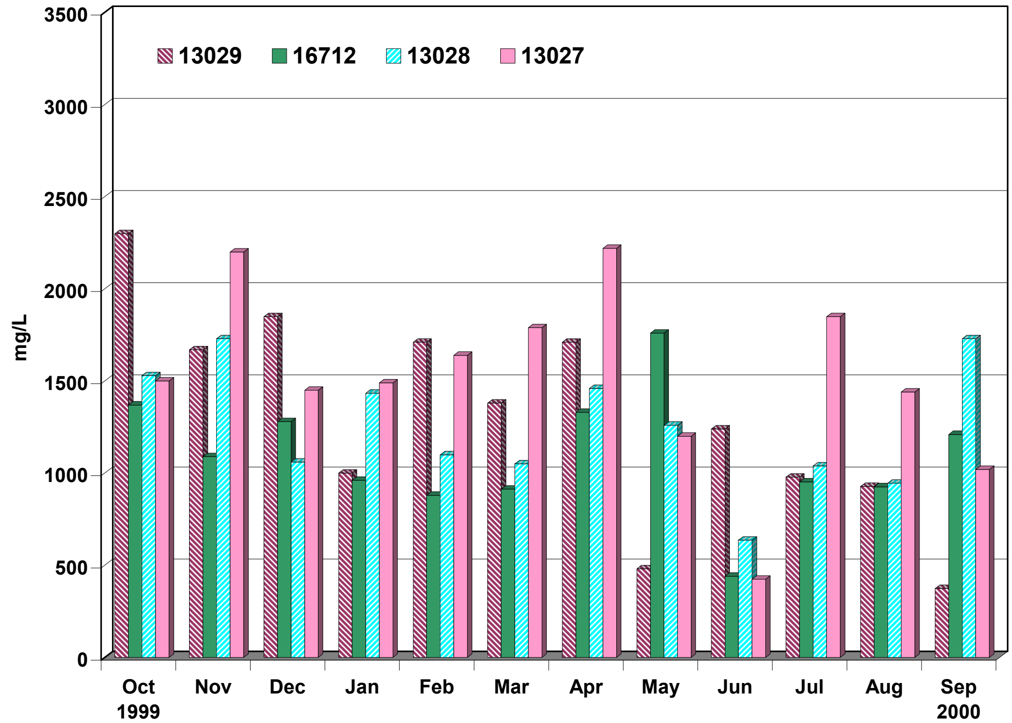

Fig. 34. Comparison of Chloride concentrations at Oso Creek stations.

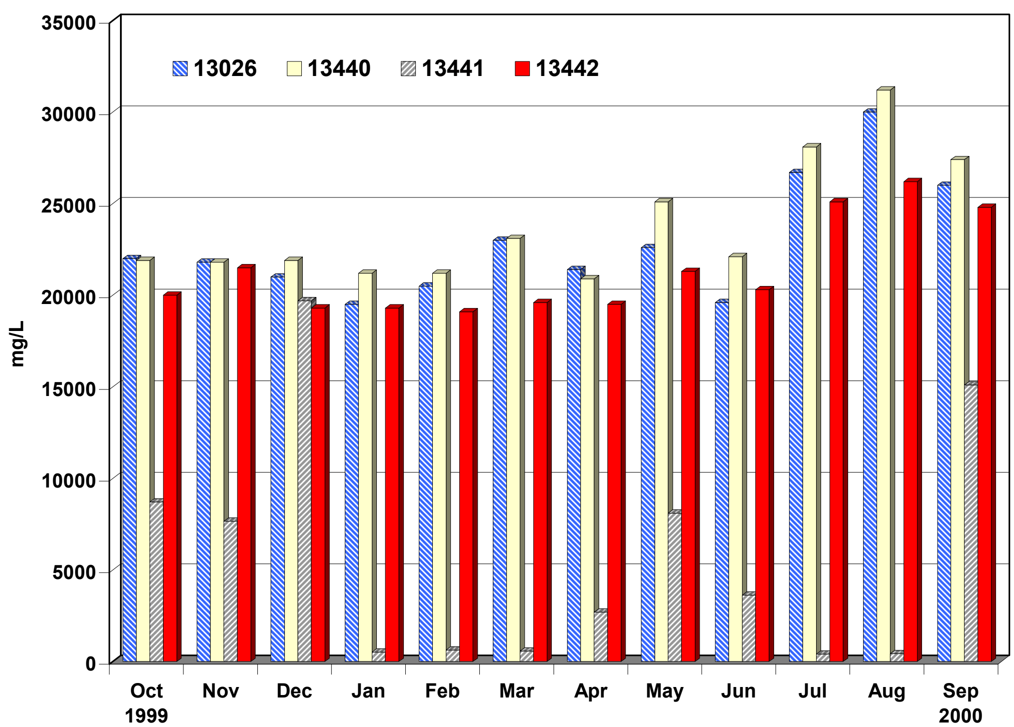

Fig. 35. Comparison of Chloride concentrations at Oso Bay stations.

Sulfate (mg l^{-1})

In Oso Creek, mean sulfate levels were lowest at Station 16712 (251 mg l^{-1}), highest at Station 13027 (321 mg l^{-1}), and monthly values recorded ranged from 84 mg l^{-1} to 473 mg l^{-1} (Fig. 36). As seen with chlorides, inputs from the GWWTP above Station 16712 often diluted the higher sulfate levels from upstream Station 13029, with levels then increasing along the downstream gradient to Stations 13028 and 13027. Range was lowest over the twelve-month period at Station 16712 and highest at Station 13027. No statistically significant differences existed between the four Oso Creek stations (Table 5). In Oso Bay, mean sulfate levels were lowest at Station 13441 (868 mg l^{-1}) due to the inputs from the OWWTP and highest at Station 13440 (3207 mg l^{-1}). Monthly values recorded ranged from 161 mg l^{-1} to 4370 mg l^{-1} (Fig. 37). Range was lowest over the twelve-month period at Station 13442 and highest at Station 13441 and statistically significant differences existed between the four Oso Bay stations (Table 5). As with chlorides, mean sulfate levels were higher in the more saline estuarine waters of Oso Bay.

Total Alkalinity (mg l^{-1})

In Oso Creek, mean total alkalinity levels were lowest at Station 13027 (123 mg l^{-1}), highest at Station 13029 (184 mg l^{-1}), and monthly values ranged from 80.0 mg l^{-1} to 259.0 mg l^{-1} (Fig. 38). Range was lowest over the twelve-month period at Station 16712 and highest at Station 13029 and statistically significant differences existed between the four Oso Creek stations (Table 5). In Oso Bay, mean total alkalinity levels were lowest at Station 13442 (150 mg l^{-1}) and highest at Station 13441 (167 mg l^{-1}). Monthly values recorded ranged from 128.0 mg l^{-1} to 211.0 mg l^{-1} (Fig. 39). Range was lowest over the twelve-month period at Station 13442 and greatest at Station 13440. No statistically significant differences existed between the four Oso Bay stations (Table 5). Comparison of the two segments showed mean levels to be approximately equal.

Total Dissolved Solids (mg l^{-1})

In Oso Creek, mean TDS values were lowest at Station 16712 (2576 mg l^{-1}), highest at Station 13027 (3595 mg l^{-1}), and monthly values ranged from 1060 mg l^{-1} to 5380 mg l^{-1} (Fig. 40). Range was lowest over the twelve-month period at Station 16712 and highest at Station 13027. No statistically significant differences existed between the four Oso Creek stations (Table 5). In Oso Bay, mean TDS levels were lowest at Station 13441 (10,971 mg l^{-1}) and highest at Station 13440 (44,700 mg l^{-1}). The monthly values recorded ranged from 1140 mg l^{-1} to 44,700 mg l^{-1} (Fig. 41). Range was lowest over the twelve-month period at Station 13442, greatest at Station 13441 located below the OWWTP, and statistically significant differences did exist between the four Oso Bay stations (Table 5). As expected, segment comparison showed mean TDS levels to be higher in the estuarine waters of Oso Bay.

Sulfate

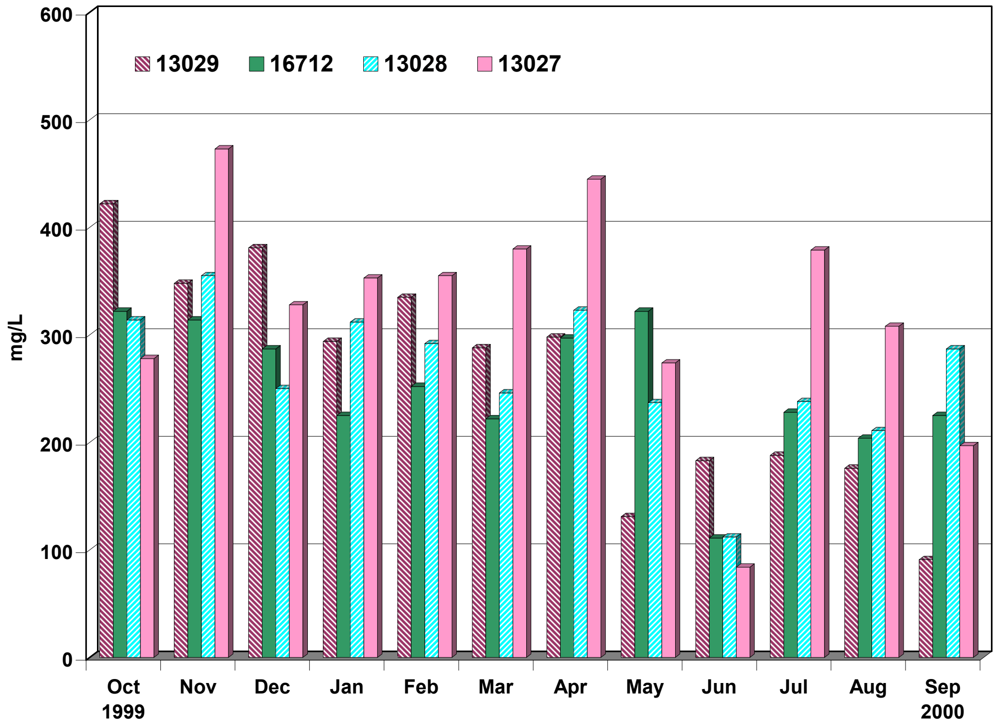

Fig. 36. Comparison of Sulfate concentrations at Oso Creek stations.

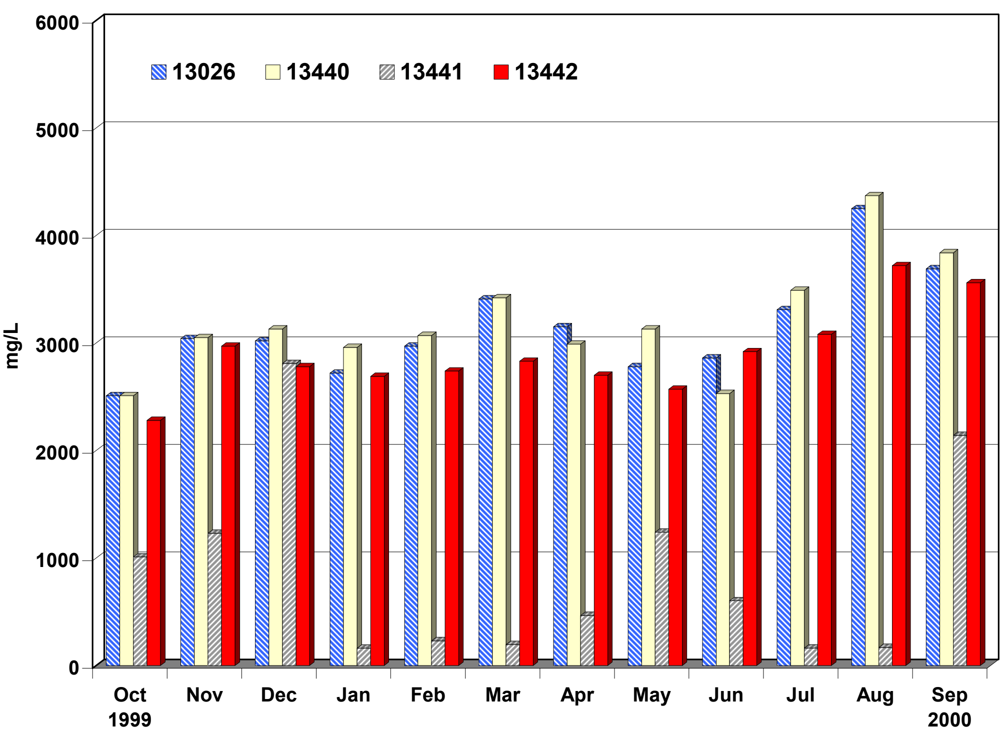

Fig. 37. Comparison of Sulfate levels concentrations at Oso Bay stations.

Total Alkalinity

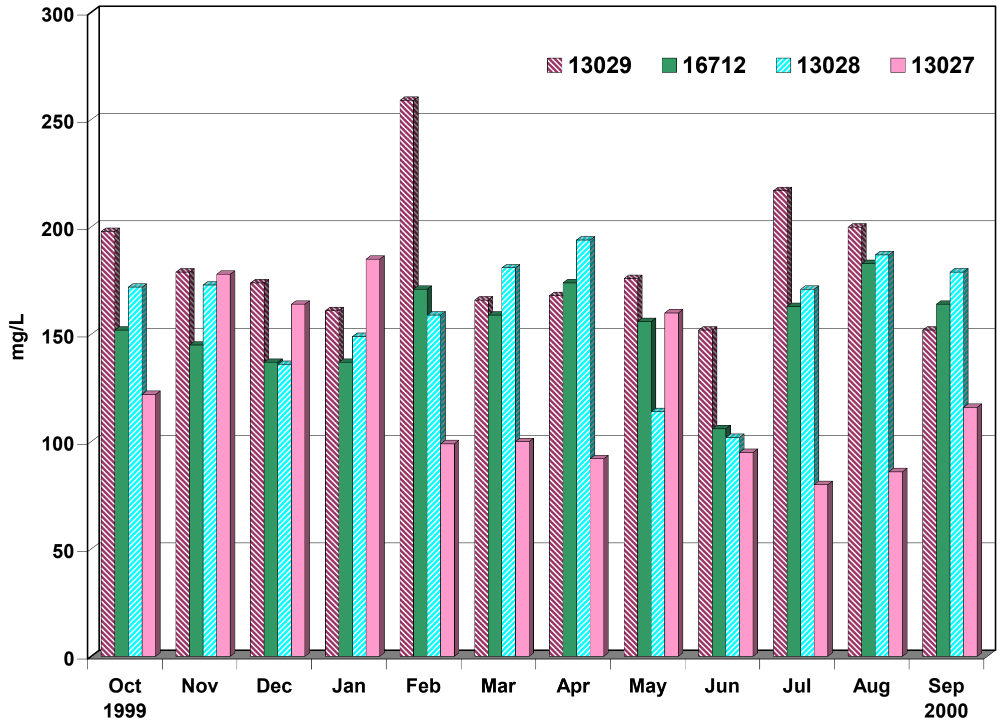

Fig. 38. Comparison of Total Alkalinity concentrations at Oso Creek stations.

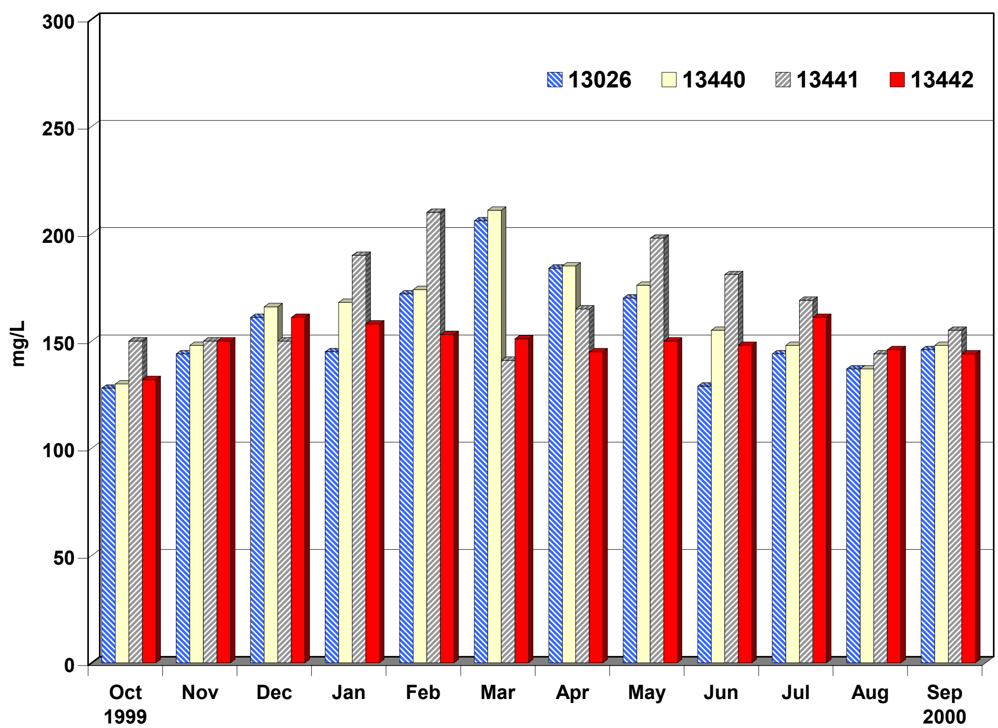

Fig. 39. Comparison of Total Alkalinity concentrations at Oso Bay stations

Total Dissolved Solids

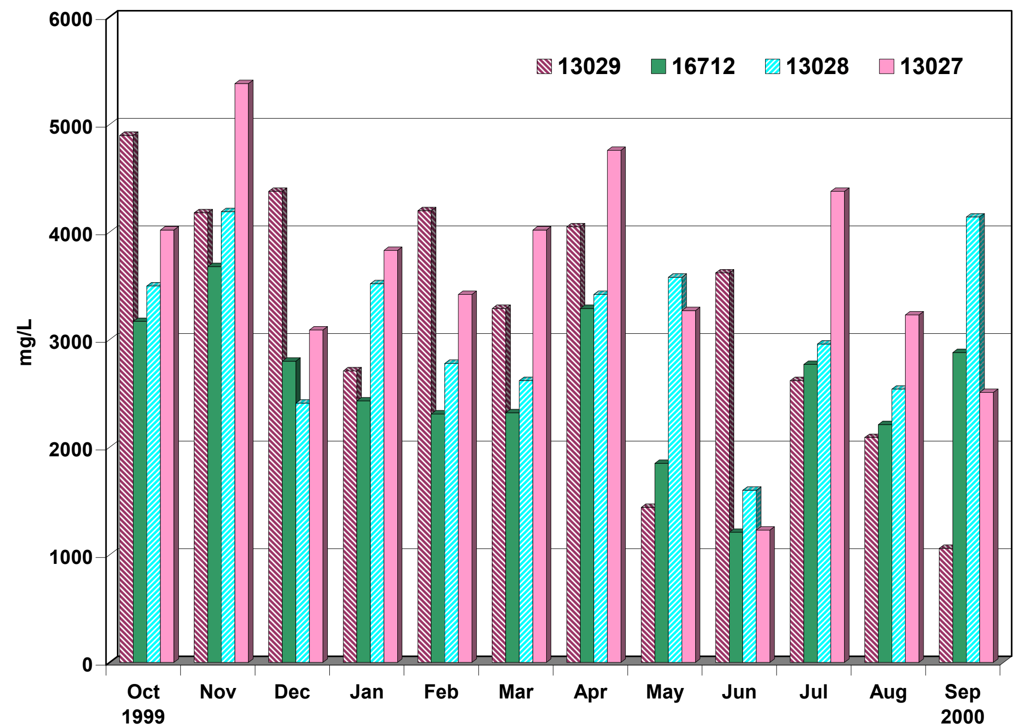

Fig. 40. Comparison of Total Dissolved Solids concentrations at Oso Creek stations.

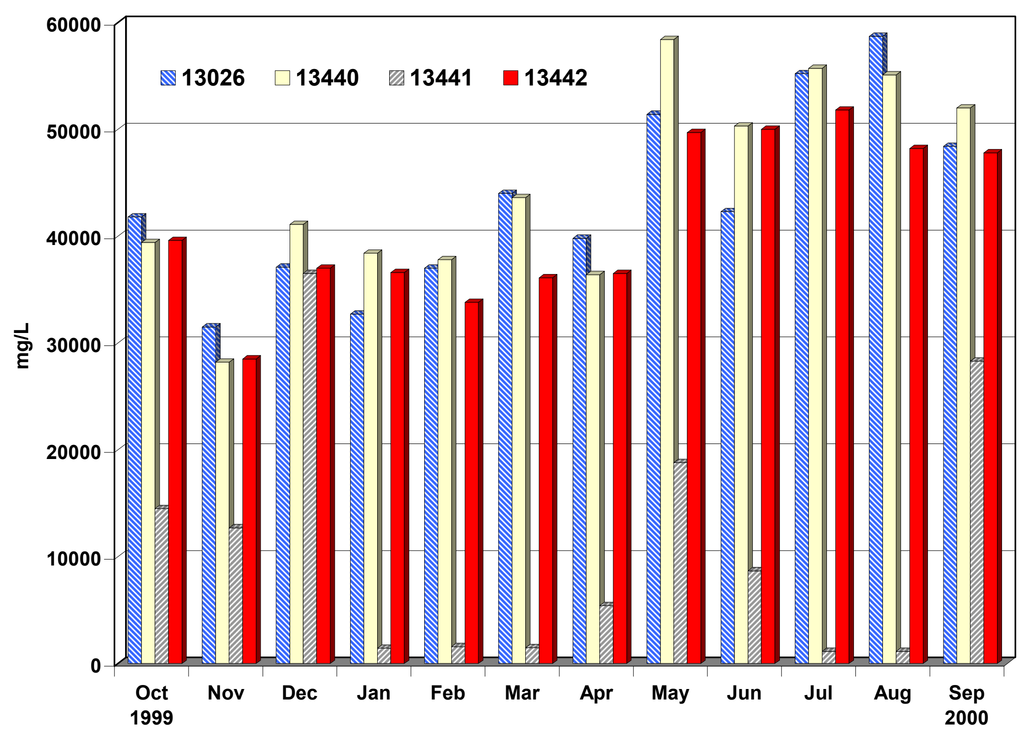

Fig. 41. Comparison of Total Dissolved Solids concentrations at Oso Bay stations.

Total Suspended Solids (mg l^{-1})

In Oso Creek, mean TSS values were lowest at Station 16712 (23.0 mg l^{-1}) below the GWWTP, highest at Station 13027 (137.1 mg l^{-1}), and monthly values ranged from 8.0 mg l^{-1} to 552.0 mg l^{-1} (Fig. 42). Higher TSS levels seen at upstream station 13029 declined at Station 16712 below the GWWTP and then rose steadily at the two downstream stations (13028 and 13027) in the segment. Range was lowest over the twelve-month period at Station 16712 and highest at Station 13028 and statistically significant differences existed between the four Oso Creek stations (Table 5).

In Oso Bay, mean TSS levels were lowest at Station 13441 (82.4 mg l^{-1}) below the OWWTP and highest at Station 13440 (144.6 mg l^{-1}). Monthly values ranged from 11.0 mg l^{-1} to 706.0 mg l^{-1} (Fig. 43). Range was lowest over the twelve-month period at Station 13026 and greatest at Station 13440. No statistically significant differences existed between the four Oso Bay stations (Table 5). Segment comparison showed mean TSS levels to be higher in the estuarine waters of Oso Bay.

Volatile Suspended Solids (mg l^{-1})

In Oso Creek, mean VSS values were lowest at Station 16712 (8.0 mg l^{-1}) below the GWWTP, highest at Station 13027 (28.2 mg l^{-1}), and monthly values ranged from 3.0 mg l^{-1} to 57.0 mg l^{-1} (Fig. 44). Like TSS, the monthly values recorded for VSS often tended to be higher at upstream station 13029 before declining at Station 16712 below the GWWTP and then increasing at the two downstream stations (13028 and 13027) in the segment. Range was lowest over the twelve-month period at Station 13029 and highest at Station 13027 and statistically significant differences existed between the four Oso Creek stations (Table 5).

In Oso Bay, mean VSS levels were lowest at Station 13442 (12.6 mg l^{-1}) at the entrance to Corpus Christi Bay and highest at Station 13440 (21.6 mg l^{-1}). Monthly values recorded ranged from 3.0 mg l^{-1} to 98.0 mg l^{-1} (Fig. 45). Range was lowest over the twelve-month period at Station 13442 and greatest at Station 13440 but no statistically significant differences existed between the four Oso Bay stations (Table 5). Segment comparison showed relatively overall equal mean VSS levels in the two segments.

Total Suspended Solids

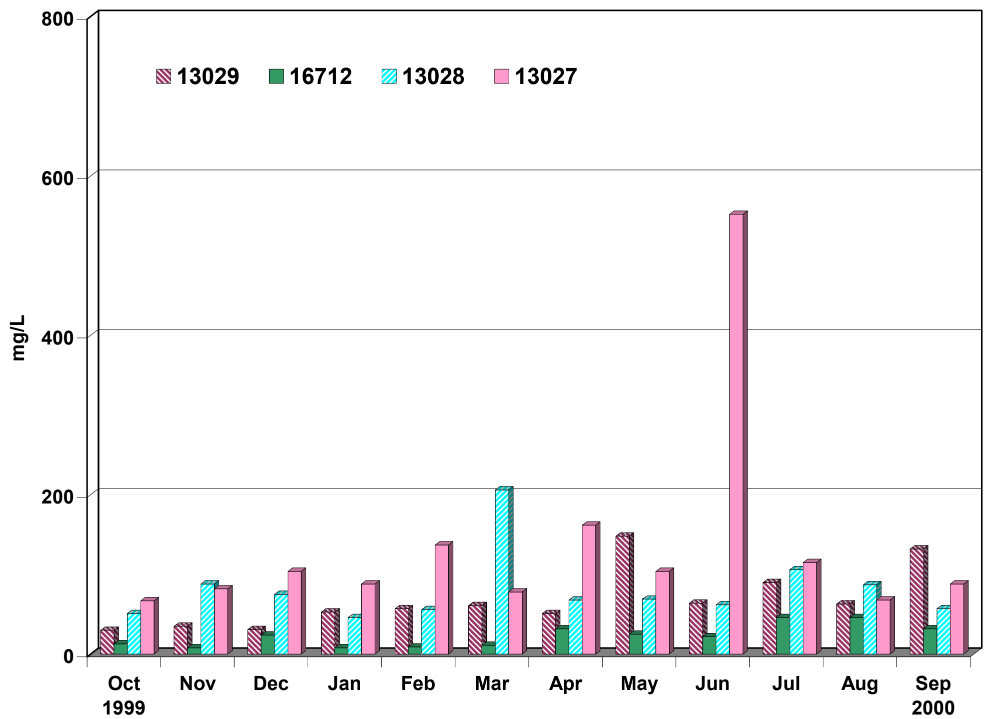

Fig. 42. Comparison of Total Suspended Solids concentrations at Oso Creek stations.

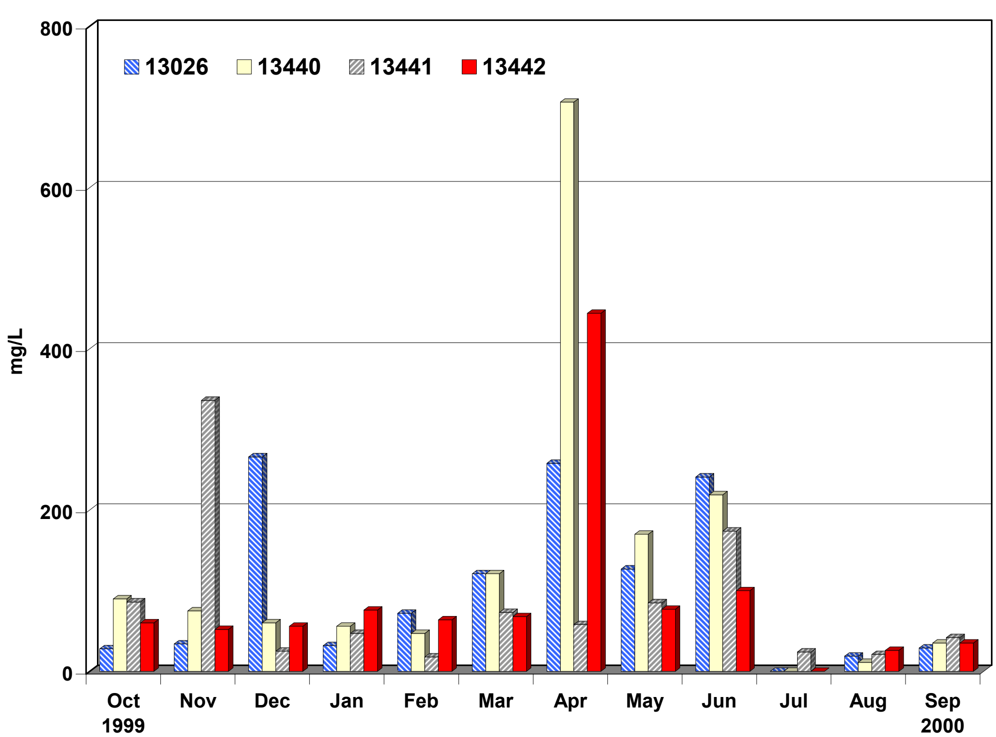

Fig. 43. Comparison of Total Suspended Solids concentrations at Oso Bay stations.

Volatile Suspended Solids

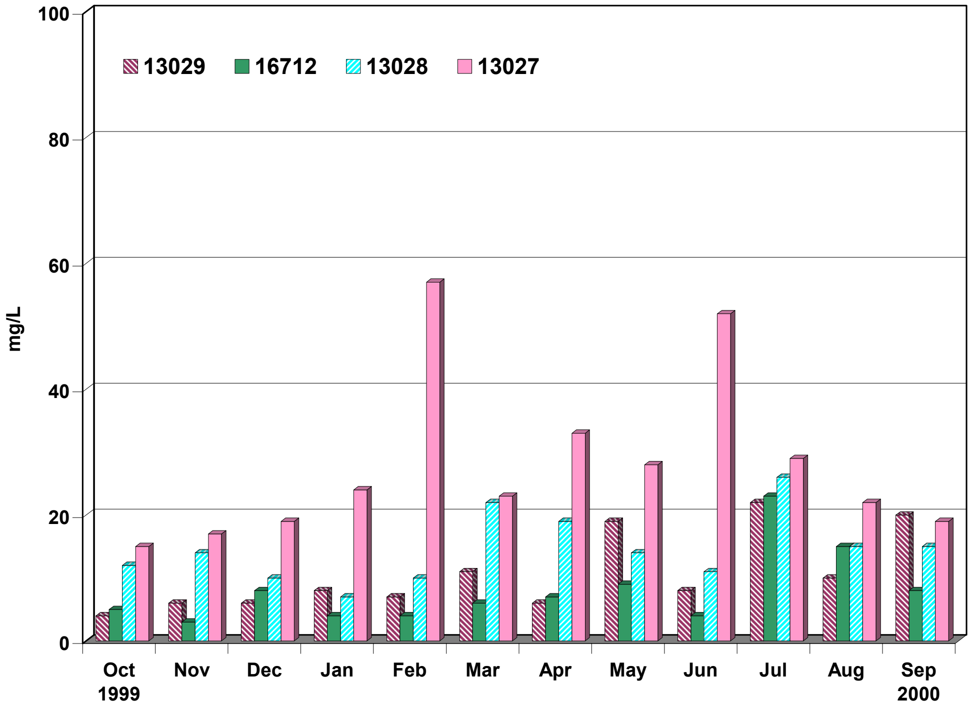

Fig. 44. Comparison of Volatile Suspended Solids concentrations at Oso Creek stations.

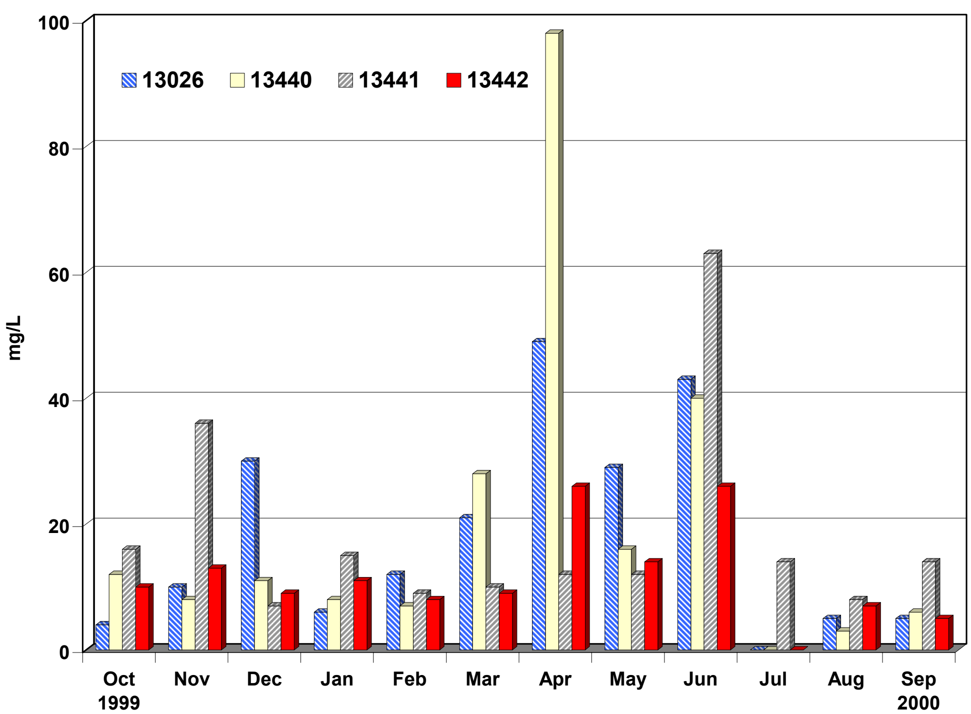

Fig. 45. Comparison of Volatile Suspended Solids concentrations at Oso Bay stations.

Microbiological Indicators

Texas Department of Health shellfish classification maps identified concerns for elevated bacterial concentrations within Oso Bay, resulting in Segment 2485's inclusion on the 2000 303(d) list for non-support of the oyster water use. Utilization of new indicators, *Escherichia coli* and *Enterococci*, for contact recreation and continued use of fecal coliform as the designated Oyster Water indicator provided new assessment information. Routine grab sampling data produced definite concerns, and continued non-support of designated uses.

As stated in Heilman *et al*. 2000, environmental factors in an aquatic ecosystem can affect bacterial concentrations. Decreases or increases in concentrations cited are factors such as bacterial competition, predation, temperature, nutrient concentration, light, and other physical and chemical parameters. As seen in Heilman *et al*. (2000), bacterial indicators routinely exceeded standards and there is a definite concern for the Non-Support of the Oyster Water use designation currently assigned to Oso Bay. Compared to historical data, the water quality regarding bacterial contamination in Oso Bay does not show improvement. Heilman *et al*. (2000) revealed that a major source of fecal contamination in Oso Bay appeared related to the presence of birds (shorebirds, waterfowl, and colonial waterbirds), especially near the OWWTP. While this possibly may influence the other locations within Oso Bay, the fact exists that bacterial counts in one segment of the bay are not always realistic in characterizing the entire segment when one takes into consideration all the potential sources.

The validity of listing Oso Bay as oyster waters is beyond the scope of this project. However, considering the effect this classification has on many bay areas in Texas, it is important to communicate findings of comparative studies and perhaps reassess the situation on a case-by-case basis. Notwithstanding, even if reclassified, non-support continued to be the norm in Oso Bay despite a higher concentration level using the new indicator.

Escherichia coli (CFU/100 ml)

In Oso Creek, mean *E. coli* concentrations were lowest at Station 13029 (310 CFU/100 ml) and highest at Station 13027 (799 CFU/100 ml) (Fig. 46). Monthly values ranged from 8 to 8650 CFU/100 ml. Based on screening levels for a single grab sample, in a non-designated tidal stream segment with contact usage (394 CFU/100 ml), Stations 13029, 16712, and 13028, exceed criteria 25.0% and Station 13027 exceeded criteria 8.3% of the time sampled, respectively. Range was lowest over the twelve-month period at Station 13029 and highest at Station 13027 and statistically significant differences ($p = 0.022$) existed between stations.

Enterococci (CFU/100 ml)

In Oso Bay, mean *Enterococci* concentrations were lowest at Station 13026 (89 CFU/100 ml) and highest at Station 13441 (957 CFU/100 ml) (Fig. 47). Monthly values in ranged from 1 to 4800 CFU/100 ml. Based on screening levels for a single grab sample, in a designated estuarine segment with contact usage (89 CFU/100 ml), Stations 13026, 13440, 13441, and 13442 exceed criteria by 25.0%, 50.0%, 91.6%, and 33.3% of the time sampled, respectively. Range was lowest over the twelve-month period at Station 13026 and highest at Station 13441 at the OWWTP and statistically significant differences ($p = 0.028$) existed between stations.

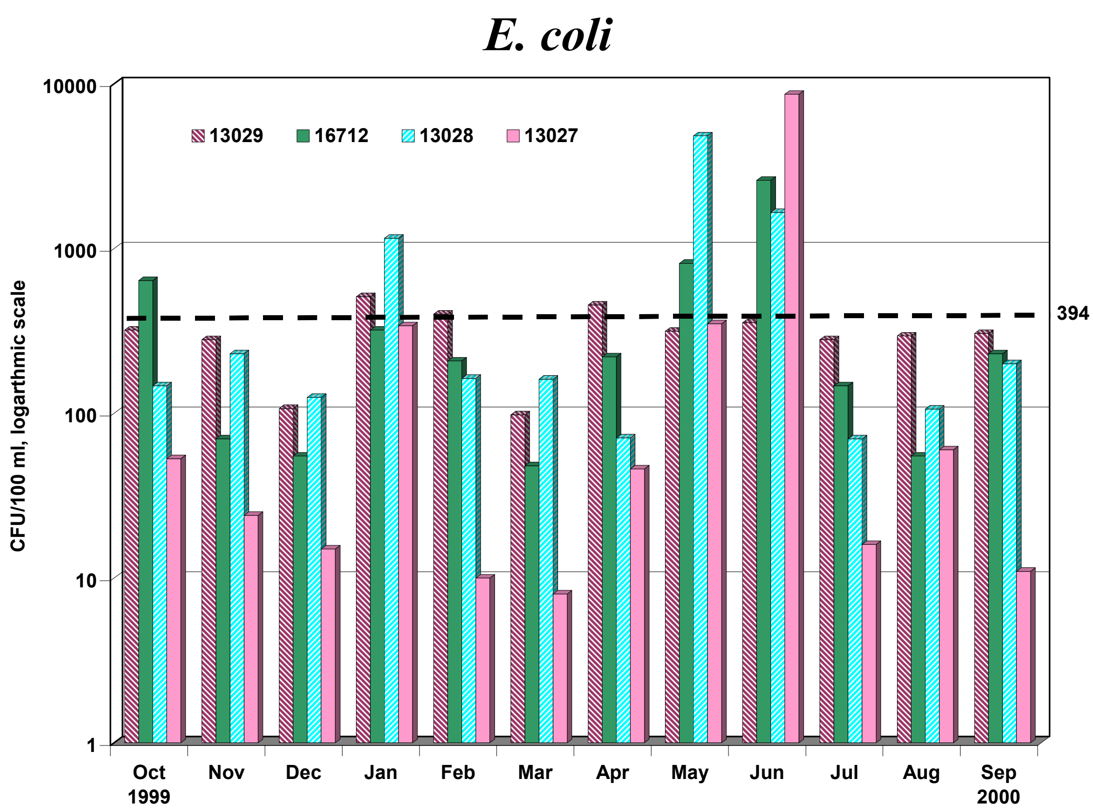

Fig. 46. Comparison of *E. coli* concentrations at Oso Creek stations.

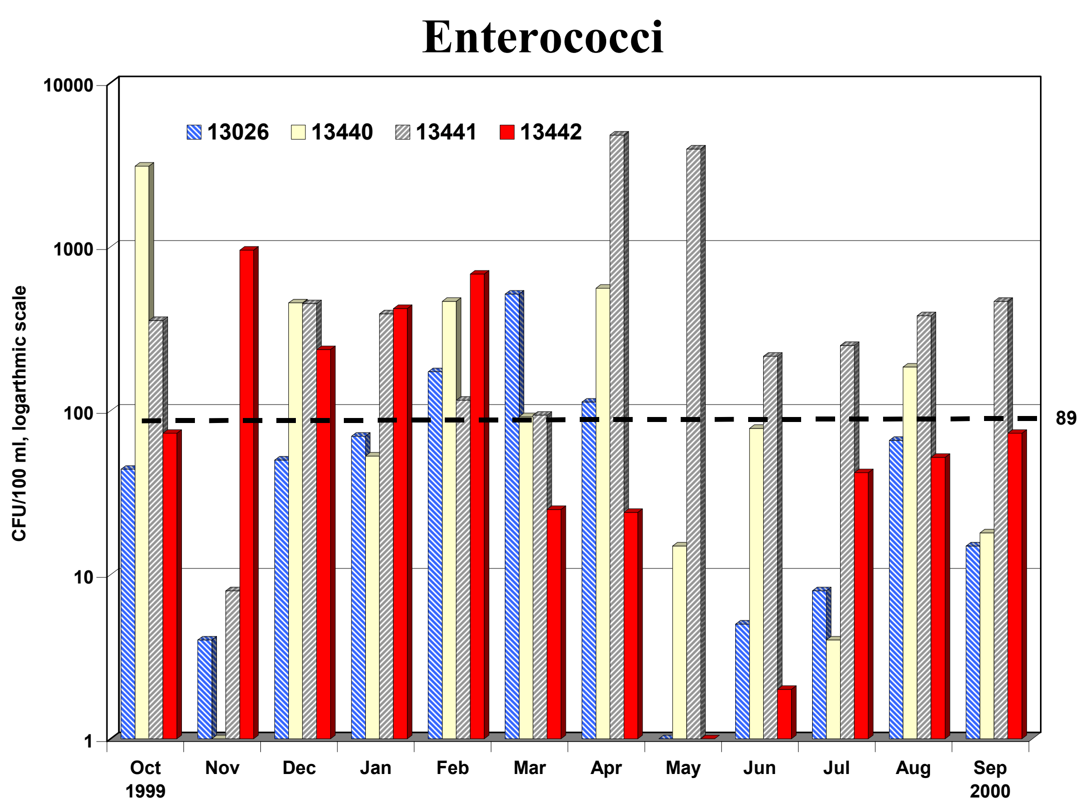

Fig. 47. Comparison of enterococci concentrations at Oso Bay stations.

Fecal Coliform (CFU/100 ml)

In Oso Creek, mean levels were lowest at Station 13029 (281 CFU/100 ml) and highest at Station 13027 (675 CFU/100 ml). Monthly values ranged from 6 to 6750 CFU/100 ml (Fig. 48). Based on screening levels for a single grab sample, in a non-designated tidal stream segment with contact usage (400 CFU/100 ml), Stations 13029, 16712, 13028, and 13027 exceeded criteria by 27.3%, 16.6%, 25.0%, and 16.6% of the time, respectively. Range was lowest at Station 13029 and highest at Station 13027. No statistically significant differences ($p = 0.287$) existed between the Oso Creek stations.

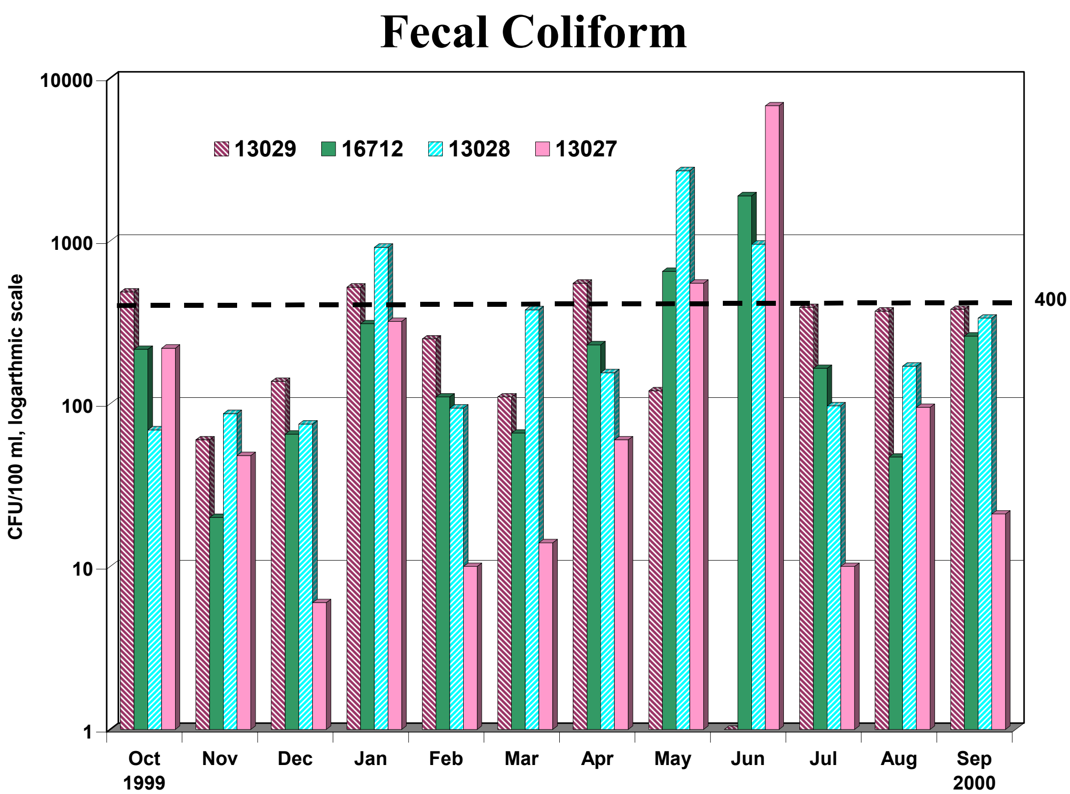

Fig. 48. Comparison of fecal coliform concentrations at Oso Creek stations.

Fecal Coliform (CFU/100 ml)

In Oso Bay, mean levels were lowest at Station 13026 and highest at Station 13441. Monthly values ranged from 2 to 4650 CFU/100 ml (Fig. 49). Based on screening levels for a single grab sample, in a designated estuarine segment with contact usage, and exceptional aquatic habitat listed as Oyster Waters (14 CFU/100 ml), Stations 13026, 13440, 13441 and 13442 exceeded criteria by 33.3%, 66.6%, 83.3%, and 66.6% of the time, respectively. Range was lowest at Station 13026 and highest at Station 13441 and statistically significant differences ($p = 0.001$) existed between Oso Bay stations.

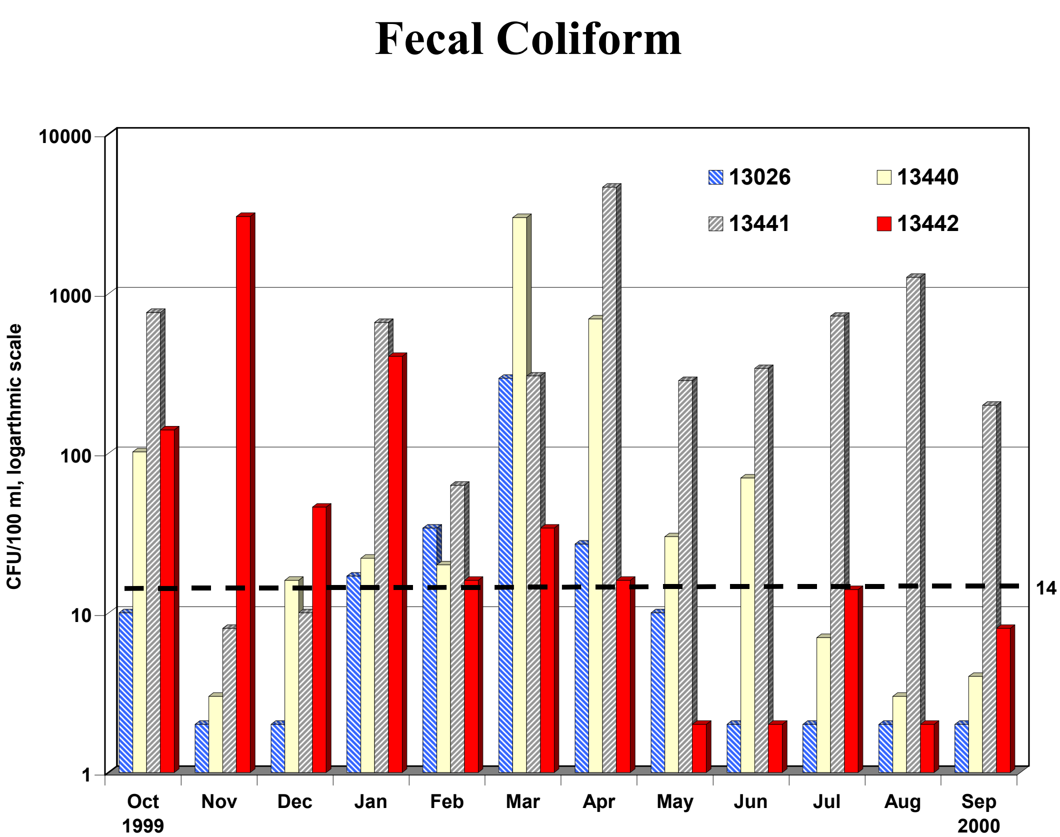

Fig. 49. Comparison of fecal coliform concentrations at Oso Bay stations.

Benthic Macroinfaunal Community

Due to the limited mobility of benthic infauna, strong environmental fluctuations that may occur due to point and non-point source inputs make these organisms excellent indicators of changing conditions, with large-scale changes often affecting benthic infaunal distribution and abundance. Benthic organisms represent a critical component to the estuarine ecosystem through sediment-water interface modifications, organic matter decomposition, nutrient recycling, and energy transfer through the food web. Diverse and abundant populations of benthic invertebrates provide a necessary food source for many species. Due to the importance of benthic organisms in the food chain, these fluctuations may ultimately influence recruitment patterns in estuarine coastal fisheries and ultimately affect overall habitat quality necessary to sustain aquatic life.

Analysis of benthic cores produced 45,725 organisms representing 118 species from 11 phyla (Appendix V). Annelids, primarily polychaetes, represented the greatest percentage of species collected, followed by arthropods, molluscs, and other species (cnidarians, platyhelminthes nemerteans, nematodes, bryozoans, chaetognathas, echinoderms, and chordates) (Fig. 50A; Table 6). However, comparison of the four Oso Creek stations (33 species from six phyla with 11,636 organisms collected) and the four Oso Bay stations (100 species from nine phyla with 34,089 organisms collected) revealed markedly different composition in the benthic communities. As expected, arthropods, primarily insects dominated the brackish water Oso Creek stations and annelids, primarily polychaetes dominated the estuarine Oso Bay stations (Fig. 50B and C; Table 6).

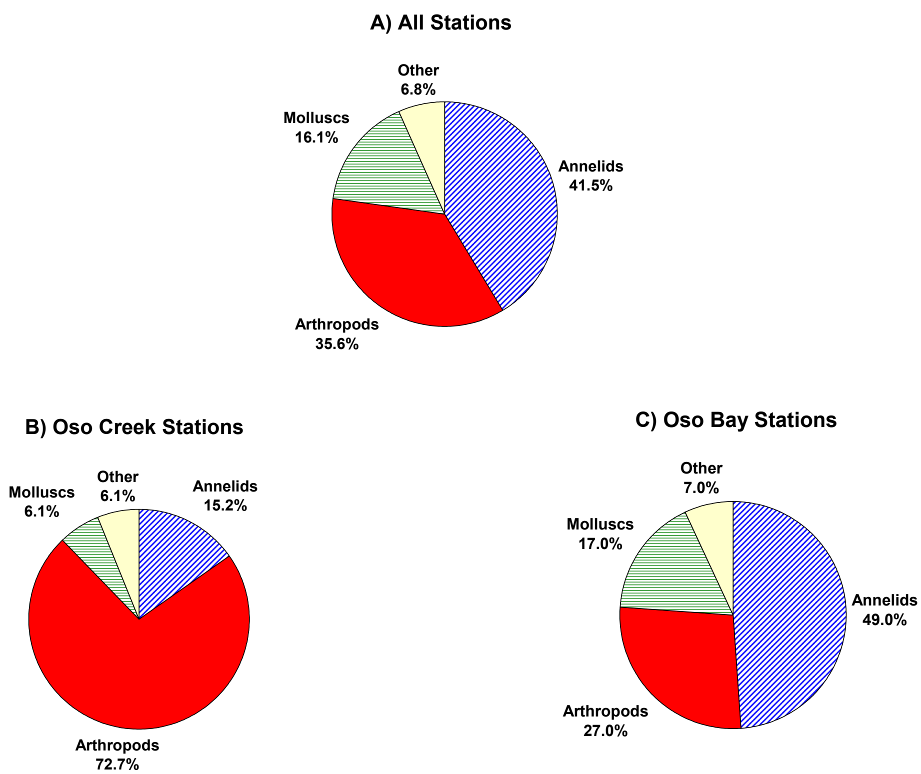

Fig. 50. Percent benthic taxa composition for A) all stations, B) Oso Creek Stations, and C) Oso Bay Stations.

TABLE 6. Number of benthic species collected, with Shannon (H') species diversity and evenness values, from Oso Creek and Oso Bay stations (= *Lowest value*, = **Highest value**).

	Oso Creek Stations				Oso Bay Stations				
	13029	**16712**	**13028**	**13027**	**13026**	**13440**	**13441**	**13442**	**Total**
Annelids									
Polychaetes	4	3	4	4	33	22	8	29	48
Oligochaetes	1	1	1	1	1	1	1	1	1
Total Annelids	5	4	5	5	34	23	9	30	49
Arthropods									
Crustaceans	3	4	4	3	14	12	3	17	22
Insects	9	8	9	10	3	1	4	1	19
Other								1	1
Total Arthropods	12	12	13	13	17	13	7	19	42
Molluscs									
Bivalves					9	4	2	11	14
Gastropods				2	1	1		1	5
Total Molluscs				2	10	5	2	12	19
Other									
Cnidarians					1			1	1
Platyhelminthes	1								1
Nemerteans					1	1		1	1
Nematodes	1	1		1				1	1
Bryozoans				1					1
Chaetognatha					1				1
Echinodermata								1	1
Chordata					1				1
Total Other	2	1		2	4	1		4	8
Total Number Species	19	*17*	18	22	**65**	42	18	**65**	118
Total Number Individuals	*1538*	3603	2974	3521	7156	6715	2671	**17,547**	45,725
Species Diversity (H')	**0.71**	0.44	0.51	0.51	0.57	*0.22*	0.61	0.43	
Evenness	**0.56**	0.36	0.40	0.38	0.32	*0.13*	0.49	0.24	

Station 13026 located below the CP&L-BD discharge and Station 13442 at the entrance to Corpus Christi Bay produced the highest total number of benthic species; each with 65 species collected (Table 6). Station 16712 located below the GWWTP in Oso Creek yielded the lowest number of species collected with 17. The number of species collected at the individual Oso Creek stations was relatively equal while those at Oso Bay stations ranged

from 18 to 65. Shannon species diversity (H') and distribution evenness was highest at Station 13029 in Oso Creek and lowest at Station 13440 in Oso Bay (Table 6).
Detailed analysis of benthic data showed insects (chironomids) and oligochaetes dominating benthic densities at Oso Creek stations (Fig. 51). Station 16712 produced the highest mean monthly density of 5926 individuals m^{-2} collected in the Oso Creek stations (Fig. 52); with oligochaetes and insects accounting for 67.9% and 17.7% of the total number of individuals collected at that station, respectively. Station 13027 followed with 5791 individuals m^{-2} collected. As opposed to Station 16712, insects dominated species collections; representing 61.5%, followed by oligochaetes with 12.0%, of the total number of individuals collected.

In Oso Bay, polychaetes dominated benthic densities at all locations (Fig. 51). This dominance resulted in Station 13442 producing the highest mean monthly density recorded for all stations (Oso Creek and Oso Bay), with 28,859 individuals m^{-2} collected (Fig. 52). Polychaetes accounted for 97.0% of all individuals collected at this station. Analysis revealed statistically significant differences in density existed for the year between all eight stations ($p=0.000$), between Oso Creek and Oso Bay stations ($p=0.037$), and between the four individual Oso Creek stations ($p=0.000$) and between the four individual Oso Bay stations ($p=0.001$).

Densities ranged from 0 individuals m^{-2} at stations 16712, 13441, and 13442 during the months of May, June, and July 2000 when no individuals appeared in collections to 116,975 individuals m^{-2} at Station 13442 in March 2000 (Fig. 53). Most stations exhibited peaks in the late winter and early spring months with peaks driven by the increased numbers of the dominant species collected for that station. Lack of individuals collected in some months reflects the patchy distribution often seen in benthic sampling.

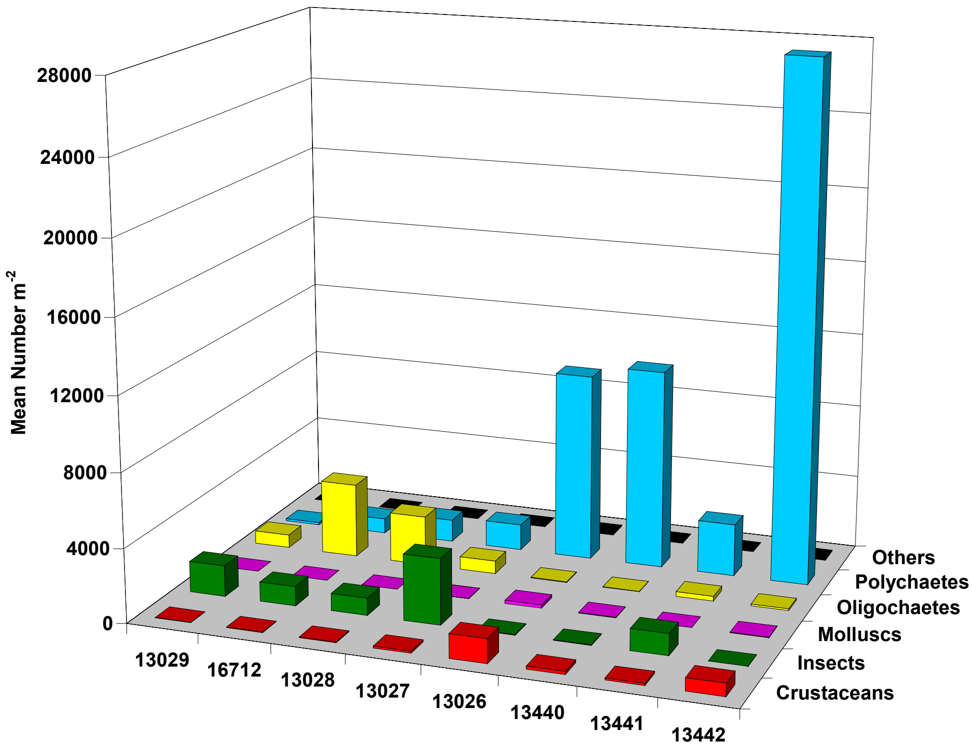

Fig. 51. Mean monthly densities of major taxa collected from benthic core samples, October 1999 through September 2000.

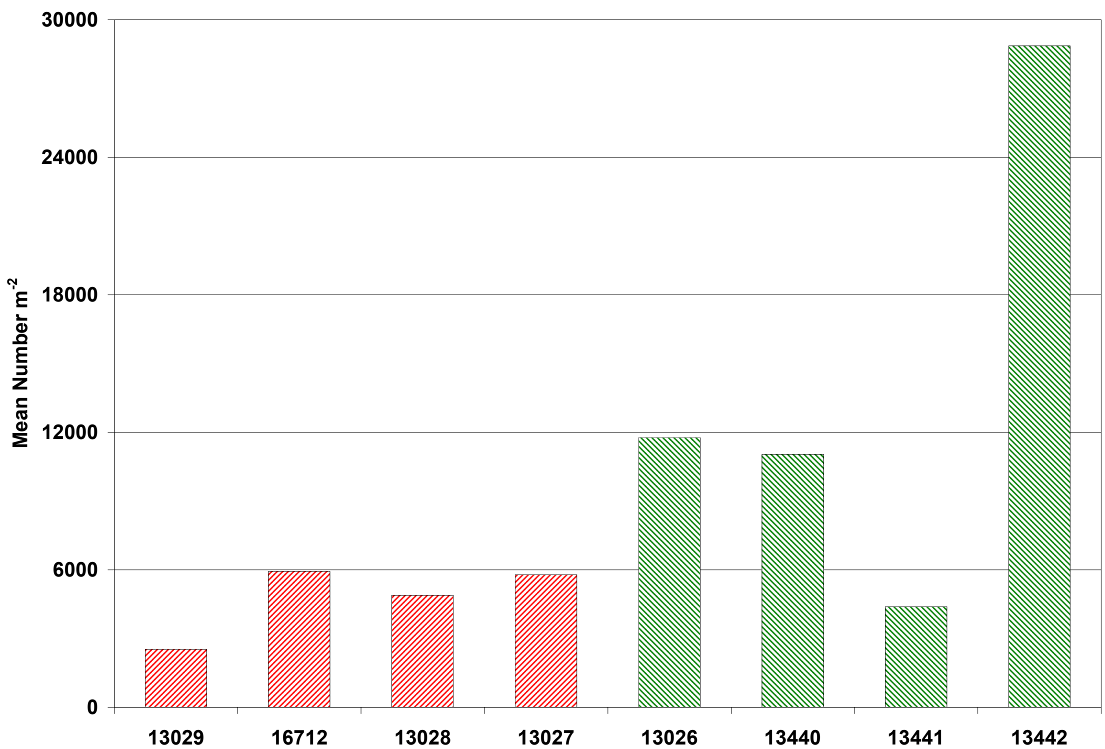

Fig. 52. Comparison of annual mean benthic densities by station.

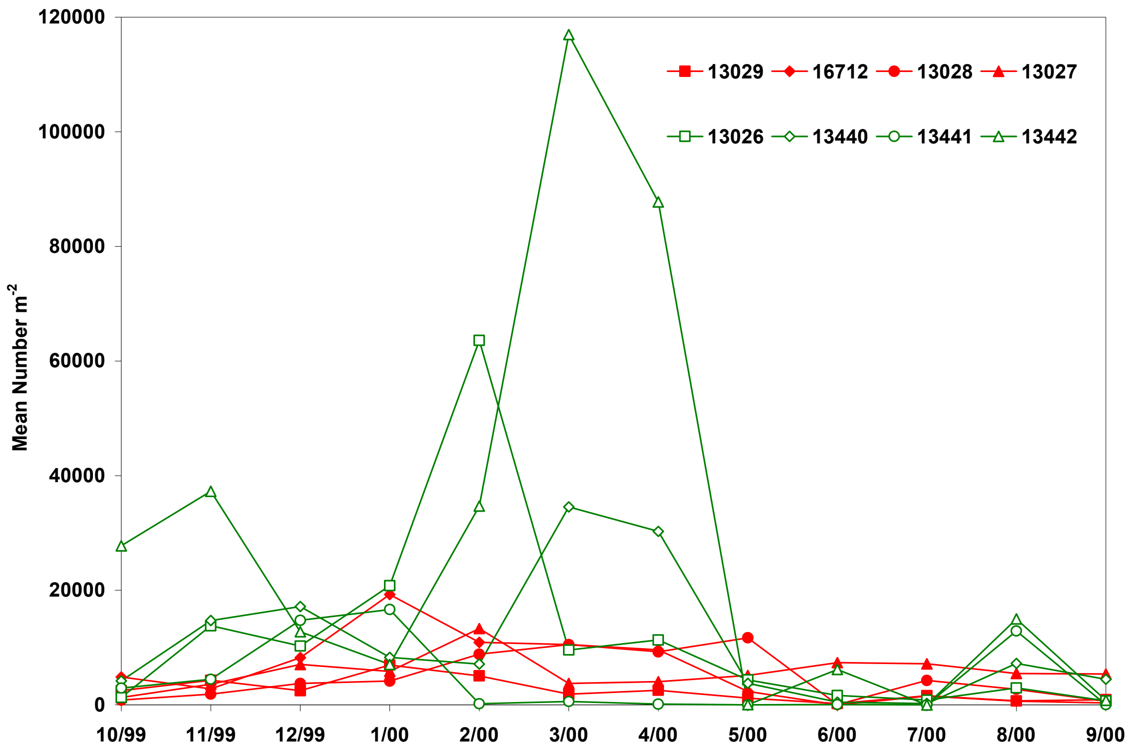

Fig. 53. Comparison of mean monthly benthic density by station, October 1999 through September 2000.

As stated, limited mobility of benthic infauna makes many benthic organisms' relatively accurate predictors/indicators of habitat and water quality conditions within an aquatic ecosystem. The inability of benthic organisms to rapidly evade strong environmental fluctuations, which may possibly occur from point and non-point source inputs, allows only the most tolerant benthic species to thrive in an environmentally stressed ecosystem.

If environmental conditions are conducive to producing stable faunal communities, high species diversity and richness values typically tend to occur; regardless of whether the population abundance is high or low. However, communities under extreme environmental stress, regardless of the stressor, exhibit lower diversity and richness values with large populations of one or two species dominating the community (Pearson and Rosenberg 1978; Bowman and Jennings 1992; Hall *et al*. 1997; Rakocinski et al. 1997; Cardell *et al*. 1999).

During this study, the dominant organisms collected were those often listed as indicators of pollution and/or extremely stressed environments. These stresses commonly relate to fluctuating physical or environmental conditions that cause these areas to undergo sudden and abrupt changes in their immediate surroundings. Oligochaetes and chironomids, so dominant in the Oso Creek stations and at Station 13441 below the OWWTP in Oso Bay, often are indicative of nutrient loading, low DO, and being representative of poor water quality. Oligochaetes in particular, typically occur in organically enriched, soft mud, substrates, and generally represent the numerically dominant species found, while chironomids tolerate varying degrees of pollution.

Regarding the dominant polychaetes, Pearson and Rosenberg (1978) restate that "opportunistic species" are the first species to repopulate areas denuded from extreme or constant environmental stress. However, often no clear delineation exists as to whether or not these species are favored in organically enriched habitats or in many habitats that are available for re-colonization after suffering short-term or long-term environmental disturbances.

To better clarify this situation they suggested the classification of "enrichment opportunists" for these early successional species found in organically enriched areas. From their study, they list only a small group of polychaetes that justifiably fit in this group. Of these polychaete species listed, two species, *Streblospio benedicti* and *Capitella capitata*, occurred as the dominant organisms found during this study within Oso Bay. The third dominant polychaete, *Hobsonia florida*, was a dominant organism found in Oso Creek and often occurs as an invasive species tolerating extreme changes in environmental variables such as salinity.

The five organisms dominating benthic core samples accounted for 89.7% of the benthic organisms collected at all eight locations. The five organisms were: the polychaetes *Streblospio benedicti (54.8%), Capitella capitata* (9.2%), and *Hobsonia florida* (4.6%), with oligochaetes (11.4%) and chironomids (9.8%) accounting for the remaining dominant organisms collected (Fig. 54).

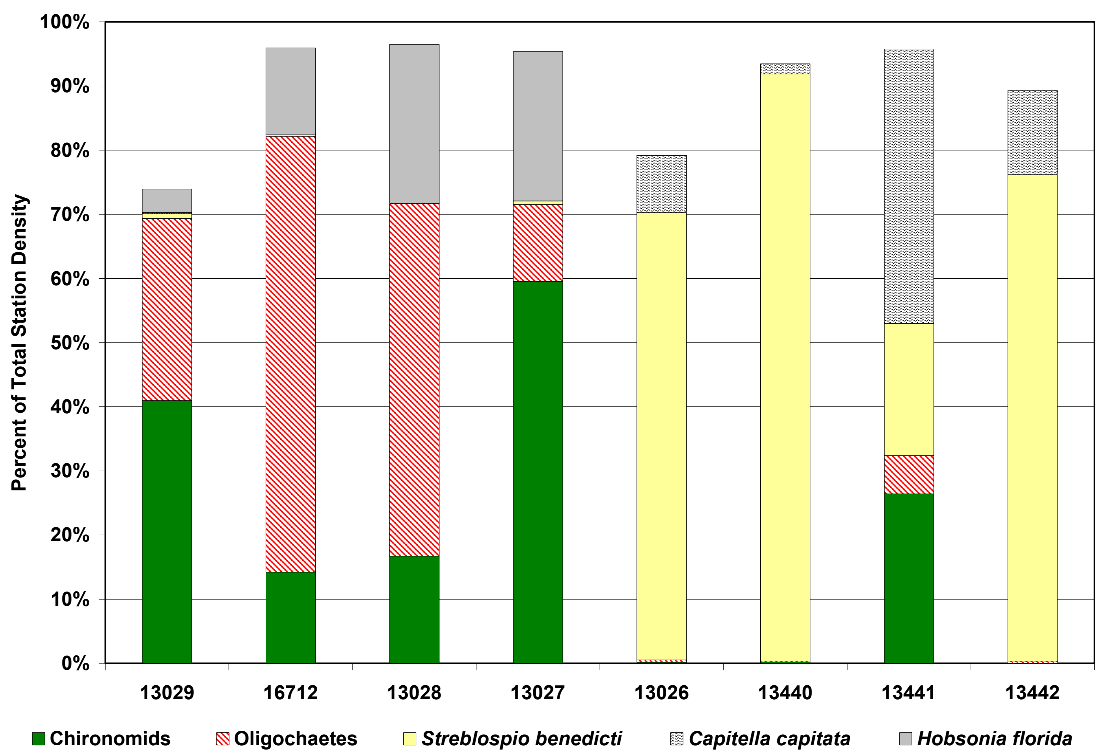

Fig. 54. Percentage of dominant benthic organisms collected at Oso Creek and Oso Bay stations, October 1999 through September 2000.

Two distinct benthic areas diverged early, as expected, with community similarity analysis of all eight stations showing divergence occurring around 28.4% (Fig. 55). The strongest community similarity occurred between Oso Creek stations 16712 and 13028, diverging at 83.3%. As these stations are located upstream and downstream, respectively, from each other similarity might be expected. Station 13027 located downstream from 13028 and Station 13029 located upstream form Station 16712 also showed strong similarity in benthic community structure with these two stations.

Note that Station 13441, located below the OWWTP in Oso Bay, rather than aligning with the other Oso Bay stations had more benthic similarity with the Oso Creek stations. As the OWWTP discharge influences this station, producing comparable substrate composition in many areas, and routinely lowering salinities to levels seen in the Oso Creek stations, this association is not unexpected. Among the Oso Bay stations, a stronger similarity occurs between Station 13026 and 13440 located upstream and downstream from each other respectively, than Station 13442 located at the entrance to Corpus Christi Bay.

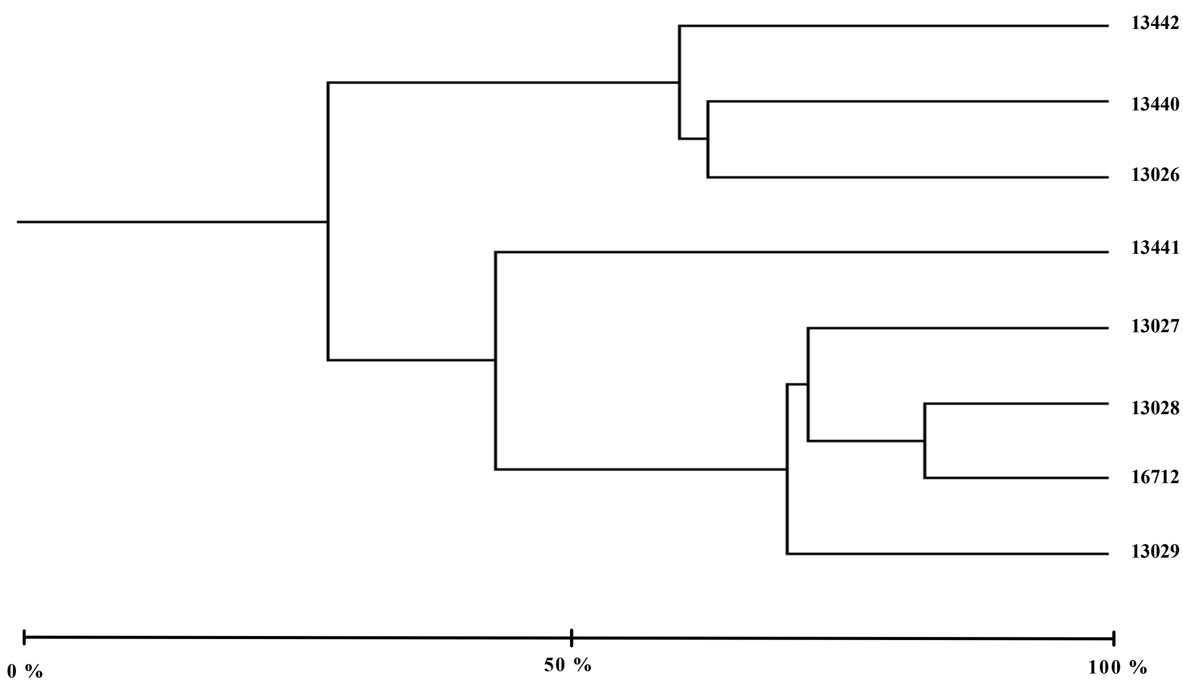

Fig. 55. Dendogram for hierarchical clustering of all sampling stations, using group-average linking of Brays-Curtis similarities calculated on Log_{10} (n +1) transformed benthic abundance data.

Epifaunal Invertebrate and Nekton Community

Numerous commercially and recreationally important species utilize estuarine habitats at some life cycle stage. Due to the importance of these species, it is important to understand the effects that point and non-point source inputs may have on the health and sustainability of this critically important aquatic life use habitat.

The dominant epifaunal organism collected during the sampling period was the mysid shrimp, *Americamysis sp*. During this study, this crustacean produced 185,870 individuals, or 79.9%, of the 232,768 organisms collected from all eight stations. While this species is an important link in the food web, past CCS research shows the dominance of this species overshadows the importance of other species collected, decreases species diversity to negligible values, and masks subtle changes occurring within and between locations. Therefore, no analysis except species richness includes this species.

Analysis of net samples produced 46,898 organisms representing 87 species from four phyla (Appendix V). Arthropods, insects and crustaceans, represented the greatest percentage of species collected, followed by fish, and other species (hirudinid and an unknown parasite) (Fig. 56A; Table 7). As with the benthic community, comparison of the four Oso Creek stations (59 species, four phyla, 30,664 organisms collected) and the four Oso Bay stations (48 species, two phyla, 16,234 organisms collected) revealed different compositions. Arthropods, primarily insects again dominated the brackish water Oso Creek stations and crustaceans dominated the estuarine Oso Bay Stations (Fig. 56B and C; Table 7).

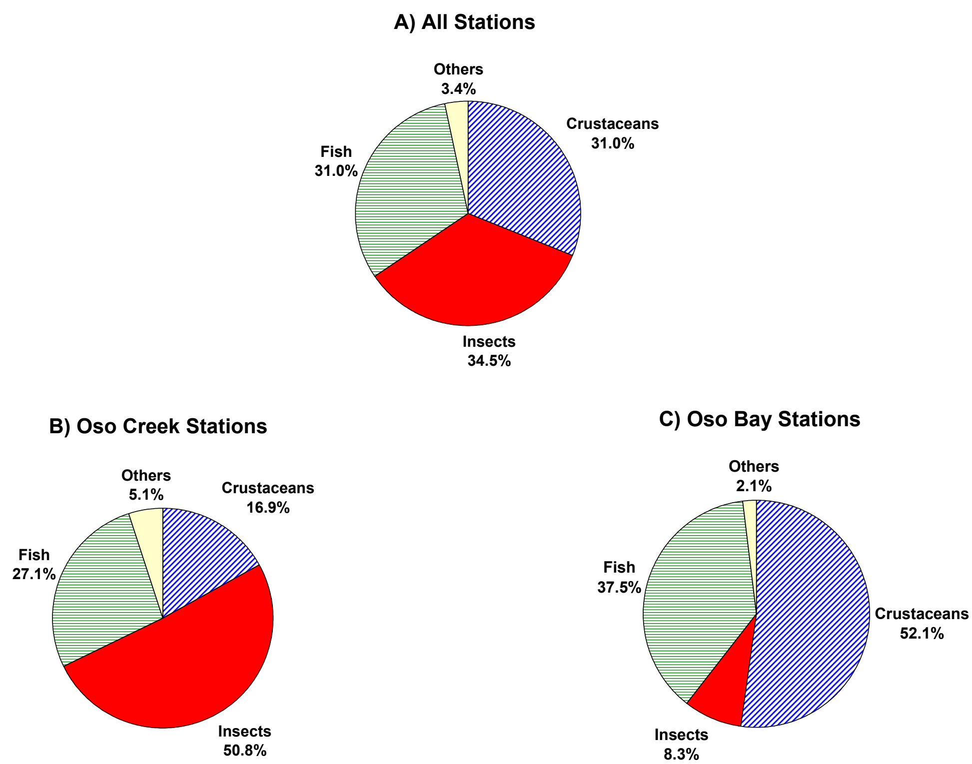

Fig. 50. Percent epifaunal invertebrate and nekton taxa composition for A) all stations, B) Oso Creek Stations, and C) Oso Bay Stations.

The farthest upstream station, 13029, produced the greatest number of species, with 41 species collected (Table 7). Station 13441 located below the OWWTP in Oso Bay yielded the lowest number of species collected with 16. Due to the relatively low number of species collected, and the even distribution of these species, Shannon species diversity (H') and distribution evenness was highest at Station 13441 in Oso Bay. (Please note that shallow water depth characteristics of this station, coupled with extremely low water encountered throughout the year, allowed sampling to occur for only four out of twelve possible months. While there is no guarantee, the number of species and individuals collected most likely would have been higher if conditions permitted. In addition, this may have resulted in entirely different diversity and evenness values). The second highest values occurred at Station13029 in Oso Creek and lowest values occurred at Stations 13026 and 13440 in Oso Bay (Table 7).

TABLE 7. Number of epifaunal invertebrate and nekton species collected, with Shannon (H') species diversity and evenness values, from Oso Creek and Oso Bay sampling stations (= *Lowest value*, = **Highest value**).

	Oso Creek Stations				**Oso Bay Stations**				
	13029	**16712**	**13028**	**13027**	**13026**	**13440**	**13441**	**13442**	**Total**
Arthropods									
Crustaceans	3	5	4	8	15	18	9	17	27
Insects	27	12	10	9	3	2	3		30
Other	1	1		1			1		1
Total Arthropods	31	18	14	18	18	20	13	17	58
Total Fish	9	8	9	7	6	11	3	13	27
Other									
Hirudinid			1	1					1
Unknown Parasite	1								1
Total Other	1		1	1					2
Total Number Species	**41**	26	24	26	24	31	*16*	30	87
Total Number Individuals	816	1058	3918	**24,872**	3950	10,052	*105*	2127	46,898
Species Diversity (H')	**0.92**	0.39	0.63	0.45	*0.34*	0.36	**0.96**	0.51	
Evenness	**0.57**	0.28	0.46	0.32	0.25	*0.24*	**0.81**	0.35	

Analysis of net data showed insects, from the families Corixidae and Chironomidae, dominating mean Catch Per Unit Effort (CPUE) at Oso Creek stations (Fig. 57). Station 13027, in Oso Creek, produced the highest mean monthly CPUE of all stations; with 2073 individuals collected (Fig. 58). Corixidae and Chironomidae accounted for 63.4% and 21.5% of the total number of individuals collected at that station, respectively.

In Oso Bay, crustaceans dominated mean monthly CPUE at all locations (Fig. 51). This dominance resulted in Station 13440 producing the highest mean monthly CPUE recorded for Oso Bay stations, with 838 individuals collected (Fig. 58). One species of caridean shrimp accounted for 79.7% of all individuals collected at this station. Analysis revealed statistically significant differences in CPUE existed for the year between the eight individual stations (p=0.000) but not between the two separate areas (p=0.435). Within the areas, statistically significant differences existed between the four individual Oso Creek stations (p=0.000) but not between the four individual Oso Bay stations (p=0.093)

CPUE ranged from 0 individuals at stations 16712, 13027, 13026, and 13442 during the various months when no individuals appeared in collections to 7302 individuals at Station 13027 in December 1999 (Fig. 59). Most stations exhibited peaks in the late fall and early winter months with peaks driven by the increased numbers of the dominant species collected for that station.

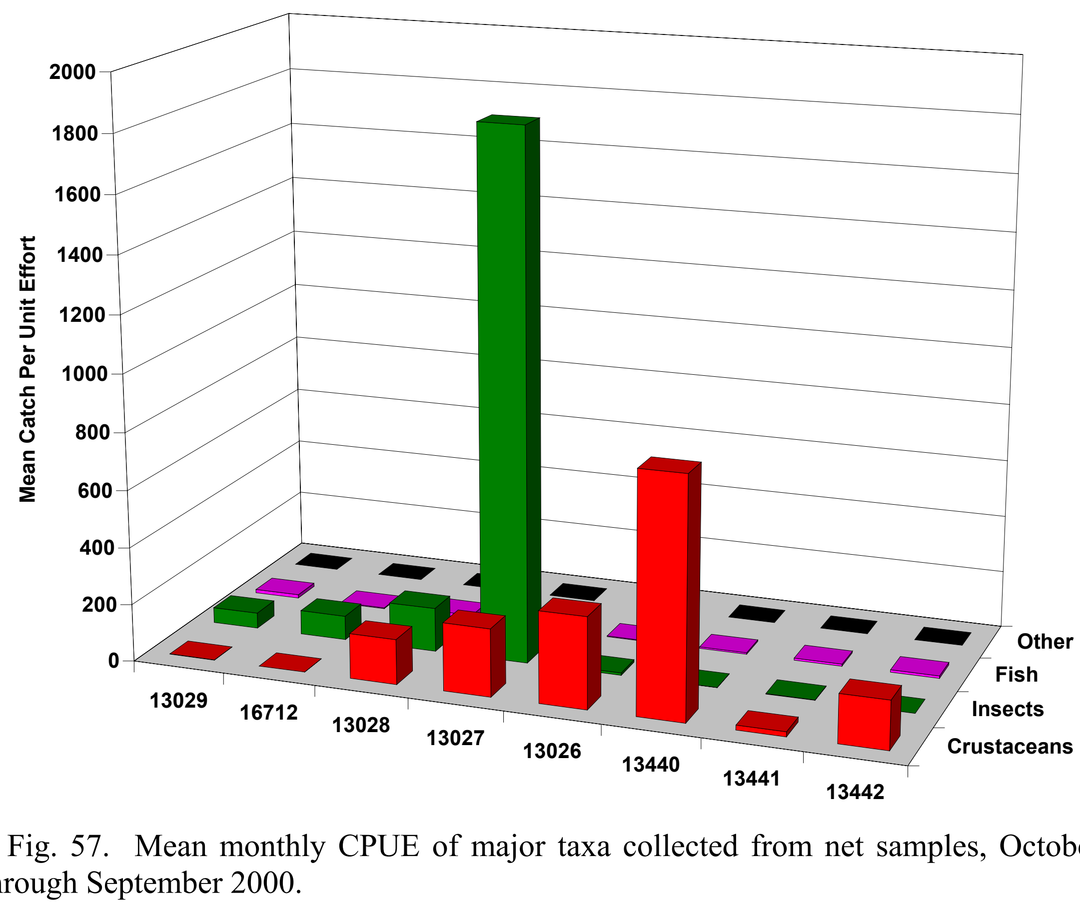

Fig. 57. Mean monthly CPUE of major taxa collected from net samples, October 1999 through September 2000.

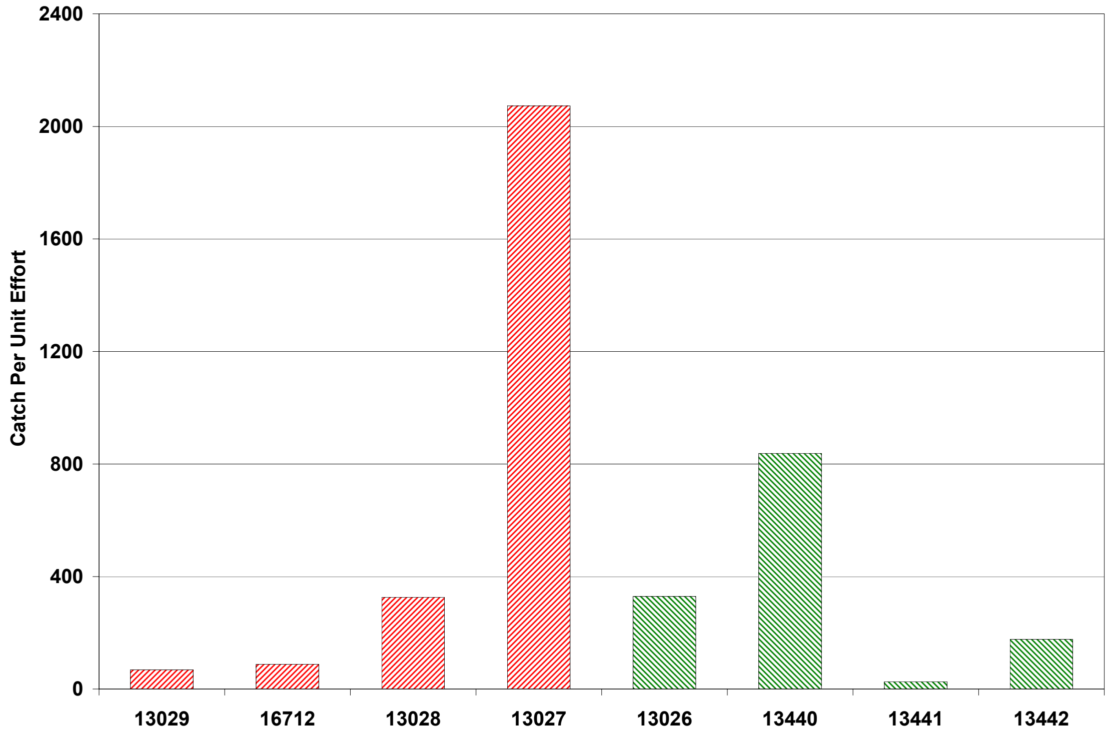

Fig. 58. Comparison of epifaunal invertebrate and nekton CPUE by year for all sampling stations.

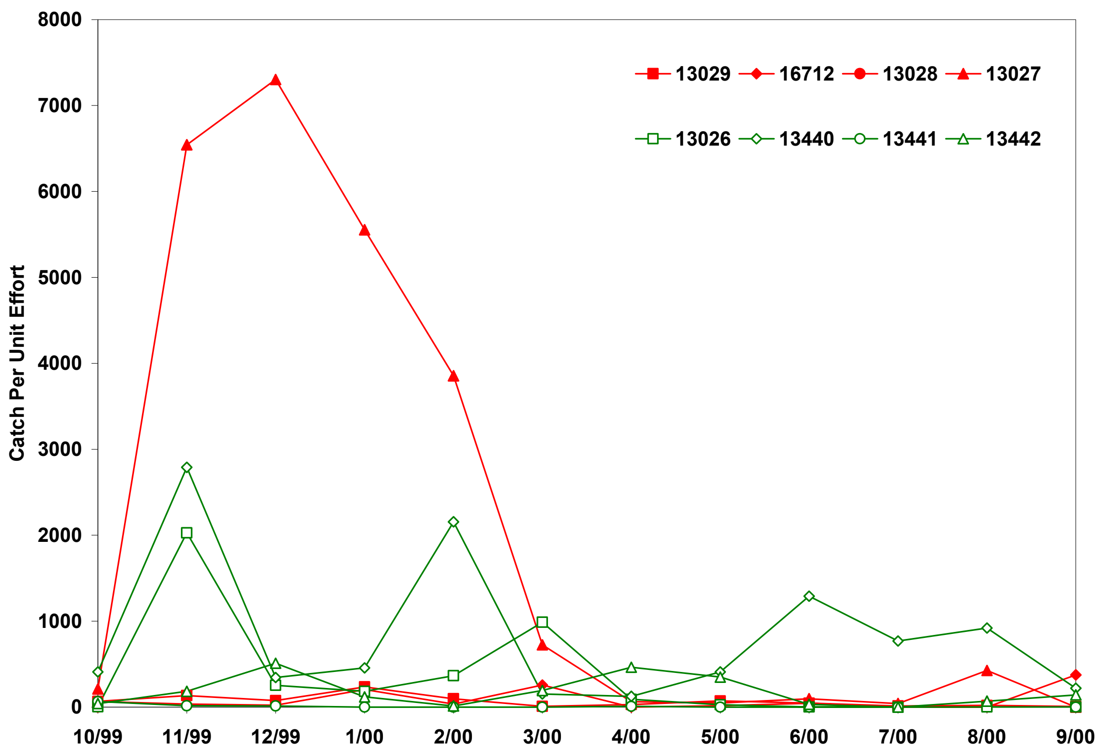

Fig. 59. Comparison of monthly epifaunal invertebrate and nekton CPUE by station, October 1999 through September 2000.

Four organisms dominated net samples and accounted for 92.1% of the total number of organisms collected at all locations. The four organisms were the Daggerblade Grass Shrimp (*Palaemonetes pugio*) (37.5%), Corixidae (36.1%), chironomids (15.5%), and Brackish Grass Shrimp (*Palaemonetes intermedius*) (3.1%) (Fig. 560).

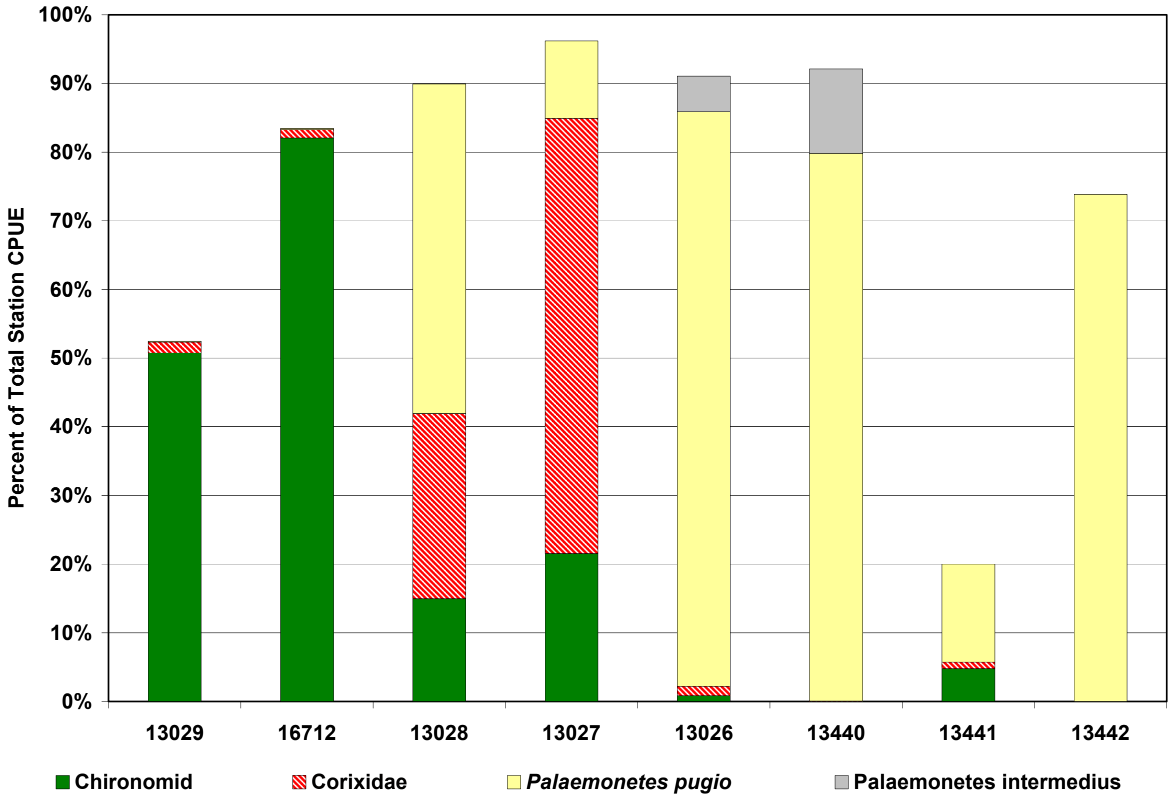

Fig. 60. Percentage of dominant epifaunal invertebrate and nekton organisms collected at Oso Creek and Oso Bay stations, October 1999 through September 2000.

As seen with the benthic organisms, dominant organisms collected by net are tolerant of extremely stressed environments commonly related to fluctuating physical or environmental conditions which may cause these areas to undergo sudden and abrupt changes. Chironomids, so dominant in benthic core collections, also dominated net collections. In addition, Corixidae, or Water Boatman, exist in many aquatic environments, often in large numbers, and are among the few insects tolerating stressful conditions. As the only aquatic Hemiptera known to eat plants, food sources may range from diatoms to Dipteran larvae; two items found in large numbers during the algal blooms at Station 13027 and in the sediments and water column in Oso Creek. Like all hemipterans, there may be little or no indicator value because their life does not depend entirely on water quality (Huggins *et al*. 1985; Hutchinson 1993; Mackie 1998). However, the algal blooms stated above are indicators of water quality and may have proved to provide a plentiful food source to attract this species.

As for the Daggerblade Grass Shrimp, this species and other members of the genus represent one of the most widely distributed and highly abundant shallow water benthic macroinvertebrate found in Gulf of Mexico estuaries (Pattillo *et al*. 1997). While the species has little commercial or recreational value, it serves as a prey item in the diet of many estuarine fishes and as an ecologically important link in the food web. Feeding activities of this species are also important in estuarine trophic dynamics through the breakdown of large detrital particles and the energy transfer of organic and detrital material to higher trophic levels (Pattillo *et al*. 1997). Typically, this species tolerates diverse habitats with wide ranges of salinity from 0 to 55 ppt, and often are abundant where turbidity is high. In addition, it is well adapted to low DO conditions and has been collected in waters with DO ranging from 2.8 to 11 mg l^{-1}. Under laboratory conditions demonstrated tolerances exist at levels <1.0 mg l^{-1} by the species ability to decrease oxygen consumption when low concentrations of DO exist (Pattillo *et al*. 1997). The relatively wide dispersal of the Daggerblade Grass Shrimp at six of the eight stations attest to survival in fluctuating conditions in the estuarine environment.

Although not listed as dominant species collected at any location, due to the overwhelming dominance of the previously mentioned species, several commercially important crustacean species did appear. None of these species occurred in the upper three stations of Oso Creek, but beginning with Station 13027, data showed the Brown Shrimp (*Farfantepenaeus aztecus*) dominated collections at Stations 13027, 13026, and 13442 (Fig. 61). At station 13440, juvenile penaeid shrimp and Brown Shrimp dominated collections. Mean monthly CPUE for Brown Shrimp increased successively at each downstream station except 13441, where lower salinities produced by the OWWTP favored the dominance of Blue Crabs (*Callinectes sapidus*), followed by White Shrimp (*Litopenaeus setiferus*), and then Brown Shrimp.

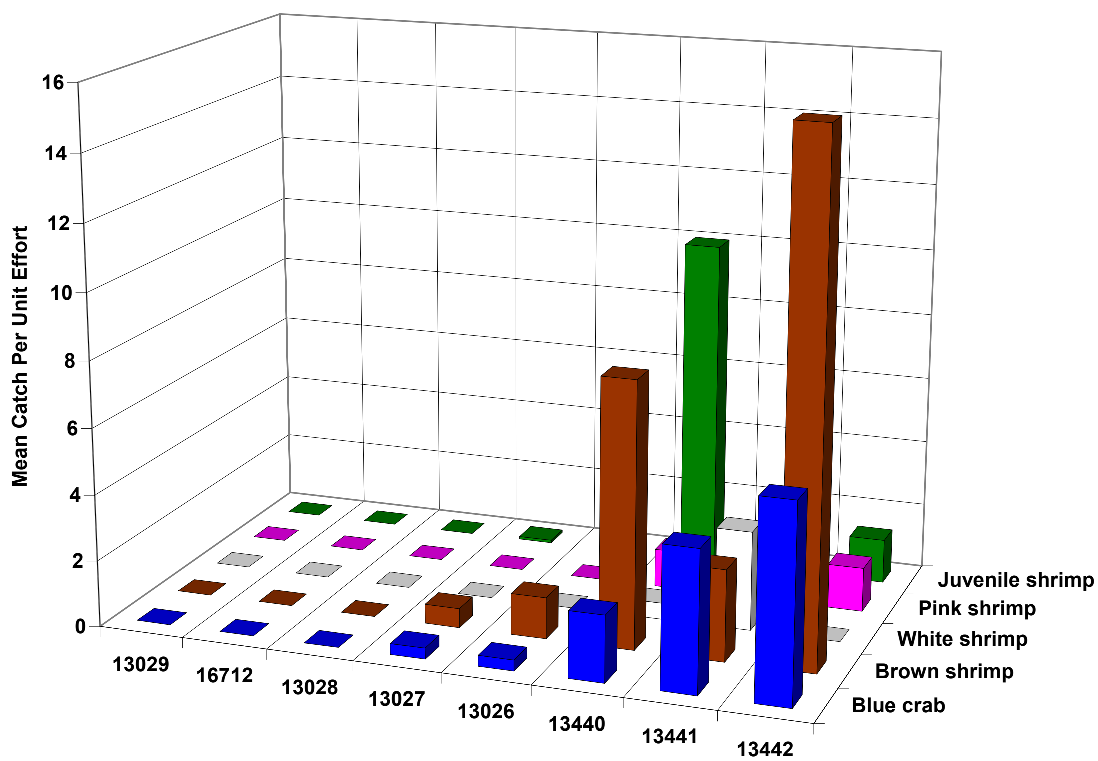

Fig. 61. Mean monthly CPUE of commercially important crustacean species collected from net samples, October 1999 through September 2000.

While fish species appeared at all sampling stations during the study, numbers of individuals collected were low and fish only contributed 1.4% of the total numbers of individuals collected over the course of the year. Of the 27 total fish species collected, five species appeared in higher concentrations then other species. Two of the five species, the Diamond Killifish (*Adinia xenia*) and the Bayou Killifish (*Fundulus pulvereus*) only occurred in Oso Creek stations, where they dominated collections at Stations 13029 and 13028 (Fig. 62). Killifish fish, routinely cited as extremely hardy species, are often indicative of adverse environmental conditions and/or poor water quality (McCain *et al.* 1996).

The dominant fish collected at the other two Oso Creek locations, Stations 16712 and 13027, were the Inland Silversides (*Menidia beryllina*) and the Sheepshead Minnow (*Cyprinodon variegatus*), respectively. The Sheepshead Minnow is also widely known to be tolerant of conditions reflecting extreme isolation, temperature, and salinity variations in habitats worldwide. The species also appears to have a strong tolerance to low DO concentrations with hypoxic conditions (DO < 2.0 mg l^{-1}) often inducing "obligate gulping" of air to relieve oxygen stress to the system (Pattillo *et al*. 1997). The Inland Silversides occurs in a variety of habitats throughout the Unites States and is tolerant of fluctuating salinity levels and extremely tolerant of DO conditions as low as 1.7 mg l^{-1}. Collections also occurred in areas where DO ranged from 9.5 to 11.0 mg l^{-1} and pH ranged from 7.2 to 9.4 (Pattillo *et al*. 1997). In Oso Bay, the Naked Goby (*Gobiosoma bosc*) dominated at all stations except 13441 at the OWWTP, where the Inland Silversides was the dominant fish collected. The Naked Goby is a ubiquitous fish found throughout the area in a wide range of habitat conditions.

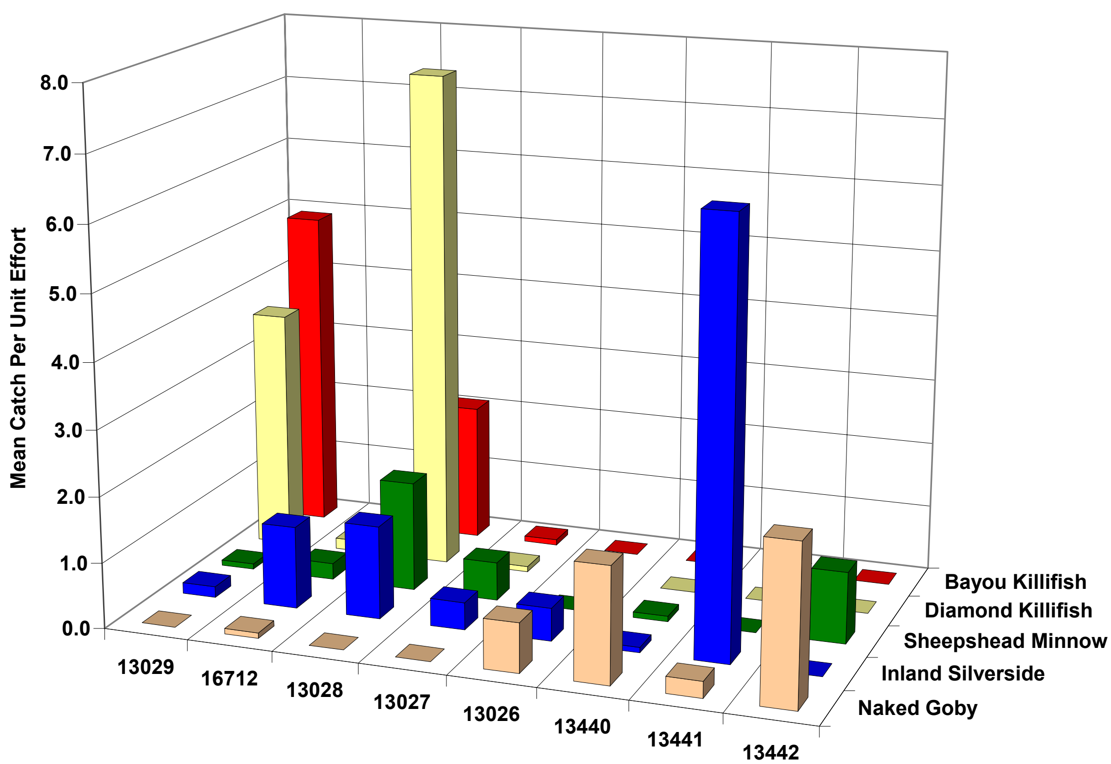

Fig. 62. Mean monthly CPUE of dominant fish species collected from net samples, October 1999 through September 2000.

As seen with the benthic community, these two distinct sampling areas diverged early, with community similarity analysis of all eight stations showing divergence occurring at 17.8% (Fig. 63). The strongest community similarity occurred between Oso Creek stations 13027 and 13028, diverging at 66.2%. Similarity decreased steadily in an upstream progression to Station 13029, which was the least similar of all the Oso Creek locations.

Similarity was equally strong at Oso Bay stations 13442 and 13440, which diverged at 65.6%. Discounting Station 13441, which was the least similar of all sampling stations and remains strongly influenced by the OWWTP discharges, these two stations are upstream and downstream of each other respectively and have many similar attributes. Station 13026 located below the CP&L-BD outfall also exhibited similarity with the two Oso Bay stations. The pattern of an upstream progression of decreasing similarity mimicked the pattern seen in Oso Creek.

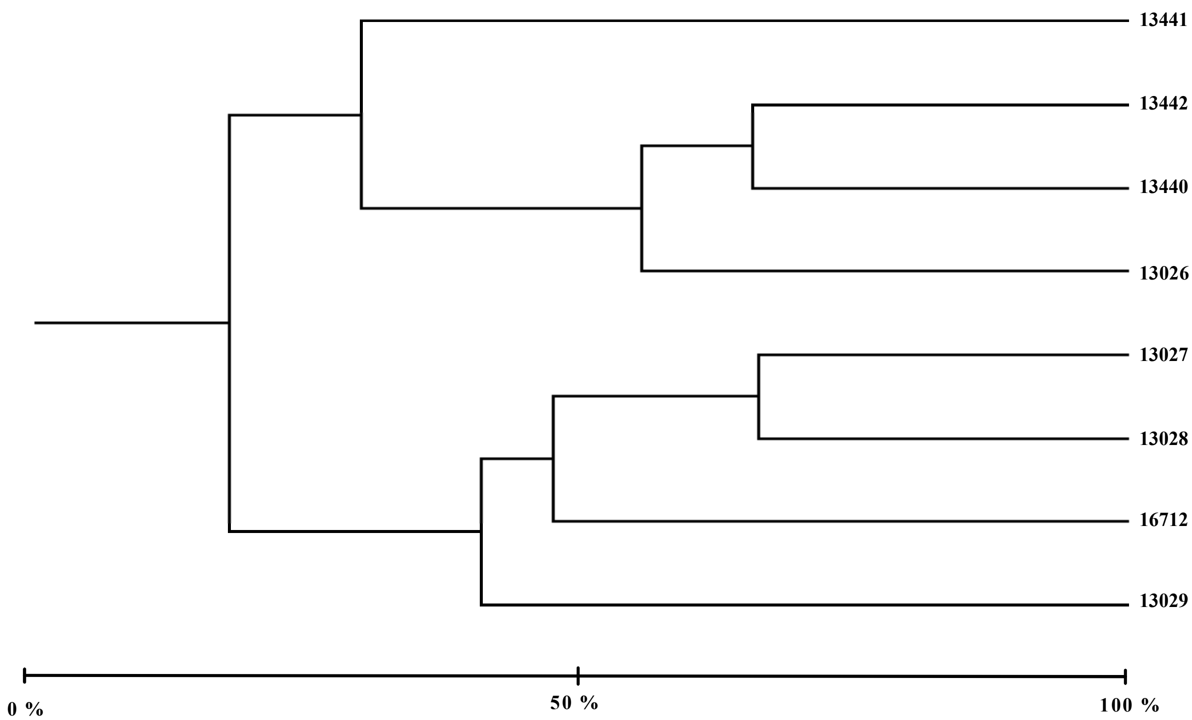

Fig. 63. Dendogram for hierarchical clustering of all stations, using group-average linking of Brays-Curtis similarities calculated on Log_{10} (n +1) transformed epifaunal invertebrate and nekton abundance data.

STATION SUMMARIES AND CONCLUSIONS

Station 13029

Located the farthest upstream, this station is above any potential influences to water quality that were examined during this study. However, the Robstown Wastewater Treatment Plant, several minor discharges, and numerous acres of agricultural land do contribute much of the constant and runoff flow, respectively, passing this station. These upstream inputs and associated flows, while not investigated during this study, undoubtedly may influence the aquatic habitat and water quality at this station. In general, stream characteristics are different at this station compared to the other sampling stations, with greater amounts of vegetation and a more channelized flow of water observed. Construction material and gravel also exist at the sampling location due to the proximity of the FM 763 Bridge located directly downstream.

The top five dominant benthic organisms accounted for 73.9% of the individuals collected (Fig. 54), with chironomids clearly dominating benthic sample collections. While this station produced the lowest number of benthic species collected, it did have the highest diversity and evenness values (Table 6), and of all stations sampled, the dominant benthic species collected represented the lowest total percentage (Fig.54).

Regarding the epifaunal invertebrate and nekton collections, Station 13029 produced the second lowest number of individuals collected overall and the lowest for the Oso Creek stations (Fig. 58). Insects dominated at this location with chironomids representing 50.7% of the total number of individuals collected (Fig. 60). Fish collections showed the highest number of Bayou Killifish and second highest number of Diamond Killifish collected over the year (Fig. 62). In respect to station totals, these two species produced 7.2% and 5.4%, of the total number of station individuals collected. Discounting Station 13441, due to the limited number of samples taken, would again show this station to have the highest diversity and evenness values (Table 7).

While this station appears relatively stable based on these species diversity values, the key species collected indicate stability may actually exist in an aquatic habitat suffering some water quality impairments. While monthly field data reveals lowest means for water temperature, DO, and pH occurring at this station, the field data does not indicate any apparent problems (Table 3). However, water chemistry data does exceed some criteria and definite water quality concerns for Nitrate + Nitrite Nitrogen 58.3% (Fig. 20), Total Phosphorus 91.6% (Fig. 22), and Ortho-Phosphate 75.0% of the time sampled, respectively (Fig. 24). In addition, bacterial contamination concerns may exist as the primary indicator, *E. coli*, exceeded the single grab sample criteria 25.0% (Fig. 46), and the secondary indictor, Fecal Coliform, exceeded the criteria 27.3% (Fig. 48), of the time sampled.

Station 16712

Located below the GWWTP, at the southwestern boundary of the City of Corpus Christi's Elliot Landfill, this station exhibits similar vegetation characteristics to Station 13029, with shoreline vegetation and shading extending down to the streambed. While the stream is substantially wider at this location, the primary differences observed were increased water depth and the substantial soft organic mud layer covering the clay substrate.

This organically enriched substrate allowed oligochaetes to displace chironomids as the dominant benthic species collected at this location and the top five species represented 95.9% of all individuals collected (Fig. 54). Compared to other Oso Creek locations, the greatest number of individuals occurred in benthic samples collected at this location. However, these high numbers produced the lowest species diversity and evenness due to the dominance of oligochaetes collected (Table 6).

Net collections showed this station producing slightly more numbers of individuals collected than upstream station 13029, but the total number of species represented fell from 41 to 26. Species diversity and evenness values were one of the lowest for the entire study, and lowest for all Oso Creek stations (Table 7). Chironomids dominated net collections, producing 82.0% of the total number of individuals collected (Fig. 60). Total number of fish collected was one of the lowest for the entire study, with the fish population dominated by Inland Silversides and Sheepshead Minnow (Fig. 62).

Based on biological information the aquatic habitat appears to be impaired. The field data showed slightly higher water temperature, DO, and pH values recorded at this station than Station 13029, but again no apparent problems are indicated as the values are not excessive (Table 3).

Water chemistry data at this location indicates a similar picture to upstream Station 13029. While there was only one exceedance (approximately 2.5 times the screening level) of the Ammonia Nitrogen criteria during the study, Station 16712 exhibited the highest overall mean Ammonia Nitrogen levels for all Oso Creek stations (Fig. 18). Nitrate + Nitrite Nitrogen (Fig. 20) also exhibited the highest mean Oso Creek levels, exceeding criteria 83.3%, Total Phosphorus and Ortho-Phosphate showed exceedance 50.0% (Figs. 22 and 24), and Chlorophyll *a* exceeded the criteria 33.3% (Fig. 26), of the times sampled, respectively. Dense algal blooms often occur at this location and there may be bacterial contamination concerns as the primary indicator, *E. coli*, exceeded the single grab sample criteria 25.0% (Fig. 46), and the secondary indictor, Fecal Coliform, exceeded the criteria 16.6% (Fig. 48), of the time sampled.

Station 13028

Located downstream from Station 16712 and the City of Corpus Christi's Elliot Landfill, this station had varying depths in the sample area ranging from 0.5 to 1.0 m with some areas greater than 1.5 m and as was seen at Station 16712, a substantial soft organic mud layer covers the bottom clay substrate. In addition to receiving inputs from upstream locations, an open ditch to the southwest, and a storm drain on the east side of the bridge, delivers runoff to this area during rain events from agricultural and municipal sources. Location of this station directly downstream of the SH 286, or Ayers Road Bridge, makes this station very accessible, and subject to extreme anthropogenic disturbances that run the gamut from dumping of building materials to small household items, dead animals, and general litter.

Oligochaetes continued to dominate benthic collections at this location but increased collections of the polychaete, *Hobsonia florida*, began to occur at this location (Fig. 54). The top five species represented 96.5% of all individuals collected and species diversity and evenness increased at this location from Station 16712 upstream.

Net collections showed this station producing the second greatest number of individuals collected in Oso Creek, but the total number of species represented was the lowest for Oso Creek. Species diversity and evenness values were the second highest for Oso Creek and third highest for all eight stations sampled (Table 7). The top four species represented 89.9% of the individuals collected at the station and distribution was more even than seen at the first two stations, with the Daggerblade Grass Shrimp accounting for 48.0% of the individuals collected (Fig. 60). Total number of fish collected at this station was the highest amount for all stations in the study, with the Diamond Killifish dominating collections (Fig. 62). The other top five fish collected, except the Naked Goby, appeared in equal numbers.

Although species diversity is higher than some of the other stations sampled, the aquatic habitat appears dominated by species that may indicate stressful environmental conditions. In addition, the field data begins to reveal increased ranges and means for DO and pH values. While the values do not appear excessive, they are indicative of an upward trend in the progression downstream (Table 3).

However, as previously seen, water chemistry data indicates potential problems and definite concerns with Nitrate + Nitrite Nitrogen (Fig. 20) exceeding criteria 58.3%, Total Phosphorus exceeding 25.0%, (two other readings fell just below the criteria) (Fig. 22), and Chlorophyll *a* exceeded the criteria 50.0% (Fig. 26), of the times sampled, respectively. Past research shows that dense algal blooms have occurred at this location over the years (Bowman and Jennings 1992). Bacterial contamination concerns center on the primary indicator, *E. coli*, and the secondary indictor, Fecal Coliform, exceeding criteria 25.0%, of the time sampled (Figs 46 and 48).

Station 13027

The sampling location is adjacent and downstream of the bridge where State Highway 2444 or Staples Street crosses Oso Creek. Vegetation characteristics are similar to Station 13028, but while vegetation grows down to the streambed, urban development of the surrounding areas removed most trees and much of the shrub within the area. One of the wider points on Oso Creek, this shallow water (0.15 to 0.70 m), low gradient location exhibits little flow. Bottom sediments are clay, covered by a substantial soft organic mud layer. A storm drain on the northeast side of the bridge, delivers runoff from the residential area to the creek. Like Station 13028, this area also serves as a constant dumping ground for debris.

Chironomids dominated this organically enriched substrate, representing 59.5% of the total number of individuals. This location produced the second greatest number of individuals collected, with the top five benthic species representing 95.4% of all individuals collected (Fig. 54). Species diversity and evenness values were the second highest and third lowest recorded, respectively (Table 6). However, net collections revealed this station producing the greatest numbers of individuals collected for all stations sampled in Oso Creek or Oso Bay (Fig. 58) but species diversity and evenness values were one of the lowest (Table 7). Corixidae dominated net collections, producing 63.4% of the total number of individuals collected (Fig. 60). The first occurrence of commercially important species occurred at this station with the collection of Blue Crab and Brown Shrimp (Fig. 61). Total number of fish collected was one of the lowest for the entire study, with the fish population dominated by Sheepshead Minnow and Inland Silversides (Fig. 62).

Historically this area exhibits some of the greatest anthropogenic disturbances to Oso Creek. Bowman and Jennings (1992) speak of brine discharges, drilling mud, agricultural chemical runoff, and municipal wastes above and below the sampling location contributing to substantial algal blooms and eutrophic conditions. Based on data from this study, it appears that as in past years, the aquatic habitat at this station is severely impaired and warrants concern. Field data recorded shows this station having one of the highest mean water temperatures, and the highest recorded maximums, greatest ranges, and mean DO and pH concentrations of any station in this study (Table 3). In addition, mean DO % saturation was the highest recorded at 135.4%. Water chemistry data shows that Nitrate + Nitrite Nitrogen (Fig. 20), exceeded criteria for 33.3%, and Chlorophyll *a* exceeded the criteria 83.3% (Fig. 26), of the times sampled, respectively. While the other nutrients (Total Phosphorus and Ortho-phosphorus) did not exceed screening levels for more than 16.6% of the time sampled, it appears that this station acts as a "processor" for excessive nutrient and water chemistry parameters. Dense algal blooms occurred at this location during this study, with DO concentrations exceeding 20.0 mg l^{-1} and DO % saturation exceeding 200.0%. While no documented data exists, the aquatic system at this location most likely "crashed", as increased biological oxygen demand on the system from microbial decomposition of dead phytoplankton most likely depleted DO levels during the night (no nightly DO sampling occurred at this station) or in the days following the bloom.

Possible bacterial concerns may center on the fact that although the primary indicator, *E. coli*, exceeded the single grab sample criteria only 8.3% of the time sampled (Fig. 46), this station recorded the highest overall mean concentrations for the year because of this one event (8650 CFU/100 ml). The secondary indictor, Fecal Coliform, exceeded the criteria 16.6% (Fig. 48), of the time sampled, and had the highest mean concentrations for the year due to the same one-time event.

Station 13026

A direct influence on the water quality and substrate characteristics surrounding this location is the CP&L-BD cooling ponds outfall located approximately 1000 m upstream of where the Yorktown Road Bridge crosses Oso Bay. The sampling area is adjacent and upstream of the bridge and water depth in the sample area ranges from 0.20 to 1.3 m. A large amount of tidal flat area exists. Access allows people to use the area heavily, often driving vehicles across open tidal flats. This results in large amounts of debris deposited on the shoreline.

The sampling area is composed of a hard clay substrate often impenetrable by the benthic coring device used in this study. Near shore, the substrate transitions to a finer clay and silt composition mixed with patches of sand. Patches of seagrass, *Halodule beaudettei* exists in this location, while full seagrass meadows exist just below the discharge outlet to the south. West of the discharge, water depths become extremely shallow as Oso Creek enters the upper reach of Oso Bay. Typically, average water depth is < 0.40 m and sometimes may become even shallower if low flow conditions exists. High salinity water discharged from the outfalls rapidly becomes brackish in Oso Creek, as the primary direction of flow is north through Oso Bay to Corpus Christi Bay.

Polychaetes dominated benthic collections with *Streblospio benedicti* representing 69.8% of the individuals collected (Fig. 54). The top five species represented 79.2% of all individuals collected and this station yielded the second highest number of individuals collected. Tied for the most number of species collected with Station 13442, Station 13026 had the third highest species diversity of all eight stations, and the second highest species diversity of the Oso Bay stations. Evenness values were low due to the dominance of *S. benedicti* (Table 6)

Net collections produced the second greatest number of individuals collected in Oso Bay and the third highest number of species. The overwhelming dominance of one species affected species diversity (lowest) and evenness values (second lowest) (Table 7). The top four species represented 91.1% of the individuals collected at the station with the Daggerblade Grass Shrimp accounting for 83.7% of the individuals collected (Fig. 60). Some Blue Crab and Brown Shrimp appeared in collections but the total numbers were low (Fig. 61). Total number of fish collected at this station was the second lowest amount for all stations in the study, with the Naked Goby and Inland Silversides dominating fish collections (Fig. 62).

Leaving Oso Creek and entering into the upper reaches of Oso Bay changed habitat characteristics and introduced new stresses. Mean salinity increased to the second highest levels, and the maximum, range, and mean DO levels recorded reached the lowest levels encountered in the study. Water temperature was similar but the range was narrow as the heated water from the discharge allowed for only minor fluctuations. pH was not a concern, as concentrations were average for the area (Table 3).

Water chemistry data indicates very little in the way of concerns at Station 13026. Mean levels of nutrients and chlorophyll *a* were some of the lowest recorded for the study. Even though this station had the lowest mean concentrations, bacterial contamination concerns center on the primary indicator, enterococci, exceeding the criteria 25.0%, and the secondary indictor, Fecal Coliform, exceeding the criteria 33.3%, of the time sampled (Figs. 47 and 49).

Station 13440

Located in mid bay, where State highway 358 or South Padre Island Drive crosses Oso Bay, this station is similar to Station 13026 in that the clearing of vegetation during bridge construction resulted in the shoreline being bare or covered in riprap to control erosion. Adjacent and downstream of the bridge the sampling area has bottom sediments that are primarily a soft clay/sand composition. Water depth ranged from 0.30 to 0.80 m with some areas greater than 1.0 m and seagrass beds composed of *Halodule beaudettei* exist to the north side of the station. Prevailing southeasterly winds constantly mix the water within this area of Oso Bay. Easy access fortunately makes this an attractive spot for anglers but as seen at other stations, unfortunately this often results in trash/debris deposited on the shoreline.

This station yielded the third highest number of benthic species collected and polychaetes completely dominated benthic cores, with *Streblospio benedicti* representing 91.5% of the individuals collected (Fig. 54). The top five species represented 93.5% of all individuals collected and this station yielded the third highest number of individuals collected. Species diversity and evenness was lowest of all stations sampled due to the dominance of *S. benedicti* (Table 6)

Net collections showed this station producing the greatest number of individuals collected in Oso Bay and the highest number of nekton species. The overwhelming dominance of one species affected species diversity (second lowest) and evenness values (lowest) (Table 7). The top four species represented 92.1% of the individuals collected at the station with the Daggerblade Grass Shrimp accounting for 79.7% of the individuals collected (Fig. 60). Blue Crab, Brown Shrimp, and juvenile shrimp species appeared in greater numbers than Station 13026 (Fig. 61). Total number of fish collected at this station was the fourth highest amount for all stations in the study, and second highest for Oso Bay stations. The Naked Goby dominated fish collections (Fig. 62).

Habitat stresses focused on mean salinity increasing to the highest levels recorded, with a maximum reading of 51.4 ppt. DO levels recorded yielded the lowest minimum at 2.1 mg l^{-1}, and mean DO levels recorded were equal to the low recorded at Station 13026 of 5.4 mg l^{-1}. Mean DO % saturation levels were also low at 78.7%. Water temperature was slightly lower than most other stations and pH was not a concern as concentrations were average for the area (Table 3).

Water chemistry data indicates very little in the way of concerns at Station 13440 with only one parameter exceeding criteria one time (Total Phosphorus – Fig. 17). Mean levels of nutrients and chlorophyll *a* were some of the lowest recorded for the study. However, some concerns exist for bacterial contamination with the primary indicator, enterococci, exceeding the criteria 50.0%, and the secondary indictor, Fecal Coliform, exceeding the criteria 66.6%, of the time sampled (Figs. 41 and 43).

Station 13441

As stated earlier, located west of Ward Island at the Hans Suter Wildlife Refuge and adjacent to the OWWTP, this station is unique in that released treated wastewater creates freshwater wetlands that transcend to the bay, with much of the area surrounded by low, mid, and high marsh vegetation. In addition, large numbers of aquatic birds occur at this location on a regular basis and may have an influence on bacterial concentrations observed during this study. Within the entire sampling area, much of the hard clay substrate encountered had an overlying layer of black organic material that typically produces a strong hydrogen sulfide smell. The potential for considerable mixing from the prevailing southeasterly winds when water levels are high is possible in this typically low energy environment. However, low water levels at this location usually result in a visible freshwater plume that flows out and mixes with the higher saline waters of Oso Bay before entering Corpus Christi Bay.

This station yielded one of the lowest number of benthic species collected (Table 6). The top five species represented 95.8% of all individuals collected at this location (Fig. 54) and yielded the second lowest number of individuals collected for all stations (Fig. 52). While polychaetes completely dominated benthic cores, with *Capitella capitata* accounting for 42.8% and *Streblospio benedicti* representing 75.9% of the individuals collected, chironomids and oligochaetes also occurred in samples (Fig. 54). While low numbers of individuals occurred at this station, the relatively equal distribution of four of the top five species produced the second highest species diversity and evenness values (Table 6).

Net collections revealed this station producing the lowest number of species and individuals collected of all stations (Please keep in mind that this station was sampled for only four out of the twelve months due to low water conditions) (Table 7). The top four species encountered for all stations only represented 20.0% of the individuals collected at this station. The Daggerblade Grass Shrimp accounted for the 14.3%, followed by chironomids at 4.8%, of the number of individuals collected at this location (Fig. 60). The low number of species and individuals collected resulted in the highest species diversity and evenness values (Table 7). While the numbers are low, a relatively equal number of Blue Crab, White Shrimp, and Brown Shrimp appeared at this location (Fig. 61) and the Inland Silversides dominated fish collections (Fig. 62). The assumption might be that this area may support a stable, but highly stressed biological community.

Overall, conditions at this station do reveal a highly stressed habitat. This station differs from the other Oso Bay stations in that the surrounding tidal flats are subjected to extended periods of emergence, which results in additional stressors on the biological community. While not excessive for this region, the maximum, range, and mean water temperature values recorded were high. Mean salinity values were low but the range was substantial due to the inputs from the OWWTP and the general mixing of water within the area. Mean DO levels were one of the highest recorded but the range and maximum values show extreme fluctuations. Regarding pH this station produced the lowest mean value but range and maximum values were higher than those recorded at other stations (Table 3).

Although Station 13441 is located in Oso Bay, the influence exerted by inputs from the OWWTP produced many similarities to Oso Creek stations. As previously seen at some of the Oso Creek stations, water chemistry data indicates potential problems and definite concerns for surface water quality. Mean levels for all nutrients and chlorophyll *a* were highest, for those stations within Oso Bay, and exceeded screening criteria numerous times throughout the study, with Ammonia, Nitrate + Nitrite, Total Phosphorus, and Chlorophyll *a* exceeding criteria for 100.0%, 75.0%, 83.3%, and 25.0% of the time sampled, respectively (Figs. 19, 21, 23, and 27). A high degree of concern exists with bacterial contamination as the primary indicator, enterococci (Fig. 47), and the secondary indictor, Fecal Coliform (Fig. 49), exceeded criteria 91.6% and 83.3%, of the time sampled. Even using the primary indicator for tidal streams, as there is a strong freshwater influence at this location, produces the primary indicator criteria, *E. coli*, exceeding levels by 33.3%.

Station 13442

The predominant features of this station, located where Oso Bay connects with Corpus Christi Bay, are the high rates of tidal exchange that induce significant wash and scour effects. The sampling area is adjacent and upstream of the bridge and bottom sediments include broken shell and sand over clay substrate. Water depth within the sampling area ranged from 0.30 to 0.50 m with areas greater than 1.0 m located in the channel under the bridge. Seagrass beds composed of *Halodule beaudettei* exist on the southern portion of the sampling area. As with Station 13026 and 13440, vegetation clearing during bridge construction resulted in much of the shoreline being bare or covered in riprap to control erosion. As seen at other stations, people have easy access to the water and this often results in debris deposited on the shoreline in the immediate area.

This station yielded one of the highest number of benthic species collected with the core sampler (Table 6). The top five species represented 89.3% of all individuals collected at this location and yielded the highest number of individuals collected for all stations (Fig. 52). Polychaetes completely dominated benthic cores, with *Streblospio benedicti* representing 75.9% of the individuals collected (Fig. 54). Species diversity and evenness was second lowest of all stations sampled due to the dominance of *S. benedicti* (Table 6)

Net collections showed this station producing the third lowest number of individuals collected in Oso Bay but produce the second highest number of individual species (Table 7). Of the top four species collected during the study, only the Daggerblade Grass Shrimp occurred, accounting for the 73.9% of the individuals collected (Fig. 60). This dominance produced average species diversity but evenness was low (Table 7). The highest number of Brown Shrimp and Blue Crab appeared at this location (Fig. 61). The Naked Goby dominated fish collections and the total number of fish collected at this station was the third highest amount for all stations, and the highest amount for Oso Bay stations, based on 12 sampling events (Station 13441 shows a higher mean CPUE due to the limited number of sampling events) (Fig. 62).

Overall, the conditions at this station appear to reveal a healthy habitat. The influence of Corpus Christi Bay, due to good tidal exchange, made habitat stresses hard to discern at this location. Mean water temperature, salinity, DO, and pH levels recorded represented relatively typical values for this area (Table 3).

Water chemistry data did indicate Ammonia, Nitrate + Nitrite, Total Phosphorus, and Chlorophyll *a* parameters occasionally exceeding criteria (Figs. 19, 21, 23, and 27) but the highest percent any one parameter exceeded criteria was 16.6%. However, some concerns may exist for bacterial contamination with the primary indicator, enterococci, exceeding the criteria 33.3%, and the secondary indictor, Fecal Coliform, exceeding the criteria 66.6%, of the time sampled (Figs. 47 and 49). High levels of bacteria may be due to the general flow of water leaving the OWWTP. Typically, flow travels along the southern, then eastern, edge of Ward Island and then down the shoreline along Ocean Drive to the point that it reaches the bridge, at which time it flows out into Corpus Christi Bay.

CONCLUSION

Based on data collected, results suggest that significant concerns exist for nutrient loadings, bacterial contamination, and DO concentrations, within the Oso Creek/Oso Bay system. The low natural flow conditions that exist within Oso Creek allow effluent from permitted municipal discharges to be the dominant source of flow. This source of nutrient loadings ultimately exhibits a strong influence on the water quality and aquatic life within the area. However, without these flows Oso Creek would most likely have no significant flow, thereby establishing a unique paradox within this system.

Within Oso Creek, nutrient and chlorophyll *a* parameters exceeded criteria in such large percentages that unfortunately, exceedance was the normal condition of the water body. The data presented shows how these loadings ultimately affect other water quality parameters. A clear demonstration of this is the steady progression downstream in which the maximum, range, and mean DO (grab samples only) and pH concentrations increased to a point that the farthest downstream station sampled on Oso Creek (13027) exhibited such wide fluctuations it resulted in dense algal blooms and generally poor habitat conditions.

The lower stretch of Oso Creek, from just above Station 13027 to Station 13026 in Oso Bay, appears to act as a sink for all constituents within the system. Due to the natural low gradient of the streambed, and persistent low flow conditions, nutrients are contained in the system for long periods and large amounts of suspended organic material accumulate within the sediments. Eventually periodic intense precipitation results in flooding of Oso Creek and causes the re-suspension of sediments that flush downstream and out into Oso Bay. In addition, based on biological species information gathered, supporting evidence exists for the poor water quality and habitat assessment, as often-cited indicator species such as oligochaetes and chironomids completely dominated Oso Creek sample collections.

Within Oso Bay (Segment 2485), water quality was considerably better, the exception being Station 13441 located below the OWWTP. The excessive exceedance of nutrient and chlorophyll *a* criteria, wide fluctuations in water quality parameters, and the resultant algal blooms seen in Oso Creek did not occur in most of Oso Bay. The combined effect of significant amounts of Upper Laguna Madre water discharged through the CP&L-BD plant and the larger water body most likely served to absorb the inputs from Oso Creek and buffer most other influences on water quality.

Biological information indicates that many species of aquatic organisms exist within Oso Bay, with most stations producing a high species richness and abundance, except for the biological community around the OWWTP. However, within all station communities there tended to be a few species that dominated collections. While the biological community at Station 13441 did have high species diversity and evenness value, as calculated on the lower numbers of species and individuals collected, it appeared to be indicative of what could best be called a “stable-stressed” environment.

In addition to the influence of inputs from the OWWTP, possible additional stressors on the biological community at Station 13441 may result from the surrounding tidal flats subjected to extended periods of emergence during various times of the year. Most of the species collected at all Oso Bay stations are prevalent within the region, and while not necessarily indicative of poor water quality or habitat conditions, they serve as indicators of stressful environments. These stresses commonly relate to a number of varying parameters such as high or extreme fluctuations in salinity or low or extreme fluctuations in DO. The primary question one might ask of Oso Bay is, "Does an abundance of stressed organisms equal impairment of the water body". Regarding biological indicators, it appears that in most areas within this region the species collected are quite typical and have appeared in collections from various studies over many years. On the surface, the answer to the question appears to be it does not mean the segment is impaired.

However, when one takes into consideration all the data, definite concerns do exist for bacterial contamination, and depressed DO concentrations within Oso Bay. Additional concerns definitely exist for the area surrounding the OWWTP as nutrient screening criteria for Ammonia, Nitrate + Nitrite, Total Phosphorus, and Chlorophyll *a* exceeded criteria 100.0%, 75.0%, 83.3%, and 25.0% of the time sampled, respectively.

As bacterial indicators routinely exceeded standards, there is a definite concern for the Non-Support of the Oyster Water use designation currently assigned to Oso Bay. Even a reclassification to a contact recreation area using the new indicator, *Enterococci*, would not improve the situation. Based on a screening level of 89 CFU/100 ml Stations 13026, 13440, 13441, and 13442 would be listed as Non-Supporting, with criteria exceeded by 25.0%, 50.0%, 91.6%, and 33.3% of the time sampled, respectively. Even using fecal coliform as the indicator, with the higher screening criteria of 400 CFU/100 ml, would elicit some concerns, with criteria exceeded by 41.6% (Non-Support) at Station 13441, and by 16.6% (Partial Support) at Stations 13440 and 13442 of the time sampled, respectively.

Regarding depressed DO conditions; clearly, the shallow nature of this bay system plays a large part in the naturally occurring fluctuations of this important aquatic life parameter. Analysis of the data shows wide diurnal fluctuations that are common and expected in such a shallow, warm water, highly saline system typical of South Texas. While the exceptional habitat designation for Oso Bay may be justified, it is clear that the natural hydrodynamics of this system, coupled with the nutrient loadings from the OWWTP, play a critical part in DO levels occurring in this bay system.

As seen with grab sample DO measurements, the continuously collected 24-hour DO data reflected daily and seasonal cycles experienced in this shallow, effluent dominated system (Appendix II). Interestingly, the reference station (17121) in the Upper Laguna Madre (listed as exceptional habitat), with similar characteristics to Oso Bay concerning shallow depths, warm waters, and hypersaline conditions, failed to meet the criteria as much as the Oso Bay stations. Currently, Segment 2491 – Upper Laguna Madre is on the Year 2000 303(d) list for depressed DO levels in the upper third portion of the Laguna Madre.

While not influenced by effluent or warm water discharges, this shallow depth station (17121) is located in highly productive seagrass beds endemic to the Upper Laguna Madre system. Increased biological activity, associated with the daily regime of oxygen production through photosynthesis, and oxygen consumption through respiration, clearly influences DO concentrations seen in the water column; and is indicative of naturally occurring DO levels experienced in portions of many shallow, hypersaline bays throughout South Texas. It is clear that prevailing conditions associated with each of these unique areas presents a problem in accurately assessing support of aquatic life criteria. Listed on the 303d list as exhibiting partial or non-support of the DO standard, these are natural fluctuations within water bodies of the region and the possibility exists that the standard for exceptional habitat designation will never be attainable. Should a downgrade in habitat classification occur or should there be a site specific standard developed for the water body, perhaps information gathered in this study provides necessary data to begin discussions to eventually answer this question.

While the DO standard may be difficult to attain under present conditions, recommendations at this time center on the concerted effort to bring all stakeholders to the table to discuss the nutrient loadings and general conditions that exist within this unique, but totally effluent dominated system. This next step is vital in meeting the TNRCC TMDL initiative of assessing pollution levels entering a water body, from both point and non-point sources, and establishing limits, standards, and criteria screening levels that accurately reflect the water body in question and that are suitable to supporting aquatic life and protecting public health. In addition, based on data collected within this and similar systems in the State of Texas, the opportunity may exist to assess whether a variable DO criteria based on the relationship between salinity and temperature may be more appropriate for assessing water quality; rather than the present fixed numerical criteria system.

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APPENDIX I. Historical annotated data review of water/sediment quality, and biological studies within the Oso Bay system.

Water and Sediment Quality Studies

HDR Engineering, Inc., Shiner, Mosley, & Associates, Inc., Naismith Engineering, Inc., in association with University of Texas Marine Science Institute. 1991. Nueces Estuary Regional Wastewater Planning Study - Phase I. Prepared for the City of Corpus Christi, Port of Corpus Christi Authority, Corpus Christi Board of Trade, South Texas Water Authority, and Texas Water Development Board. Austin, Texas

The historical impacts of municipal wastewater returns and the discharge of saltwater via Central Power & Light – Barney Davis Power Plant were evaluated. Results include: vegetative cover increase and localized channels.

Heilman, S., J.B. Mott, and B.A. Nicolau. 1999. Fecal Coliforms, Enterococci, *E. coli*, and Total Coliforms as Indicators of Water Quality in Oso Bay, Corpus Christi, Texas. Texas A&M University-Corpus Christi, Center for Coastal Studies Technical Report No. TAMU-CC-0001-CCS. 61 pp.

Researchers conducted a one-year survey of bacterial indicators present in Oso Bay. Bacterial densities were correlated with freshwater outflows, shorebird usage, weather, and salinity. Bacterial densities were highest near a wastewater treatment plant with heavy bird usage. Bacterial densities were also associated with significant rainfall events, with lower densities occurring during drought conditions and warmer air temperatures.

Hollyfield, S. and V.K. Sharma. 1995. Organic Contaminants and Characteristics of sediments in Oso Bay, South Texas, USA. Environmental Geology 25:137.

Research addressed the contamination present in Oso Bay through the analysis of organics present in the water at nine sites located in Oso Creek and Oso Bay. Results suggest that Oso Bay contains common bay margin sediments.

TNRCC. 1994. Regional Assessment of Water Quality in the Nueces Coastal Basins. TNRCC Report AS-35. Austin, Texas.

TNRCC. 1996. Regional Assessment of Water Quality in the Nueces Coastal Basins. TNRCC Report SFR-44. Austin, Texas.

The Texas Clean Rivers Act requires assessments of water quality be conducted in each river basin in the State of Texas. The purpose of these biennial reports is to provide information on the management and status of water quality.

Watson, R. 1991. Oso Bay tide and discharge study. Pp 1-7, *in* Hydrologic study of water exchange structures - Blind Oso habitat enhancement program. Report to the City of Corpus Christi. Corpus Christi, Texas. 15 pp.

Water exchange structures in Oso Bay were evaluated in conjunction with the Blind Oso Habitat Enhancement Program for the City of Corpus Christi. Specifications for a larger connection between the Blind Oso and Corpus Christi Bay were recommended in the report.

Biological Studies

Carrillo, T. B. 2000. Historic Vegetation Changes in the Blind Oso (Oso Bay), Texas; Avian Abundance and Habitat Use of the Resulting Wetland Mosaic. Master Thesis. Texas A&M University-Corpus Christi, Texas. 164 pp.

Evaluated historic vegetation changes in Oso Bay (Blind Oso) and the effects of these changes on avian abundance and habitat use of the area. Management suggestions include the exclusion of vehicular and pedestrian traffic in the Blind Oso to provide protection to nesting bird species.

Goebel, L. 1977. Water Birds of Oso Bay, Corpus Christi, Texas. Unpublished Report to Corpus Christi Museum of Science and History, Corpus Christi, Texas 23 pp.

Surveyed bird populations of Oso Bay from 1973 to 1977. One hundred and nine species of water birds were recorded. Common species included: White Pelican, Great Blue Heron, Snowy Egret, Willet, and Laughing Gull.

Hildebrand, H. H. and D. King. 1979. A biological study of the Cayo del Oso and the Pita Island area of the Laguna Madre. Final Report 1972-1978 to Central Power and Light Co. Corpus Christi, Texas. 2 vols. 472 pp.

An extensive six-year study (1972-1978) was conducted to examine the biology of the Cayo del Oso (Oso Bay), both before and after the construction of the Central Power & Light Company - Barney Davis Power Plant. The crustaceans, *Penaeus setiferus, Penaeus aztecus,* and the fishes, *Micropogon undulatus, Sciaenops ocellata,* and *Brevoortia patronus*, were reported as important species of Oso Bay. Notable changes during the study include the increase of the seagrass, *Halodule wrightii*, in the previously muddy substrate of the Cayo del Oso

Morton, R.A. and J.G. Paine. 1984. Historical Shoreline Changes in Corpus Christi, Oso, and Nueces Bays, Texas Gulf Coast. Bureau of Economic Geology, University of Texas. Austin, Texas. 66 pp.

The stability of shorelines in the Corpus Christi area was determined from studying historical maps and photographs. Results indicated that unprotected shorelines were retreating in the area

O'Brien, R. 1995. A Study of the Vegetation of Hans Suter Wildlife Area.

Vegetation present at the Hans Suter Wildlife Area, adjacent to Oso Bay and the wastewater treatment plant was quantitatively surveyed and characterized in the spring of 1995. Dominant upland vegetation includes: the brush species, *Acacia rigidula* and *Pithecellobium flexicaule,* and the grass *Panicum maximum*; while, saltmarsh vegetation present includes: *Batis maritima* and *Borrechia frutescens*.

Tunnell, J.W. 1991. An Annotated Checklist of the Fauna and Flora of Oso Bay, Nueces County, Texas.

In 1991, the Center for Coastal Studies prepared an internal annotated checklist of the fauna and flora of Oso Bay. This document was integrated into the "*Current Status and Historical Trends of the Estuarine Living Resources within the Corpus Christi Bay National Estuary Program Study Area*" published in January 1996 (CCBNEP-06 – 4 Volumes). A review of the literature, both published and unpublished, available at the time is also presented.

Tunnell, J.W. 1991. Final Report: Blind Oso habitat enhancement program. Corpus Christi State University, Center for Coastal Studies. CCSU-9102-CCS. Corpus Christi, Texas. 15 pp.

A Blind Oso Habitat Enhancement program was presented to the City of Corpus Christi as mitigation for seagrass damage in other areas of the Coastal Bend. Human impacts to the Blind Oso include: roadway impoundments, wastewater discharge, pipelines, and housing developments. The project was terminated due to the presence of a federally protected species, the Piping Plover.

Withers, K. and B. R. Chapman. 1993. Seasonal Abundance and Habitat use of Shorebirds on an Oso Bay Mudflat, Corpus Christi, Texas. Journal of Field Ornithology. 64:382-392.

Researchers conducted a one-year study of shorebird populations that utilize the wind-tidal mudflats surrounding Oso Bay (Blind Oso). Shorebird usage of the area was highest during the winter and early spring, while the lowest usage occurred during the summer months. The highest species diversity, however, was observed during fall migration.

Withers, K. and J.W. Tunnell. 1998. Identification of Tidal Flat Alterations and Determination of Effects on Biological Productivity of These Habitats Within the Coastal Bend. CCBNEP-26. Corpus Christi Bay National Estuary Program, Corpus Christ, Texas. 171 pp.

Trends in tidal flat alterations and biological productivity for the Corpus Christi Bay National Estuary Program Study Area were evaluated, including the tidal flats associated with Oso Bay. The Blind Oso tidal flat was characterized by relatively high species richness with moderate organic enrichment.

APPENDIX II. Continuously collected 24-hour Dissolved Oxygen data (Bold indicates the portion of the readings collected within the index period of March 15 through October 15). No data reported represents failure to meet QA/QC requirements).

Station 17121 – Upper Laguna Madre 0.7 km Southeast of Yorktown Road

Date	Minimum	Maximum	Range	24-Hr Mean	< 5.0 mg l^{-1}
08/22/2000	**1.06**	**4.36**	**3.30**	**3.14**	√
08/30/2000	**-**	**-**	**-**	**-**	
09/06/2000	**-**	**-**	**-**	**-**	
09/13/2000	**1.27**	**5.23**	**3.96**	**3.05**	√
09/20/2000	**-**	**-**	**-**	**-**	
09/26/2000	**-**	**-**	**-**	**-**	
10/05/2001	**-**	**-**	**-**	**-**	
10/11/2000	**6.36**	**11.72**	**5.36**	**8.40**	
10/18/2000	-	-	-	-	
10/25/2000	3.31	7.42	4.11	5.22	
11/01/2000	-	-	-	-	
11/08/2000	-	-	-	-	
11/15/2000	-	-	-	-	
11/22/2000	-	-	-	-	
11/29/2000	4.50	7.12	2.62	5.64	
12/06/2000	-	-	-	-	
12/13/2000	-	-	-	-	
12/20/2000	4.54	8.32	3.78	6.62	
12/27/2000	-	-	-	-	
01/02/2001	-	-	-	-	
01/09/2001	6.39	8.47	2.08	7.20	
01/16/2001	-	-	-	-	
01/23/2001	4.90	8.56	3.66	7.32	
01/30/2001	-	-	-	-	
02/06/2001	4.75	7.51	2.76	5.47	
02/13/2001	-	-	-	-	
02/20/2001	-	-	-	-	
02/27/2001	-	-	-	-	
03/02/2001	5.60	7.79	2.19	6.83	

Station 17121 (continued).

Date	Minimum	Maximum	Range	24-Hr Mean	< 5.0 mg l⁻¹
03/12/2001	3.87	10.38	6.51	6.38	
03/20/2001	-	-	-	-	
03/27/2001	-	-	-	-	
04/03/2001	3.28	8.81	5.53	5.44	
04/10/2001	-	-	-	-	
04/17/2001	-	-	-	-	
04/24/2001	3.32	10.36	7.04	6.09	
05/01/2001	-	-	-	-	
05/08/2001	-	-	-	-	
05/15/2001	3.88	8.38	4.50	5.46	
05/22/2001	2.54	7.96	5.42	4.36	√
05/29/2001	3.03	8.32	5.29	5.42	
06/05/2001	-	-	-	-	
06/12/2001	3.18	6.96	3.78	4.88	√
06/19/2001	1.99	8.04	6.05	5.01	
06/26/2001	2.18	9.06	6.88	5.13	
07/03/2001	-	-	-	-	
07/10/2001	2.80	9.27	6.47	4.73	√
07/17/2001	1.64	7.67	6.03	4.66	√
07/24/2001	-	-	-	-	
07/31/2001	-	-	-	-	
08/07/2001	2.80	6.53	3.73	4.80	√
08/14/2001	1.22	7.90	6.68	5.18	
08/21/2001	1.68	9.53	7.85	4.61	√
08/28/2001	-	-	-	-	
09/04/2001	1.06	6.62	5.56	3.49	√
09/11/2001	0.39	8.83	8.44	4.96	√
09/18/2001	-	-	-	-	
09/25/2001	0.11	9.38	9.27	5.77	
10/02/2001	2.92	11.54	8.62	7.57	
10/09/2001	0.11	7.78	7.67	4.92	√

Station 17120 – Oso Bay @ Yorktown Road

Date	Minimum	Maximum	Range	24-Hr Mean	< 5.0 mg l^{-1}
08/18/2000	**3.05**	**6.71**	**3.66**	**4.89**	√
08/22/2000	-	-	-	-	
08/31/2000	-	-	-	-	
09/07/2000	-	-	-	-	
09/13/2000	-	-	-	-	
09/20/2000	-	-	-	-	
09/26/2000	-	-	-	-	
10/05/2001	-	-	-	-	
10/11/2000	-	-	-	-	
10/18/2000	-	-	-	-	
10/25/2000	3.57	9.36	5.79	6.19	
11/01/2000	-	-	-	-	
11/08/2000	-	-	-	-	
11/15/2000	6.43	9.95	3.52	8.01	
11/21/2000	-	-	-	-	
11/29/2000	3.80	8.15	4.35	5.64	
12/06/2000	-	-	-	-	
12/13/2000	-	-	-	-	
12/20/2000	5.98	10.23	4.25	7.91	
12/27/2000	-	-	-	-	
01/03/2001	-	-	-	-	
01/09/2001	7.13	11.49	4.36	8.69	
01/12/2001	5.75	9.22	3.47	6.82	
01/16/2001	6.23	10.76	4.53	7.90	
01/23/2001	-	-	-	-	
01/30/2001	-	-	-	-	
02/06/2001	5.62	8.95	3.33	6.65	
02/13/2001	-	-	-	-	
02/20/2001	-	-	-	-	
02/27/2001	-	-	-	-	
03/06/2001	-	-	-	-	

Station 17120 (continued).

Date	Minimum	Maximum	Range	24-Hr Mean	< 5.0 mg l^{-1}
03/12/2001	4.15	8.53	4.38	6.32	
03/20/2001	-	-	-	-	
03/26/2001	-	-	-	-	
04/03/2001	3.97	6.82	2.85	5.32	
04/10/2001	-	-	-	-	
04/17/2001	-	-	-	-	
04/24/2001	4.21	7.32	3.11	4.96	√
05/01/2001	3.62	6.29	2.67	4.84	√
05/08/2001	-	-	-	-	
05/15/2001	4.01	6.58	2.57	5.19	
05/22/2001	3.71	8.69	4.98	6.53	
05/29/2001	2.80	4.04	1.24	3.51	√
06/05/2001	-	-	-	-	
06/12/2001	3.16	6.36	3.20	4.82	√
06/19/2001	2.60	6.40	3.80	4.64	√
06/26/2001	5.38	11.22	5.84	7.32	
07/03/2001	4.15	7.11	2.96	5.46	
07/10/2001	2.45	5.82	3.37	4.22	√
07/17/2001	-	-	-	-	
07/24/2001	3.24	8.70	5.46	5.64	
07/31/2001	2.34	5.76	3.42	3.79	√
08/07/2001	3.04	6.07	3.03	4.31	√
08/14/2001	1.89	5.56	3.67	3.85	√
08/21/2001	2.56	6.66	4.10	4.26	√
08/28/2001	-	-	-	-	
09/04/2001	3.20	4.35	1.15	3.67	√
09/11/2001	-	-	-	-	
09/18/2001	-	-	-	-	
09/25/2001	-	-	-	-	
10/02/2001	3.40	8.00	4.60	5.57	
10/09/2001	-	-	-	-	

APPENDIX II (continued)

Station 17119 – Oso Bay @ Holly Road RR tracks

Date	Minimum	Maximum	Range	24-Hr Mean	< 5.0 mg l^{-1}
08/17/2000	**1.80**	**7.15**	**5.35**	**4.21**	√
08/22/2000	**-**	**-**	**-**	**-**	
08/29/2000	**-**	**-**	**-**	**-**	
09/06/2000	**-**	**-**	**-**	**-**	
09/13/2000	**-**	**-**	**-**	**-**	
09/20/2000	**-**	**-**	**-**	**-**	
09/26/2000	**-**	**-**	**-**	**-**	
10/05/2001	**-**	**-**	**-**	**-**	
10/11/2000	**6.29**	**8.72**	**2.43**	**7.40**	
10/18/2000	-	-	-	-	
10/25/2000	3.27	6.20	2.93	4.81	√
11/01/2000	-	-	-	-	
11/08/2000	-	-	-	-	
11/15/2000	-	-	-	-	
11/22/2000	-	-	-	-	
11/29/2000	4.42	9.44	5.02	6.58	
12/06/2000	-	-	-	-	
12/13/2000	-	-	-	-	
12/20/2000	-	-	-	-	
12/27/2000	-	-	-	-	
01/02/2001	-	-	-	-	
01/09/2001	-	-	-	-	
01/16/2001	-	-	-	-	
01/23/2001	6.34	12.73	6.39	9.04	
01/30/2001	-	-	-	-	
02/06/2001	3.73	7.99	4.26	4.91	√
02/13/2001	-	-	-	-	
02/20/2001	-	-	-	-	
02/27/2001	-	-	-	-	
03/06/2001	-	-	-	-	
03/14/2001	**3.27**	**10.35**	**7.08**	**6.87**	
03/20/2001	**-**	**-**	**-**	**-**	

Station 17119 (continued).

Date	Minimum	Maximum	Range	24-Hr Mean	< 5.0 mg l^{-1}
03/27/2001	5.49	6.97	1.48	6.20	
04/03/2001	3.91	7.67	3.76	5.57	
04/10/2001	-	-	-	-	
04/17/2001	-	-	-	-	
04/24/2001	4.19	7.08	2.89	5.20	
05/01/2001	-	-	-	-	
05/08/2001	1.53	10.40	8.87	5.41	
05/15/2001	3.99	6.60	2.61	5.26	
05/22/2001	2.81	7.03	4.22	4.81	√
05/29/2001	3.29	6.61	3.32	4.97	√
06/05/2001	-	-	-	-	
06/12/2001	-	-	-	-	
06/19/2001	2.61	5.88	3.27	4.58	√
06/26/2001	-	-	-	-	
07/03/2001	-	-	-	-	
07/10/2001	-	-	-	-	
07/17/2001	1.92	7.32	5.40	4.64	√
07/24/2001	1.53	7.57	6.04	4.87	√
07/31/2001	1.51	6.91	5.40	4.04	√
08/07/2001	2.00	6.98	4.98	4.48	√
08/14/2001	1.22	5.33	4.11	3.23	√
08/21/2001	1.88	7.80	5.92	4.87	√
08/28/2001	-	-	-	-	
09/04/2001	1.14	7.79	6.65	3.07	√
09/11/2001	1.53	8.44	6.91	4.65	√
09/25/2001	3.62	10.11	6.49	6.10	
10/02/2001	1.76	10.11	8.35	5.54	
10/09/2001	-	-	-	-	

APPENDIX II (continued)

Station 17118 – Oso Bay @ SH 358 (South Padre Island Drive)

Date	Minimum	Maximum	Range	24-Hr Mean	< 5.0 mg l^{-1}
09/20/2000	**2.39**	**5.85**	**3.46**	**4.14**	√
09/26/2000	**-**	**-**	**-**	**-**	
10/04/2000	**-**	**-**	**-**	**-**	
10/11/2000	**6.06**	**8.64**	**2.58**	**7.38**	
10/18/2000	-	-	-	-	
10/25/2000	3.22	6.01	2.79	4.60	√
11/01/2000	-	-	-	-	
11/08/2000	-	-	-	-	
11/15/2000	5.40	8.75	3.35	7.39	
11/22/2000	-	-	-	-	
11/29/2000	-	-	-	-	
12/06/2000	-	-	-	-	
12/13/2000	-	-	-	-	
12/20/2000	5.92	8.01	2.09	6.96	
12/27/2000	-	-	-	-	
01/02/2001	-	-	-	-	
01/09/2001	7.37	7.97	0.60	7.62	
01/16/2001	-	-	-	-	
01/23/2001	6.64	10.84	4.20	8.44	
01/30/2001	-	-	-	-	
02/06/2001	-	-	-	-	
02/13/2001	5.09	6.70	1.61	5.81	
02/20/2001	-	-	-	-	
02/27/2001	3.63	6.70	3.07	5.15	
03/05/2001	-	-	-	-	
03/12/2001	-	-	-	-	
03/20/2001	**-**	**-**	**-**	**-**	
03/27/2001	**-**	**-**	**-**	**-**	
04/03/2001	**4.26**	**7.62**	**3.36**	**5.98**	
04/10/2001	**-**	**-**	**-**	**-**	
04/17/2001	**-**	**-**	**-**	**-**	
04/24/2001	**4.01**	**6.34**	**2.33**	**4.97**	√

Station 17118 (continued).

Date	Minimum	Maximum	Range	24-Hr Mean	< 5.0 mg l^{-1}
05/01/2001	-	-	-	-	
05/08/2001	-	-	-	-	
05/18/2001	-	-	-	-	
05/22/2001	4.95	9.05	4.10	5.97	
05/29/2001	3.66	6.13	2.47	4.82	√
06/05/2001	3.24	8.59	5.35	5.58	
06/12/2001	-	-	-	-	
06/19/2001	3.42	10.94	7.52	5.16	
06/26/2001	-	-	-	-	
07/03/2001	3.04	8.08	5.04	5.65	
07/10/2001	-	-	-	-	
07/17/2001	-	-	-	-	
07/24/2001	-	-	-	-	
07/31/2001	2.97	7.63	4.66	4.73	√
08/07/2001	-	-	-	-	
08/14/2001	3.25	9.96	6.71	6.32	
08/21/2001	-	-	-	-	
08/28/2001	-	-	-	-	
09/04/2001	-	-	-	-	
09/11/2001	1.35	8.37	7.02	4.63	√
09/18/2001	0.45	6.05	5.60	3.38	√
09/25/2001	3.69	6.87	3.18	5.29	
10/02/2001	1.08	6.59	5.51	4.56	√
10/09/2001	2.96	5.66	2.70	4.37	√

Station 13442 – Oso Bay @ Ocean Drive

Date	Minimum	Maximum	Range	24-Hr Mean	< 5.0 mg l^{-1}
09/13/2000	**3.15**	**7.05**	**3.90**	**5.05**	
09/20/2000	**-**	**-**	**-**	**-**	
09/26/2000	**-**	**-**	**-**	**-**	
10/05/2001	**-**	**-**	**-**	**-**	
10/11/2000	**7.39**	**8.86**	**1.47**	**8.20**	
10/18/2000	-	-	-	-	
10/25/2000	3.92	7.23	3.31	5.71	
11/01/2000	-	-	-	-	
11/08/2000	-	-	-	-	
11/15/2000	5.92	10.03	4.11	7.64	
11/22/2000	-	-	-	-	
11/29/2000	5.77	9.02	3.25	6.39	
12/06/2000	-	-	-	-	
12/13/2000	-	-	-	-	
12/20/2000	1.13	8.76	7.63	6.36	
12/27/2000	-	-	-	-	
01/02/2001	-	-	-	-	
01/09/2001	7.23	11.66	4.43	8.47	
01/16/2001	-	-	-	-	
01/23/2001	-	-	-	-	
01/30/2001	5.57	10.35	4.78	6.42	
02/06/2001	6.06	10.28	4.22	7.13	
02/13/2001	4.87	6.99	2.12	5.50	
02/20/2001	-	-	-	-	
02/27/2001	4.28	7.66	3.38	5.95	
03/06/2001	-	-	-	-	
03/13/2001	4.63	10.66	6.03	6.39	
03/20/2001	-	-	-	-	
03/26/2001	-	-	-	-	
04/03/2001	**4.25**	**6.45**	**2.20**	**5.35**	
04/10/2001	**-**	**-**	**-**	**-**	
04/17/2001	**-**	**-**	**-**	**-**	

Station 13442 (continued).

Date	Minimum	Maximum	Range	24-Hr Mean	< 5.0 mg l^{-1}
04/24/2001	5.39	12.16	6.77	6.68	
05/01/2001	3.89	5.82	1.93	4.63	√
05/08/2001	3.60	8.36	4.76	6.12	
05/15/2001	1.95	5.29	3.34	3.64	√
05/22/2001	-	-	-	-	
05/29/2001	-	-	-	-	
06/05/2001	4.18	9.30	5.12	5.79	
06/12/2001	-	-	-	-	
06/19/2001	-	-	-	-	
06/26/2001	-	-	-	-	
07/03/2001	3.83	7.09	3.26	5.71	
07/10/2001	-	-	-	-	
07/17/2001	-	-	-	-	
07/24/2001	3.50	7.01	3.51	5.25	
07/31/2001	-	-	-	-	
08/07/2001	3.73	8.47	4.74	5.48	
08/14/2001	-	-	-	-	
08/21/2001	3.08	6.92	3.84	4.79	√
08/28/2001	-	-	-	-	
09/04/2001	2.76	7.46	4.70	3.41	√
09/11/2001	4.58	8.27	3.69	6.21	
09/18/2001	-	-	-	-	
09/25/2001	-	-	-	-	
10/02/2001	3.45	7.84	4.39	5.89	
10/09/2001	5.00	7.00	2.00	5.97	

APPENDIX III. Sample volume, container types, minimum sample volume, preservation requirements, and holding time requirements.

Parameter	Matrix	Container	Preservation	Sample Volume (ml)	Holding Time
Field Parameters					
Air Temperature	Air	Field	NA	NA	NA
Dissolved Oxygen	Water	Field	NA	NA	NA
Water Temperature	Water	Field	NA	NA	NA
pH	Water	Field	NA	NA	NA
Conductivity	Water	Field	NA	NA	NA
Salinity	Water	Field	NA	NA	NA
Secchi Depth	Water	Field	NA	NA	NA
Water Color	Water	Field	NA	NA	NA
Water Odor	Water	Field	NA	NA	NA
Flow Severity	Water	Field	NA	NA	NA
Turbidity	Water	Field	NA	NA	NA
Water Surface	Water	Field	NA	NA	NA
Tide Stage	Water	Field	NA	NA	NA
Wind Direction	Air	Field	NA	NA	NA
Wind Intensity	Air	Field	NA	NA	NA
Present Weather	Air	Field	NA	NA	NA
Days since precipitation event (if known)	NA	Field	NA	NA	NA
Rainfall (if known) inches in past 1 day	Water	Field	NA	NA	NA
Rainfall (if known) inches in past 7 days	Water	Field	NA	NA	NA

APPENDIX III (continued)

Parameter	Matrix	Container	Preservation	Sample Volume (ml)	Holding Time
Biological					
Macroinvertebrates	Sediment	500 Fm mesh BioBag	10% formalin 45% isopropyl	NA	NA
Macroinvertebrates	Water	Kick/Dip Net	10% formalin 45% isopropyl	NA	NA
Epibenthic invertebrates/Nekton	Water	Benthic Sled	10% formalin 45% isopropyl	NA	NA
Microbiological					
Fecal Coliform	Water	Plastic	cool to 4 ^{o} C	500/1000	6 hours
Enterococci	Water	Plastic	cool to 4 ^{o} C	500/1000	6 hours
Escherichia coli	Water	Plastic	cool to 4 ^{o} C	500/1000	6 hours
Routine Chemical					
Alkalinity	Water	Cubitainer 1	cool to 4 ^{o} C, dark	100	14 days
TSS/VSS	Water	Cubitainer 1	cool to 4 ^{o} C, dark	400	7 days
Chloride	Water	Cubitainer 1	cool to 4 ^{o} C, dark	100	28 days
Sulfate	Water	Cubitainer 1	cool to 4 ^{o} C, dark	100	28 days
o-phosphorous	Water	Cubitainer 1	cool to 4 ^{o} C, dark	150	Filter ASAP; analyze w/in 48 hours
Nitrate/nitrite-N	Water	Cubitainer 1	cool to 4 ^{o} C, dark	150	48 hours
TDS	Water	Cubitainer 1	cool to 4 ^{o} C, dark	250	7 days
Ammonia-N	Water	Cubitainer 2	1-2 ml conc. H_2SO_4 and cool to 4^{o}C, dark	150	28 days
TOC	Water	Cubitainer 2	1-2 ml conc. H_2SO_4 and cool to 4^{o}C, dark	150	28 days
Total Phosphorus	Water	Cubitainer 2	1-2 ml conc. H_2SO_4 and cool to 4^{o}C, dark	100	28 days
TKN	Water	Cubitainer 2	1-2 ml conc. H_2SO_4 and cool to 4^{o}C, dark	600	28 days
Chlorophyll-*a* & Pheophytin-*a*	Water	Amber Nalgene Bottle 1	cool to 4 ^{o} C, dark	1000	filter <48 hrs filters frozen up to 30 days

APPENDIX IV. Significant rainfall event monitoring of the Oso Creek/Oso Bay system.

Although project plans required four monitoring events during and after significant rainfall, we encountered numerous difficulties for this portion of the study. Primary difficulties centered on the key component, significant rainfall, not occurring for most of the study due to prevailing drought conditions throughout the region. In addition, when rainfall did occur; it was neither system wide, plentiful, or persistent. Coupled with temporal constraints that rainfall must occur only on Monday, Tuesday, or Wednesday; as the TNRCC Laboratory could not receive samples on Fridays due to previous commitments and high workloads, and that the lab was not open on weekends, resulted in a very narrow sampling timeframe. The author wishes to state that without the no-cost assistance of the TNRCC laboratory, no aspect of the analytical water chemistry portion of this study could have been accomplished. However, it is apparent that these constraints hampered this portion of the study and resulted in inadequate rainfall data with which to meet a stated projective objective.

Only one event, occurring in March 2000, produced enough adequate rainfall to consider the event significant (3.66 inches of rainfall in a 24-hour period). This rainfall met all the constraints as listed above, with the recorded flow at Station 13029 reaching a high of 580 CFS on March 15 2000 (Table A1). Flow decreased quickly in the days following the rainfall event and was back to normal levels by the next regularly scheduled sampling event in April 2000. This flow substantially reduced the high salinities seen in Oso Bay but values quickly returned to normal levels by April (Figure A1). However, Station 13441 at the OWWTP actually saw an increase in salinities, as the freshwater inflows appeared to displace higher salinity water into the Blind Oso portion of Oso Bay. The other "events" occurred in May and August of 2000 and only produced rainfall amounts of 0.41 and 0.79 inches, respectively. These "events" failed to meet all the constraints as the rainfall was not system wide, plentiful, or persistence. Flow at Station 13029 reached a maximum of 2.20 CFS and typically averaged only 1.70 CFS. These insufficient amounts yielded questionable data from which to make a reliable analysis.

Table A1. Daily mean flow data for Oso Creek from the United States Geological Survey Gauge No. 08211520 located at Station 13029 – Oso Creek at FM 763.

Date	CFS
3/13/2000	1.1
3/14/2000	373.0
3/15/2000	580.0
3/16/2000	84.0
3/17/2000	22.0
3/18/2000	7.0
4/11/2000	1.4

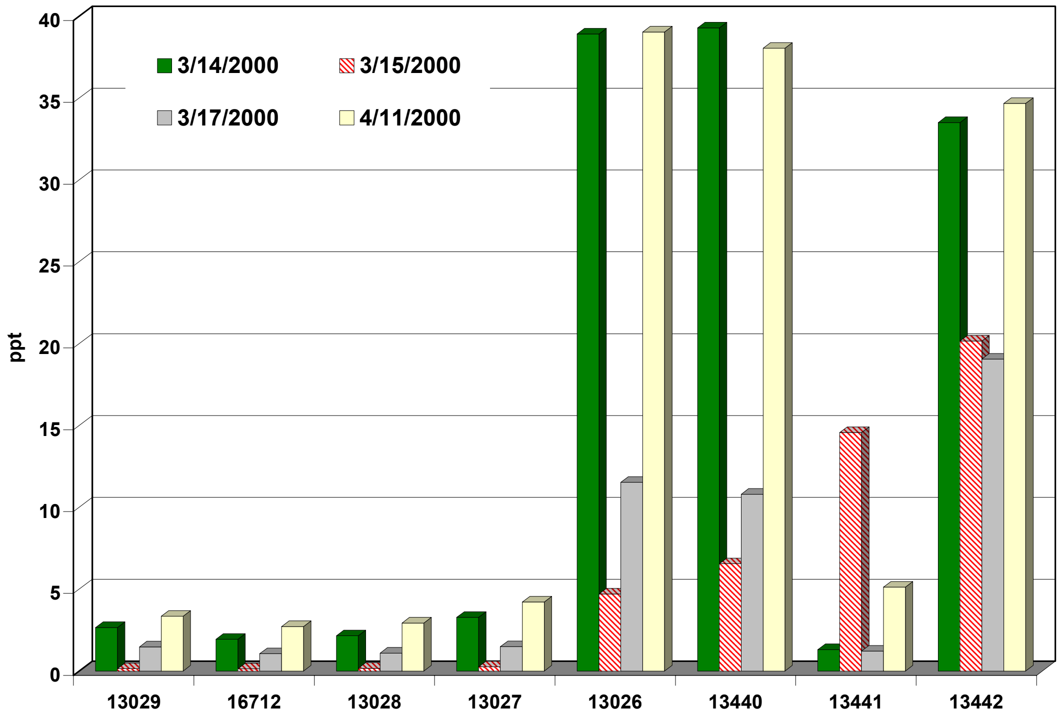

Fig. A1. Comparison of salinity concentrations at Oso Creek and Oso Bay stations before, during, and after the March 15, 2000 significant rainfall event.

The following Routine Conventional water chemistry data presented is only for those parameters with screening level criteria (Ammonia, Nitrate + Nitrite, Total Phosphorus, Ortho-Phosphate, and Chlorophyll *a*). Data includes the regularly scheduled sampling day of March 14, 2000, immediately before and during the major portion of the event of March 15, 2000, and the regularly scheduled sampling day of April 11, 2000 the following month. Only bacteriological sampling occurred immediately after the rainfall event on March 17, 2000, as sampling for routine conventional parameters would have resulted in the samples arriving at the TNRCC Laboratory on a Friday or Saturday. Analysis of the data revealed that typically, during a substantial rainfall event, higher concentrations appeared to be flushed down Oso Creek and into Oso Bay. Oso Creek concentrations typically increased by the following month while Oso Bay concentrations typically decreased.

Comparison of Ammonia concentrations (Fig. A2) for Oso Creek stations revealed slight increases following the rainfall but there were no exceedances of the screening values. In Oso Bay, low levels at recorded at Stations 13026, 13440, and 13442 before the rainfall, exceeded the screening criteria on March 15, before falling back to low levels in April. High levels for Station 13441 at the OWWTP decreased substantially on March 15 before rising to one of the highest levels recorded for the year in April. Decreased amounts at Station 13441 on March 15 may possibly relate to increased salinity levels or flows occurring at this station during the rainfall event.

Appendix IV (continued).

Comparison of Nitrate + Nitrite levels (Fig. A3) for Oso Creek stations showed levels exceeding criteria on March 14 at Stations 13029, 16712, and 13028, decreasing below screening criteria on March 15 as flows increased, before rising above screening criteria levels again in April at Stations 13029 and 16712. Station 13027 showed a decreasing trend for all three sampling dates with all levels well below screening criteria. In Oso Bay, the reverse trend occurred at Stations 13026, 13440, and 13442 as levels rose and then fell by April. However, most levels did exceed the screening criteria. Station 13441 at the OWWTP exceeded levels for all three sampling dates; resembling the situation seen in Oso Creek.

Comparison of Total Phosphorus and Ortho-Phosphate concentrations (Figs. A4 and A5) revealed generally the same pattern observed in Oso Creek for Nitrate + Nitrite, with high levels decreasing during the event as flooding occurred in Oso Creek, followed by increasing levels in April. Typically, most exceedance of the screening criteria took place at Stations 13029, 16712, and 13028. Station 13027 generally resembled the Oso Bay stations 13026, 13440, 13441, and 13442, which typically saw levels increase during the height of the flows as water from Oso Creek filled Oso Bay. In addition, screening criteria was exceeded at most stations on March 15.

Patterns were less discernable in Chlorophyll *a* concentrations (Fig A6) but generally increased at Stations 16712 and 13028 and decreased at Station 13027 on March 15 during the maximum flow period. The same pattern also occurred in Oso Bay stations 13440, 13441, and 13442. Screening criteria exceedance on March 15 occurred only at Station 13441 at the OWWTP.

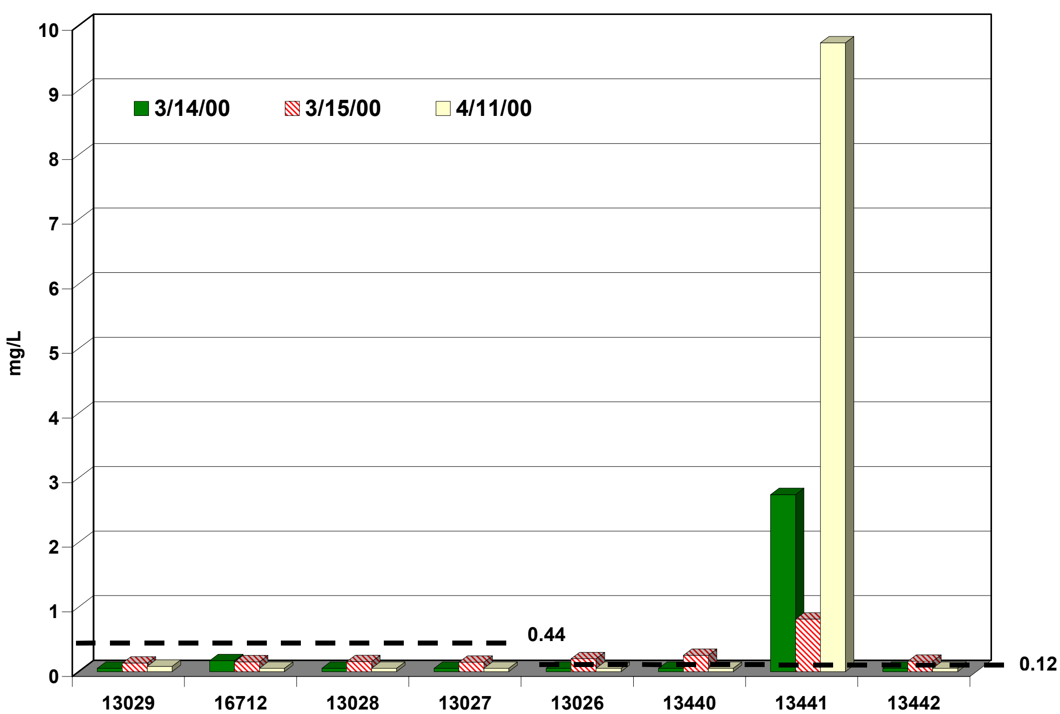

Fig. A2. Comparison of Ammonia Nitrogen concentrations at Oso Creek and Oso Bay stations before, during, and after the March 15, 2000 significant rainfall event.

Appendix IV (continued).

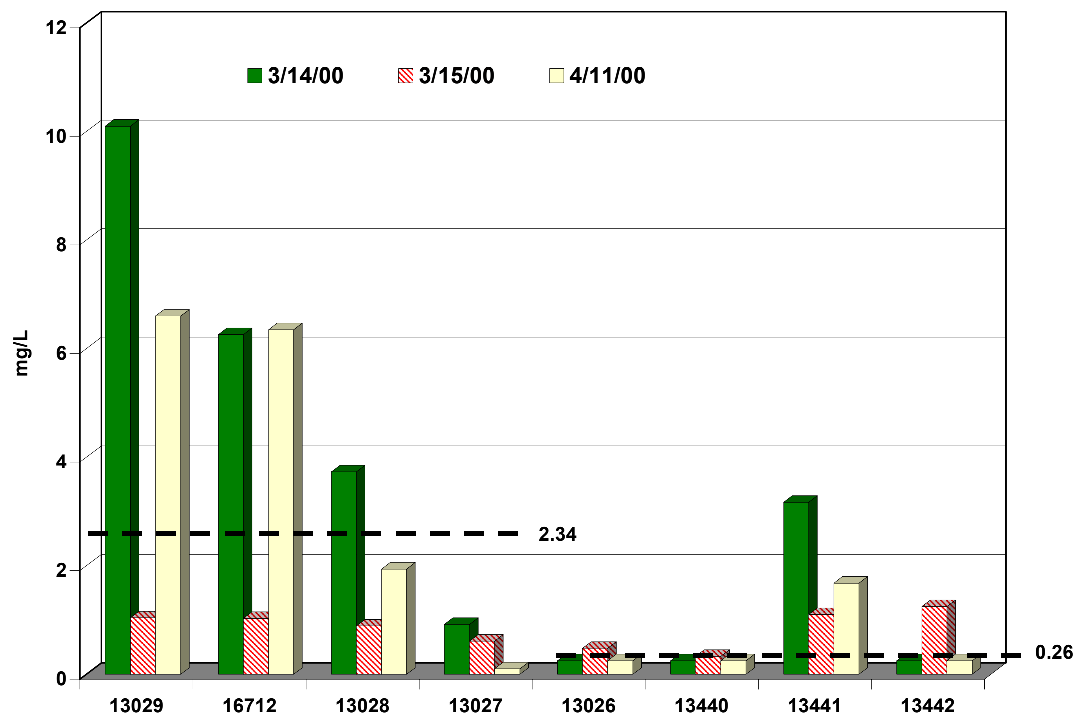

Fig. A3. Comparison of Nitrate + Nitrite concentrations at Oso Creek and Oso Bay stations before, during, and after the March 15, 2000 significant rainfall event.

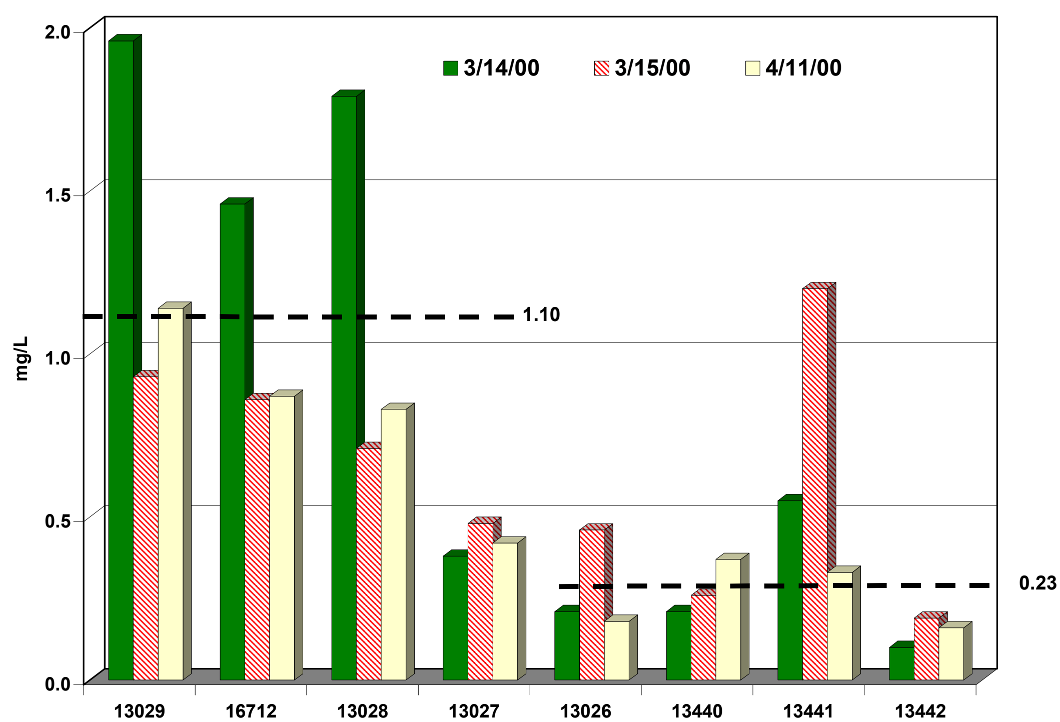

Fig. A4. Comparison of Total Phosphorus concentrations at Oso Creek and Oso Bay stations before, during, and after the March 15, 2000 significant rainfall event.

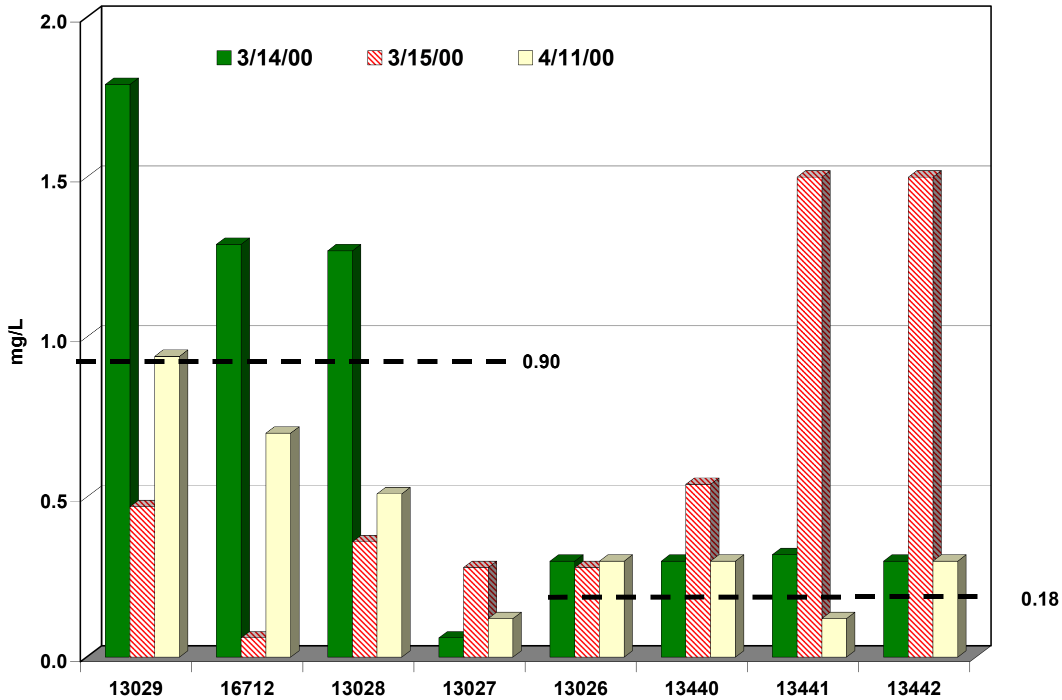

Fig. A5. Comparison of Ortho-Phosphate concentrations at Oso Creek and Oso Bay stations before, during, and after the March 15, 2000 significant rainfall event.

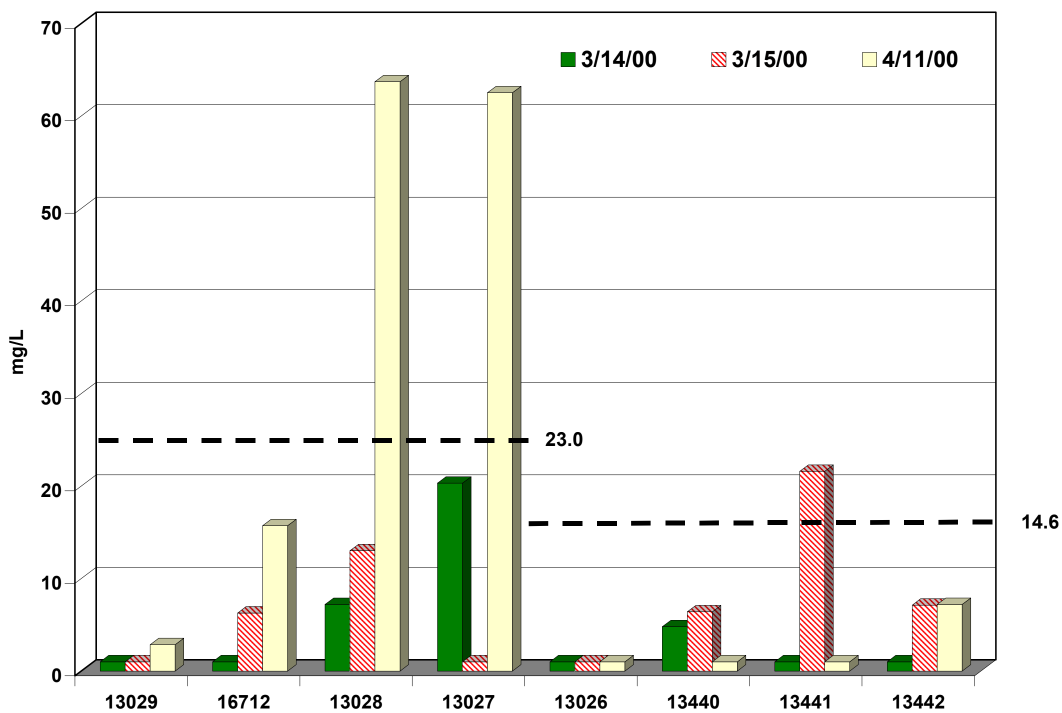

Fig. A6. Comparison of Chlorophyll *a* concentrations at Oso Creek and Oso Bay stations before, during, and after the March 15, 2000 significant rainfall event.

Most of the extremely high levels of bacteria seen in Oso Creek and Oso Bay over the course of the one-year study occurred during the significant rain event of March 15. As stated in Heilman *et al.* 2000, the data collected was consistent with results of other studies which show bacterial concentrations increasing in the water column from runoff following significant rainfall events (Francy and Darner 1998). The general expectation is that bacteria concentrations are typically higher following heavy precipitation often resulting from runoff from malfunctioning local septic systems and other non-point sources. Storms also tend to increase current and flow rates and shift bank boundaries, thus affecting indicator bacteria concentrations. Additionally, surface water flow from storm drains and natural streams contribute major terrestrial bacterial inputs (Heilman *et al*. 2000).

Comparison of *E. coli* concentrations (Fig. A7) in Oso Creek showed that levels below the criteria increased at all stations during the highest flow periods on March 15. Although still exceeding the criteria, concentrations quickly decreased at all stations except 13029 by March 17, and were below the criteria at all stations except 13029 by April 11, 2000. Analysis of Oso Bay enterococci concentrations (Fig. A8) produced the same pattern of increased concentrations on March 15 followed by decreases by March 17. As seen in Oso Creek, many concentration levels were the highest recorded for the entire year. However, while Oso Creek stations gradually declined by April, Oso Bay stations typically increased in April and routinely exceeded the criteria. Fecal coliform concentrations (Fig. A9) for both areas generally followed the same pattern and both the screening level for a single grab sample, in a non-designated tidal stream segment with contact usage (400 CFU/100 ml) and the Oyster Water screening level (14 CFU/100 ml) were routinely exceeded.

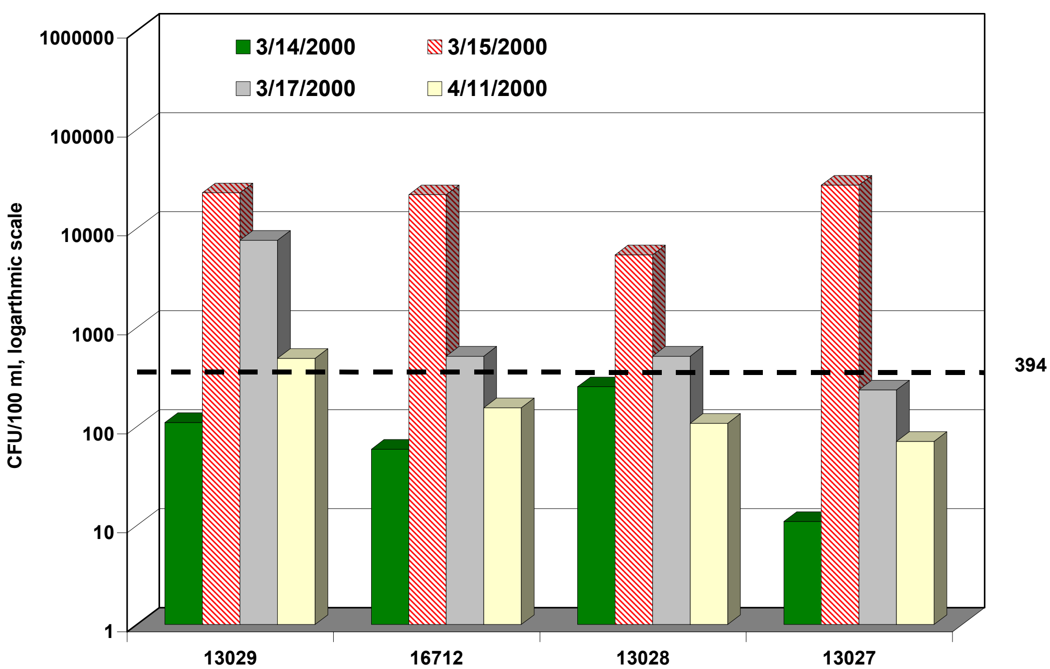

Fig. A7. Comparison of *E. coli* concentrations at Oso Creek stations before, during, and after the March 15, 2000 significant rainfall event.

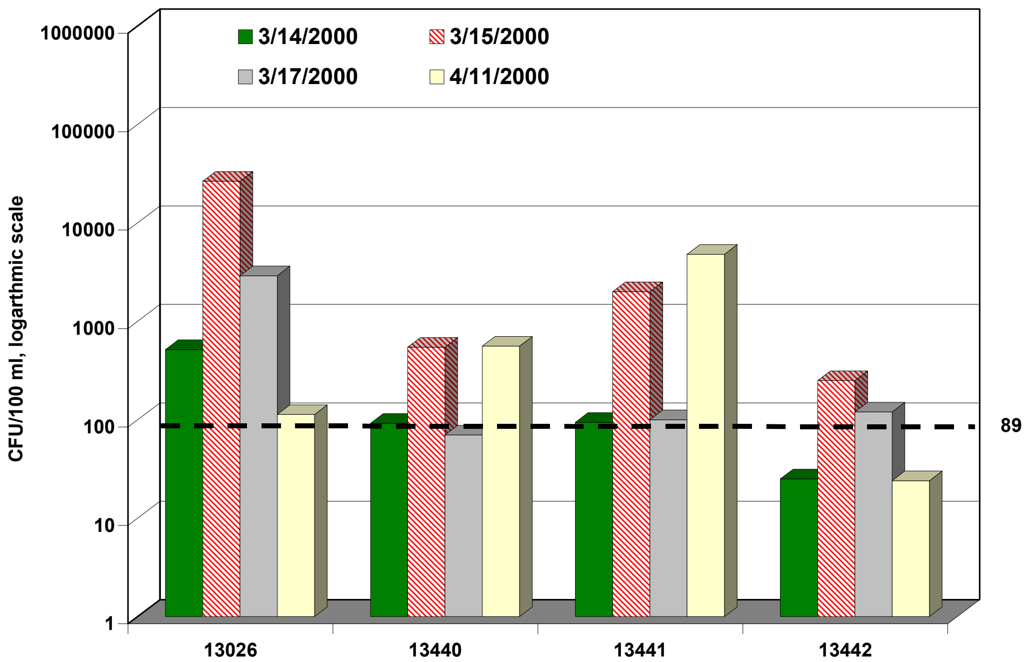

Fig. A8. Comparison of Enterococci concentrations at Oso Bay stations before, during, and after the March 15, 2000 significant rainfall event.

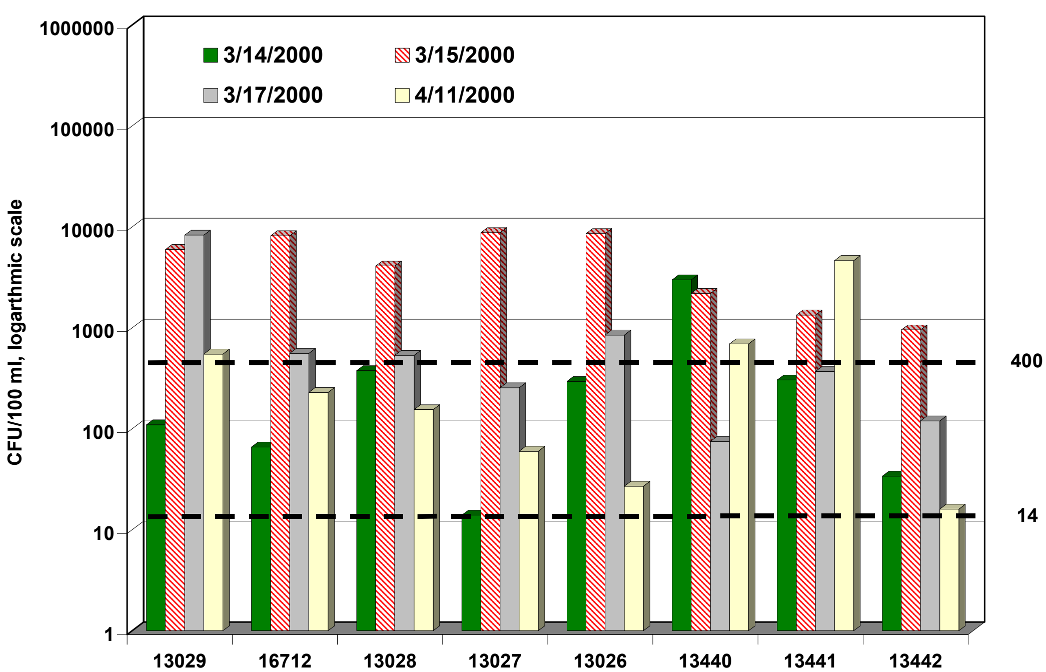

Fig. A9. Comparison of Fecal Coliform concentrations at Oso Creek and Oso Bay stations before, during, and after the March 15, 2000 significant rainfall event.

APPENDIX V. Systematic list of organisms, with total number of individuals collected, from each location, October 1999 to September 2000. (P = Phylum, SP = Subphylum, C = Class, O = Order, F = Family, SM = Sampling Method (MN = Marsh net, BC = Benthic core).

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
P. Cnidaria										
C. Anthozoa										
O. Actiniaria										
F. Actinidae					2			3	5	BC
P. Platyhelminthes										
C. Turbellaria	1								1	BC
P. Nemertea					27	4		16	47	BC
P. Nematoda	1	1		8				3	13	BC
P. Mollusca										
C. Gastropoda										BC
O. Ctenobranchia										
F. Hydrobiidae				1					1	BC
F. Littoridinidae										
Texadina barretti						1			1	BC

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
O. Basommatophora										
F. Physidae				1					1	BC
O. Steganobranchia										
F. Aplysiidae										
Aplysia sp.								1	1	BC
O. Steganobranchia										
F. Atyidae										
Haminoea antillarum					1				1	BC
C. Bivalvia										
O. Mytiloidea										
F. Mytilidae										
Brachidontes exustus								1	1	BC
Amygdalum papyria					1			1	2	BC
O. Myoida										
F. Hiatellidae										
Hiatella arctica								1	1	BC
O. Nuculoida										
F. Nuculidae										
Nuculana acuta								1	1	BC
O. Veneroida										
F. Mactridae										
Mulinia lateralis					4	1		4	9	BC
F. Cultellidae										
Ensis minor								2	2	BC

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
F. Tellinidae										
Macoma mitchelli					1				1	BC
Tellina tampaensis					59	7	1	3	70	BC
Tellina texana					2	2		1	5	BC
F. Semelidae										
Cumingia tellinoides					1				1	BC
F. Solecurtidae										
Tagelus divisus					1				1	BC
F. Veneridae										
Anomalocardia auberiana					32	5	1	2	40	BC
Chione cancellata					1			2	3	BC
Mercenaria campechiensis								1	1	BC
P. Annelida										
C. Polychaeta										
O. Orbiniida										
F. Orbiniidae										
Scoloplos fragilis					7	3		27	37	BC
Haploscoloplos foliosus					6	2		17	25	BC
Naineris laevigata					1				1	BC
F. Paraonidae										
Paraonides cf. lyra							1		1	BC

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
O. Phyllodocida										
F. Phyllodocidae										
Eteone heteropoda					28	1		5	34	BC
Paranaitis speciosa								1	1	BC
F. Syllidae										
Brania clavata					2				2	BC
Brania sp.					2			1	3	BC
Exogone dispar					4				4	BC
F. Pilargidae										
Parandalia sp.					1				1	BC
Ancistrosyllis papillosa								1	1	BC
F. Nereidae										
Laeonereis culveri	2		1	17	236	199	8	249	712	BC
Steninonereis martinii					53	2		1	56	BC
Namanereis sp.						11	2	7	2	BC
F. Hesionidae										
Gyptis brevipalpa					1				1	BC
F. Goniadidae										
Ophioglycera sp.					1			1	2	BC
Unknown Goniadidae						1		2	3	BC
O. Capitellida										
F. Capitellidae										
Capitella cf. *capitata*	3	1	1	2	637	108	1,143	2,297	4,192	BC
Mediomastus ambiseta					14	36	26	564	640	BC

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
Heteromastus cf. *filiformis*					36	27		397	460	BC
Capitella fragments								79	79	BC
F. Maldanidae										
Axiothella mucosa					1			1	2	BC
Asychis elongatus					5	1		3	9	BC
F. Arenicolidae										
Arenicola cristata								3	3	BC
O. Spionida										
F. Spionidae										
Polydora cf. *ligni*					61	3	1	2	67	BC
Polydora cf. *aggregata*						1			1	BC
Polydora cf. *ciliata*					2				2	BC
Polydora cf. *socialis*					1				1	BC
Streblospio benedicti	11	7	2	19	4,994	6,146	550	13,313	25,042	BC
Prionospio sp.					4	3			7	BC
Scolelepsis sp.						1			1	BC
Prionospio heterobranchia					66	16		1	83	
Prionospio pinnata						1		3	4	BC
O. Eunicida										
F. Eunicidae										
Marphysa sanguina					10	2		3	15	BC
Lysidice ninetta					1				1	BC
F. Onuphidae										
Diopatra cuprea					2			2	4	BC

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
Diopatra sp.					1			1	2	BC
Americonuphis cf. *magna*								1	1	BC
F. Dorvilleidae										
Schistomeringos rudolphi								3	3	BC
Dorvillea sp.					1				1	BC
O. Terebellida										
F. Ampharetidae										
Amphicteis floridus	56	488	736	819	1				2,100	BC
Melinnia maculata					1				1	BC
Melinnia sp.					1	1			2	BC
O. Sabellida										
F. Sabellidae										
Chone duneri					2	1		9	12	BC
Sabella micropthalma					2				2	BC
Fabriciola trilobata							1		1	BC
F. Serpulidae										
Eupomastus dianthus						8			8	BC
O. Cirratulida										
F. Cirratulidae										
Tharyx cf. *annulosus*								19	19	BC
C. Oligochaeta	437	2,448	1,634	422	23	9	159	62	5,194	BC
C. Hirudinea			7	15					22	MN

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
P. Arthropoda										
C. Arachnida										
O. Araneida	2	1		1			1		5	MN
SP. Crustacea										
C. Pycnogonida								3	3	BC
C. Ostracoda	7	13	26	42	3		3		94	BC
C. Copepoda							1		1	MN
C. Cirrepedia										
O. Thoracica										
Balanus improvisus					25				25	MN
C. Branchiura										
O. Arguloida										
F. Argulidae										
Argulus sp.		1	4	7	1			1	14	MN
C. Malacostraca										
O. Cumacea										
F. Diastylidae										
Diastylis quadrinspinosa								1	1	MN
Oxyurostylis smithi					19	2		12	33	BC
F. Bodotriidae										
Cyclaspis varians					1				1	BC
O. Cladocera										
Unknown Cladocera	2	3			1				6	BC/MN

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
O. Isopoda										
F. Bopyridae										
Probopyrus pandalicola			1	6	3	7			17	MN
F. Idoteidae										
Erichsonella sp.					61	77		38	176	BC/MN
Edotea triloba		1			18	7		26	52	BC/MN
F. Anthuridae								4	4	BC
cf. *Ananthura* sp.								9	9	BC
F. Sphaeromatidae										
Cymodoce faxoni					185	232		17	434	MN
Paracerceis sp.					16	36			52	MN
Sphaeroma sp.						1		1	2	MN
F. Cirolanidae										
Anopsilana jonesi				1		1			2	BC
O. Mysidacea										
F. Mysidae										
Americamysis almyra	82	62,696	1,872	18,732	65,516	9,178	18,996	8,798	185,870	MN
O. Tanaidacea										
F. Partanaidae										
Leptochelia rapax			1		28			2	31	BC
O. Amphipoda										
F. Corophiidae										
Cerapus tubularis					28	17		10	55	BC
Corophium louisianum		2			616	25	55	53	751	BC

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
Corophiidae sp. A					12	9		4	25	BC
F. Gammaridae										
Gammarus mucronatus	1	4	1	23	60	18	8	131	246	BC
F. Ampithoidae										
Cymadusa compta					5			42	47	BC
F. Ampelisca										
Ampelisca abdita		2	1		2	7		51	63	BC
Ampelisca vadorum								1	1	BC
F. Hyalidae										
Hyale nilssoni						2			2	BC
F. Melitidae										
Melita nitida					1	1		1	3	BC
F. Caprellidae										
Caprella sp.						7		55	62	BC
Unknown Amphipod sp. A								1	1	BC
O. Decapoda										
Megalopae larva unidentified							3		3	MN
F. Palaemonidae										
Palaemonetes pugio	1	2	1,881	2,805	3,306	8,014	15	1,571	17,595	MN
Palaemonetes intermedius					204	1,236			1,440	MN
F. Alpheidae										
Alpheus heterochaelis								1	1	MN

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
F. Penaeidae										
Farfantepenaeus aztecus				7	15	96	11	187	316	MN
Penaeus duorarum						14	7	16	37	MN
Litopenaeus setiferus						6	12		18	MN
Penaeus sp. (post larval)				1	1	120	2	16	140	MN
F. Astacidae	10			1					11	MN
F. Sergestidae										
Acetes americanus louisianensis					1	50		5	56	MN
F. Hippolytidae										
Tozeuma carolinense						64		98	162	MN
Hippolyte zostericola						3		9	12	MN
F. Portunidae										
Callinectes sapidus				4	4	24	17	71	120	MN
F. Xanthidae										
Rhithropanopeus harrisii						3		5	8	MN
Neopanope texana					1				1	MN
Panopeus herbstii								1	1	BC
SP. Insecta										
O. Thysanoptera										
F. Thripidae				2					2	BC
O. Orthoptera										
F. Gryllotalpidae										
Neocurtilla hexadactyla		1							1	BC

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
O. Ephemeroptera										
F. Baetidae	79	14	2	4					99	BC/MN
F. Caenidae	173	110	38	5					326	BC/MN
F. Ephemerellidae	9								9	MN
O. Hemiptera										
F. Coroxidae	13	13	1,056	15,765	53	6	1		16,907	MN
F. Belostomatidae	6								6	MN
F. Gerridae	7								7	MN
F. Nepidae	4								4	MN
F. Naucoridae	6								6	MN
F. Veliidae	2								2	MN
Unknown Hemiptera	1								1	MN
SO. Homoptera										
F. Cicadellidae			1						1	BC
O. Trichoptera				2					2	BC
F. Limnephilidae		3	26	9					38	MN
O. Plecoptera										
F. Perlodidae	1								1	BC
O. Coleoptera										
F. Dytiscidae	1								1	MN
F. Scirtidae	29						1		30	MN
F. Elmidae	176	2	2						180	BC/MN
F. Heteroceridae			1						1	BC
F. Gyrinidae	1								1	MN

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
F. Hydrophilidae	7	1	1	1					10	BC/MN
Berosus sp.	14	13	127	138					292	BC/MN
Tropisternus sp.	1								1	MN
F. Noteridae	4								4	MN
F. Amphizoidae	1								1	MN
F. Chrysomelidae							1		1	BC
O. Odonta										
F. Calopterygidae					1				1	BC
F. Coenagrionidae	38	7		2					47	BC/MN
F. Libellulidae	1	1		9					11	MN
F. Lestidae	3								3	MN
O. Diptera										
Dipteran pupae	10	37	19	648	7				721	BC
F. Tipulidae	4									
F. Tabanidae			4						4	MN
F. Chironomidae	1,044	1,381	1,083	7,452	48	16	711	5	11,740	BC/MN
F. Ceratopogonidae	39	52	45	113	5		4		258	BC/MN
F. Stratiomyidae	1			1					2	BC/MN
F. Empididae							1		1	BC
F. Chaoboridae		14							14	MN
O. Hymenoptera										
F. Formicidae	2	1	2						5	MN

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
P. Bryozoa										
C. Gymnolaemata										
O. Cheloistomata										
F. Membraniporidae										
Membranipora tenuis				1					1	BC
P. Chaetognatha					1				1	BC
P. Echinodermata										
C. Ophiuroidea										
O. Ophiurida										
F. Amphiuridae										
Ophioderma c.f. sp.								1	1	BC
P. Chordata										
SP. Vertebrata										
Elops saurus			6	23	1	1		1	32	MN
O. Clupeiformes										
F. Clupeidae										
Brevoortia patronus							2	12	14	MN
F. Engraulidae										
Anchoa mitchilli			8		1	3			12	MN

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
O. Cyprinidontiformes										
F. Cyprinodontidae										
Adinia xenica	44	2	91	1					138	MN
Cyprinodon variegatus	1	3	20	7		1		13	45	MN
Fundulus grandis				1					1	MN
Fundulus pulvereus	59		25	1					85	MN
Lucania parva	1					2			3	MN
Fundulus jenkinsii	9								9	MN
F. Poeciliidae										
Gambusia affinis	16		15						31	MN
O. Batrachoidiformes										
F. Batrachoididae										
Opsanus beta								1	1	MN
O. Antheriniformes										
F. Antherinidae										
Menidia beryllina	2	15	17	5	6	1	26		72	MN
O. Gasterosteiformes										
F. Syngnathidae										
Syngnathus scovelli					8	16		15	39	MN
Hippocampus sp.					1				1	MN
O. Perciformes										
F. Blenniidae										
Chasmodes bosquianus								1	1	MN

APPENDIX V (continued)

Taxa	13029	16712	13028	13027	13026	13440	13441	13442	Total	SM
F. Sparidae										
Lagodon rhomboides		2	2		8	13		16	41	MN
Archosargus probatocephalus						3		7	10	MN
F. Scianidae										
Cynoscion nebulosus						1			1	MN
Bairdiella chrysoura								10	10	MN
Sciaenops ocellata						1			1	MN
F. Mugilidae										
Mugil cephalus				1					1	MN
F. Gobiidae										
Gobiosoma bosc		1			9	21	1	29	61	MN
F. Cichlidae										
Cichlasoma cyanoguttata	1	1	5						7	MN
F. Centrarchidae										
Micropterus punctulatus		8							8	MN
Lepomis macrochirus	7	5							1	MN
O. Pleuronectiformes										
F. Bothidae										
Paralichthys albigutta								1	1	MN
Syacium gunteri								1	1	MN
F. Cynoglossidae										
Symphurus plagiusa	1							1	1	MN
Total Number of Individuals	**2432**	**67,357**	**8764**	**47,125**	**76,621**	**25,945**	**21,772**	**28,472**	**278,488**	