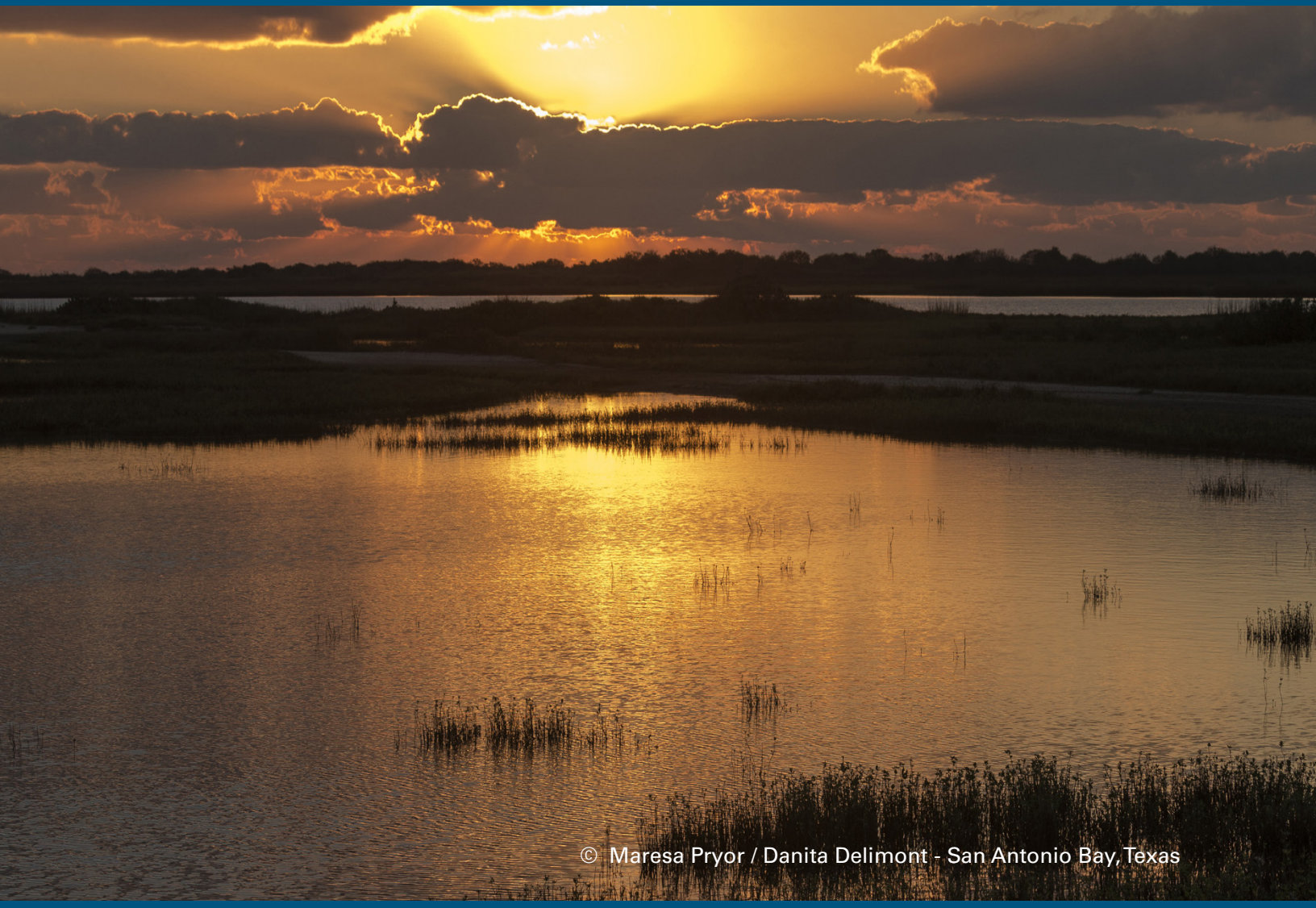
Texas Beach Watch Program
Water Quality Data Summary Report

Report: 2021-03
June 2021



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The Meadows Center
for Water and the Environment
Texas State University

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MEMBER **THE TEXAS STATE UNIVERSITY SYSTEM**

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Galveston Bay, Texas © Jo Ann Snover

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Beach near San Luis Pass © Jesse

EXECUTIVE SUMMARY

The Texas Beach Watch (TBW) Program monitors enterococci bacteria at 169 bay and gulf recreational beaches in ten counties along the Texas Gulf coast. This project analyzed TBW data temporally and spatially to identify problematic areas, conducted trend analysis and identified environmental factors that may be affecting water quality. This investigation included:

- site-specific analyses to determine fecal indicator bacteria suitability by comparing enterococci data with recreational beach criteria using the USEPA single sample beach action value (104 cfu/100 ml), TCEQ geometric mean (35 cfu/100ml), and TCEQ percent exceedance of BAV assessment criteria (<25% = fully supporting, 20-25% = concern and fully supporting, > 25% = not supporting);
- spatial and temporal analyses by geographic group (upper, middle, lower Texas coast), beach type (bay or gulf), season (peak or non-peak), station (169 stations) and county (10 Texas counties);
- temporal trend analysis of percent BAV exceedances by beach type (bay or gulf), collectively for all counties, and at the upper detection limit of the laboratory analytical enumeration method used for analysis of water samples for enterococci bacteria over time;
- correlation analyses with available environmental data sources at selected sites within counties with the highest percent exceedances of the recreational beach criteria;

SPATIAL AND TEMPORAL ANALYSIS BY SITE

Results of the site-specific analyses revealed 94 percent, or 159 stations fully supported the recreational beach criterion (< 25% exceedances of the BAV), six (3.8%) of those stations met the concern and fully supporting criterion (20 - 25% exceedances of the BAV), and ten (5.9%) stations did not support the recreational beach criterion (>25% exceedances of the BAV). All ten stations not supportive of the recreational beach criterion were located on bay beaches in Nueces, Matagorda, and Harris Counties.

Temporal trend analysis of percent BAVs for all sites by year resulted in a strong (r = 0.61) and significant (p-value = 0.04) increasing correlation over time. The percent exceedance of enterococci values at the upper detection limit (values > 24,196 cfu/100 ml) for all sites by year revealed a significant (p-value = 0.03) and strong positive correlation (r = 0.67) over time. This means both the percent BAV exceedances and the number of analytical lab results at the upper detection limit for all sites have increased significantly from 2009 to 2019.

Sites grouped geographically for spatial analysis revealed the upper and middle Texas coasts had mean enterococci values that were statistically significantly different (p-value <0.001) from the mean enterococci value of the lower Texas coast. The upper and middle Texas coasts consisted of both bay and gulf beaches, while the lower Texas coast consisted predominantly of gulf beaches.

BEACH TYPE ANALYSIS

Mean enterococci values for bay and gulf beach sites were compared spatially by beach type (i.e., bay vs. gulf) and temporally by month (i.e., Jan thru Dec) and year (i.e., 2009 thru 2019). Mean values were significantly different spatially (p-value <0.001) by beach type and temporally for all months except August (p-value = 0.35) and for all years except 2014 (p-value = 0.24).

Statewide, gulf beach sites had more single sample BAV exceedances (n = 3,614) than bay beach sites (n = 2,908), but bay beach sites exhibited an almost three-fold higher percent exceedance of the BAV (18.5%) than gulf beach sites (6.3%).

The temporal trend analysis of annual percent exceedances of the BAV for bay and gulf beach sites was not significant (p-values = 0.09 and 0.06, respectively), however strong correlation coefficients (0.52 and 0.58, respectively) and positive trends were observed. This means a positive, increasing trend in percent BAVs of enterococci bacteria for bay and gulf recreational beach sites over time was observed from 2009 to 2019.

PEAK AND NON-PEAK SEASON ANALYSIS

Peak (May - September) and non-peak (October - April) seasonal analyses revealed significant differences (p-value<0.001) between season means with higher means observed during the peak season than the non-peak season. A one-way analysis of transformed enterococci data was performed by season for beach type (i.e., beach vs. gulf). Significant differences by season exist for gulf beaches, but not for bay beaches. Gulf beach means were higher during the peak season than the non-peak season, but bay beach means were consistently high during both peak and non-peak seasons.

ANALYSIS BY COUNTY

The county analysis identified three counties, Harris, Matagorda and Cameron, as having significantly different (p-value < 0.05) mean enterococci values from all other counties. Harris (25.1%) and Matagorda (20.8%) counties had the highest percent BAV exceedances for the entire period of record. Cameron County had the lowest percent exceedances of the BAV for the entire period of record (1.2%).

MULTIVARIATE ANALYSIS

Multivariate data analysis focused on the ten stations that did not support the recreational beach criterion (>25% BAV exceedances) and the 6 stations that met the concern and fully supporting criterion (20 - 25% BAV exceedances) resulting from the station analysis. These stations were all in Harris, Brazoria, Matagorda, and Nueces counties, the top four counties with the greatest number of percent BAV exceedances from the county analysis.

Significant positive correlations between enterococci and precipitation were observed for all bay sites included in the multivariate data analysis including Sylvan Beach Park in Harris County, Palacios Pavilion in Matagorda County and Ropes Park in Nueces County. For the gulf sites, positive significant correlations between enterococci, and tidal amplitude and nitrite+nitrate-nitrogen at Sargent Beach in Matagorda County and Quintana Beach in Brazoria County were observed. Significant negative correlations for salinity, specific conductance, chloride, sulfate, and alkalinity were also observed for the sites at the two gulf beaches.

Port Arnasas, Texas at Sunrise © Ryan Conine

INTRODUCTION

Increased industrialization and land development changes in the Coastal Zone impact Texas coastal water resources. The expansion of ports and the facilities handling oil and gas import and export business has resulted in alterations of hydrodynamics and related ecosystem functions. In addition, the workforce needed to support these industries has substantially grown and placed considerable strain on existing infrastructure such as stormwater drainage, sewage handling systems, and roads which has led to an increase of nonpoint source pollution into waters within the Coastal Zone. This project seeks to analyze available environmental data, determine trends, identify critical issues, and communicate the results.

The Texas Beach Watch program (TBW) manages a network of 169 monitoring locations at 66 designated contact recreation beaches. This program has been operating for 16 years and has collected data from approximately 90,0000 sampling events.

In U.S. surface waters, outdoor recreational activities such as swimming, boating, and fishing have been estimated to account for 4 billion recreational contact events annually (DeFlorio-Barker, Wing et al. 2018). However, nearly one in four contact events (90 million) results in the contraction of a gastrointestinal, respiratory, ear, eye, or skin related illness or infection ranging from mild to severe (DeFlorio-Barker, Wing et al. 2018). The primary human health concern related to fecal waste contamination is pathogens such as bacteria (e.g., Campylobacter and Salmonella), protozoa (e.g., Cryptosporidium and Giardia), and viruses (e.g., noroviruses and adenoviruses). The more fecal waste in the environment, the less resilient the coastal system will be to increasing storm events that influence coastal physical processes and pathogen distribution (Malham, Rajko-Nenow et al. 2014). Water-borne pathogens, the leading cause of Texas surface water impairments, jeopardize human health and economic activity while decreasing the resilient capacity of coastal communities.

The analysis described in this report was designed to characterize how alterations of coastal hydrodynamics impact water resources. Analysis determined which areas are suitable for further study and informed priorities for coordinating programs. The purpose of this report was to:

1. Determine which sites reflect suitable fecal indicator bacteria (FIB) conditions and which ones demonstrate unsuitable water quality conditions based on the beach action value (BAV) (104 cfu/100 ml).
2. Determine which areas are the most problematic for FIB exceedances.
3. Determine which sites exhibit significant trends (positive or negative) over time.
4. Determine which sites are indicating correlation with hydrodynamic alterations (such as tides, precipitation, discharges, field water quality measurements, nutrients, etc.).
5. Determine if rainfall, tidal action, temperature, suspended sediments, nutrients or other relevant data relate to changes in water quality.

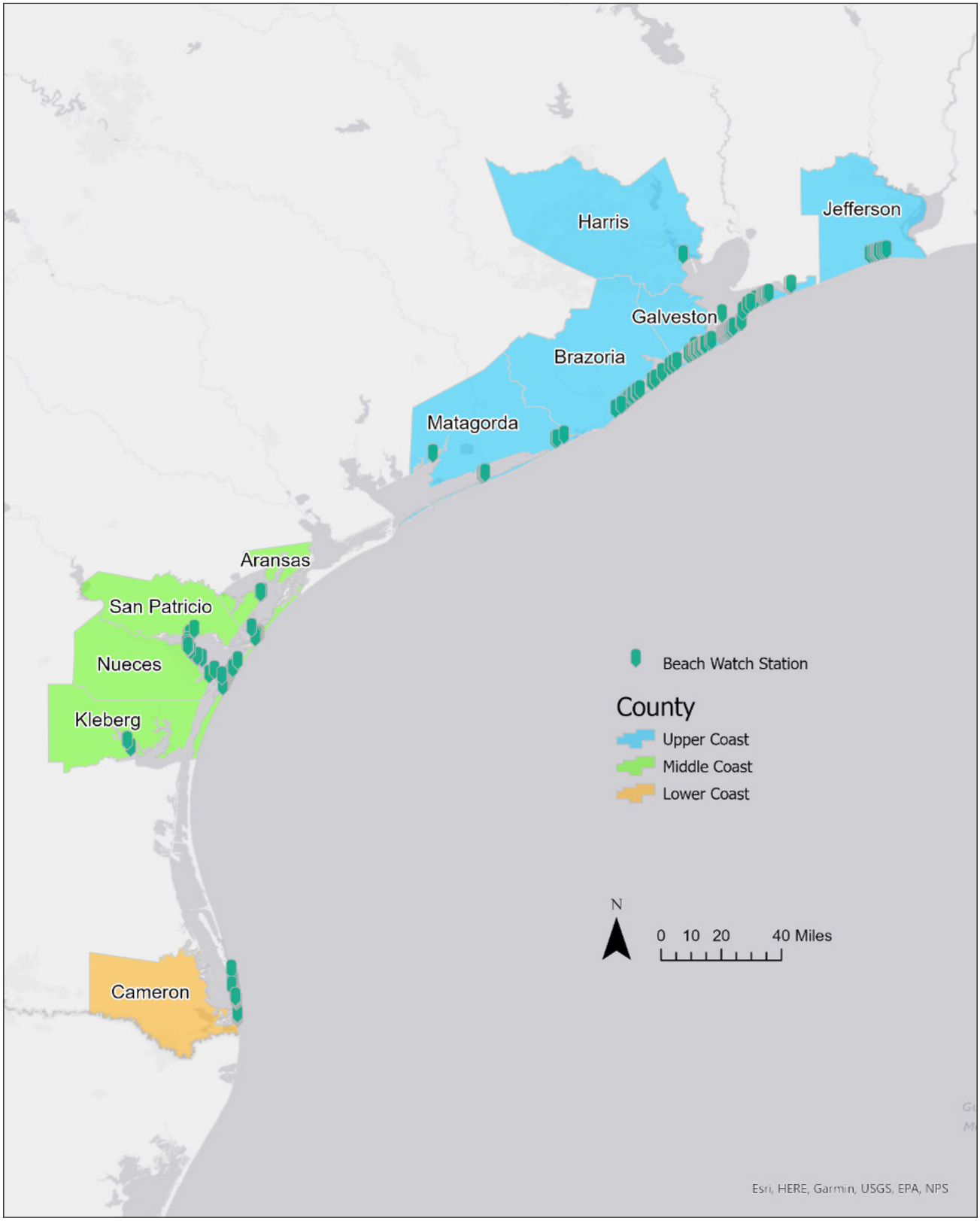

Figure 1. Texas Beach Watch monitoring sites and counties.

DATA ACQUISITION

TEXAS BEACH WATCH - ENTEROCOCCI DATA

The Meadows Center for Water and the Environment (MCWE) acquired the TBW enterococci data from the Texas General Land Office (TGLO). Water samples from 10 Texas counties, 66 beaches, and 169 stations were collected and analyzed by TGLO contractors from January 5, 2009 to December 20, 2019. All sites are used for recreational purposes and are located on the Texas Gulf coast (Figure 1). A total of 86,196 samples were collected and analyzed during this eleven-year period. Sample replicates, required by the TBW quality assurance project plan (QAPP), were averaged resulting in a total of 73,187 records.

The method detection limit (MDL) for the laboratory analytical technique, as defined by the US Environmental Protection Agency (USEPA), is the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyze concentration is greater than zero. The MDL is determined from analysis of a sample in each matrix containing the analyte. The TBW contracts with laboratories across the state to analyze the water samples collected using the USEPA-approved IDEXX Enterolert™ method of analysis. All values less than or equal to the IDEXX Enterolert™ MDL for marine waters (10 cfu/100 ml) were sorted, identified, and replaced with half the MDL or 5 cfu/100 ml. This value was used for the remainder of the analysis.

The USEPA established a BAV of 104 cfu/100 ml for recreational beaches. If the BAV is exceeded, an advisory is recommended by the TGLO and a sample is collected daily until the sample result is below the BAV or <104 cfu/100 ml.

Summary statistics including arithmetic mean, geometric mean, minimum, maximum, median, variances, and number and percent of exceedances of the BAV were calculated. Trend analyses were conducted with the percent BAV exceedances. Results of the summary statistics and trend analyses are presented in subsequent sections of this report.

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY – 2020 INTEGRATED REPORT

The Texas Commission on Environmental Quality (TCEQ) conducts statewide, biennial water quality assessments in even-numbered years to fulfill requirements of sections 305(b) and 303(d) of the Federal Clean Water Act. Assessment results are presented in a report titled Texas Integrated Report of Surface Water Quality (Integrated Report) that is made available on the TCEQ website.

The Integrated Report (IR) includes a description of the status of surface water quality bodies evaluated during the most recent seven to ten-year period of record. TCEQ established a primary contact recreation numeric criterion for enterococci bacteria in marine waters to be a geometric mean of 35 cfu/100 ml with a single sample maximum of 89 cfu/100 ml. Geometric means were compared to the corresponding criterion for primary contact recreation.

The TCEQ includes the TBW program enterococci data in the IR which represents the recreational beach conditions during the seven to ten-year assessment period. The recreational beach use is assessed using the number of beach advisories issued by the TBW program. The criterion used by TCEQ for recreational beaches is the same as the BAV used by GLO, 104 cfu/100 ml.

The GLO provides the TCEQ with a summary of the TBW data for the assessment. Table 1 describes the assessment methodology used by the TCEQ for the 2020 IR. The TCEQ assessment approach was also implemented in the current report for seven-year increments for the duration of the period of record. In addition, the number and percent exceedances of the BAV for each site and year (2009 - 2019) were also calculated. Results of the analysis using this approach are presented in subsequent sections of this report.

Table 1. TCEQ Integrated Report recreational beach use assessment criteria and listing categories.

Criterion	Listing Category
Beach advisories <25% of the time	Fully Supporting
Beach advisories 20-25% of the time	Concern and Fully Supporting
Beach advisories <20% of the time	Delisted and Fully Supporting
Beach advisories > 25% of the time	Not Supporting

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY – SURFACE WATER QUALITY MONITORING INFORMATION SYSTEM (SWQMIS) DATA

Water quality data collected by the Texas Commission on Environmental Quality were queried and acquired by MCWE for analysis in this report. TBW and TCEQ station IDs were joined in ArcGIS to identify stations in close proximity to stations corresponding to water quality data. Only data collected between January 2009 and December 2019, corresponding to the TBW period of record, were retained in the dataset. Data were further sorted by parameter code and a set of parameters with the potential to influence enterococci concentrations were maintained in the dataset. The parameters included water temperature, transparency, specific conductance, dissolved oxygen, pH, total alkalinity, salinity, total nonfiltrable reside or total suspended solids (TSS), total ammonia nitrogen, total Kjeldahl nitrogen (TKN), total nitrite plus nitrate, total phosphorus, total organic carbon (TOC), chloride, sulfate, total fluoride, total dissolved residue or total dissolved solids (TDS) and chlorophyl a. Not all parameters were available for every site, therefore the maximum number of parameters were maintained for each site. The dataset was transposed and averaged by month and year. Only measurements collected at a water depth of 0.3 m were maintained in the dataset to correspond with TBW sample depths. Sites were grouped by proximity to TBW sites for multivariate analyses.

U.S. GEOLOGICAL SOCIETY (USGS) – DISCHARGE DATA

Discharge data from the USGS Texas Water Dashboard (https://txpub.usgs.gov/txwaterdashboard/index.html) were acquired by the MCWE for analysis in this project. The Texas Water Dashboard is part of the USGS National Water Information System (NWIS) designed to acquire, process, and store national water data. Historical and current conditions are posted on the Texas Water Dashboard application daily and are available for public use. USGS gauging stations near TBW stations were identified and discharge data (cubic feet per second or cfs) were acquired and averaged by month and year for multivariate analysis. This analysis was conducted to assess the effect of upland stream flows on enterococci measurements from TBW stations.

TEXMESONET – PRECIPITATION DATA

Precipitation data were acquired from the TexMesoNet, a network of Texas weather station used to track mesoscale weather events, such as fronts, thunderstorms, and precipitation bands. Mesonet systems normally collect data on atmospheric conditions, solar energy, soil moisture, and soil temperature and can be used for weather forecasting, alternative energy development, agriculture, and for fire, flood, and freeze warnings. In this report, we used precipitation data collected near TBW sites with corresponding period of record to determine if there is a relationship between precipitation events and enterococci measurements. Historical cumulative monthly precipitation data were downloaded from January 2009 through December 2019 to correspond with the period of record for this study for multivariate analysis.

NOAA - WATER LEVEL DATA

Water level data along the Texas Gulf of Mexico coast was acquired from the NOAA Tides and Currents website (https://tidesandcurrents.noaa.gov/map/index.html?type=active&region=Texas), developed and supported by the Center for Operational Oceanographic Products and Services (CO-OPS). Tides or water level data included measurements of the periodic rise and fall of a body of water resulting from gravitational interactions among the sun, moon, and earth. The vertical measurement of the tidal wave or the monthly maximum tidal amplitude included the sum of the absolute values of the mean high water (MHW) and mean low water (MLW) in feet (ft). Stations near TBW stations with corresponding period of record were identified, and data were acquired and aggregated for multivariate analysis (Figure 2).

TEXAS PARKS AND WILDLIFE HYDROLOGICAL DATA

Hydrological data from Texas Parks and Wildlife Coastal Fisheries Division's Resource Monitoring Program were acquired for use in this project. Parameters in the dataset included dissolved oxygen (mg/l), salinity (ppt), and temperature (°C). A total of 74,435 records were used from coastal bays and the nearshore waters of the Gulf of Mexico. The period of record coincided with the Texas Beach Watch data.

Aerial of Galveston Texas

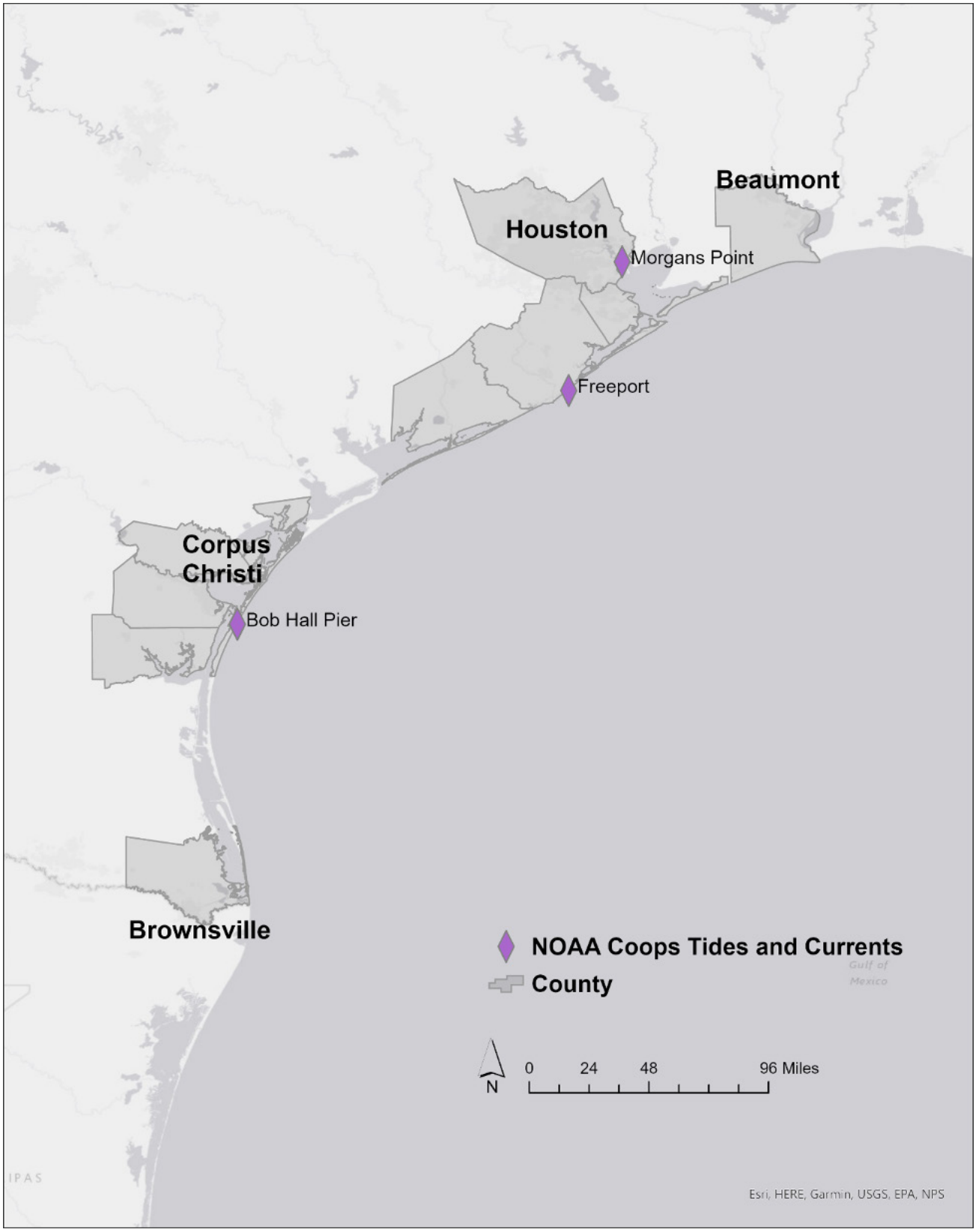

Figure 2. NOAA Coop Tides and Currents station locations used for multivariate analysis.

DATA ANALYSIS

TBW enterococci data were transformed using the natural log transformation, ln(y), and analyzed by calculating monthly annual averages. Data distribution was analyzed to test assumptions of normality and equal variances. Significant trends were identified using $\alpha = 0.05$. Statistical analyses were conducted for this project using JMP® Pro 15.1.0 (SAS Institute Inc., 2019), R 4.05 and ArcMap 10.8.1. Means were grouped and statistical tests were applied among the following groups:

- Geographic analysis - upper, middle, and lower Texas Coasts
- Beach type - Bay and Gulf
- Seasonal analysis - peak (May – September) and non-peak season (October - April)
- Station analysis – by site
- County analysis – by county (10 counties)

The TBW enterococci measurements, TCEQ SWQMIS water quality, USGS discharge, TexMesoNet precipitation, and NOAA water level data were aggregated for multivariate analysis. Monitoring data were collected at different frequencies; therefore, each dataset was averaged by month and year for the multivariate analysis.

Correlation analysis was conducted to identify relationships among the multiple variables over space (site) and time (month/year). Strong relationships were further analyzed to assess trends and identify sites exhibiting common characteristics.

Spatial modeling was conducted in ArcMap 10.8.1 using the spatial analyst extension. Maps of yearly trends were prepared for the 11-year period of record (Appendix A). The percent exceedance of BAV and hydrological data (temperature, salinity, and dissolved oxygen) from Texas Parks and Wildlife were used for the hot spot analysis. The hot spot analysis was performed for weighted features using the inverse distance weighted (IDW) interpolation by year. Each shapefile, including the percent exceedance of the BAV, was analyzed using the inverse distance squared method and the Manhattan distance approach. A hot spot analysis of percent exceedances was performed for each year and overlaid on the raster of hydrological data (33 total data frames over 6 map files).

RESULTS

GEOGRAPHIC COAST-WIDE ANALYSIS

The Texas Gulf coast has 3,359 miles of shoreline along the perimeter of offshore islands and bays and tidal rivers and creeks (NOAA, 2020). The coastline is divided into three geographically distinct areas (i.e., upper, middle, and lower) based on clusters of enterococci TBW monitoring sites (Figure 3). Thirty-eight bay and 131 gulf beach sites are presented in blue and green symbols, respectively. The upper Texas coast is comprised of Jefferson, Harris, Galveston, Brazoria, and Matagorda counties; the middle coast includes San Patricio, Aransas, Nueces, and Kleberg counties; and the lower coast includes Cameron County (Figure 4).

Summary statistics (Table 2) resulted in the following:

- The upper coast had the highest number of samples (39,324), geometric mean (13.8), and maximum value (24,196). There were more gulf beaches than bay beaches in the upper coast and it had the most BAV exceedances (3,849) of the three geographic groups.
- The middle coast had more bay beaches than gulf beaches, the highest arithmetic mean (195.1), and highest percent BAV exceedances (11%) among the three geographic groups.

- The lower coast had only gulf beaches and had the least number of samples (10,862) and the lowest values for arithmetic (11.9) and geometric (6.2) means, maximum value (2,250), number (129) and percent (1.2%) BAV exceedances among all three geographic groups.

All geographic areas had exceedances of the BAV. However, the upper and middle geographic groups exhibited the highest number and percent BAV exceedances, while the lower group had the lowest values for all statistics.

A Tukey-Kramer test was used to analyze the interaction among the three geographic areas. No statistically significant difference was found between the enterococci means of the upper and middle geographic areas (p-value=0.3042). However, the upper and middle area means were significantly different (p-value<0.001) from the lower geographic area.

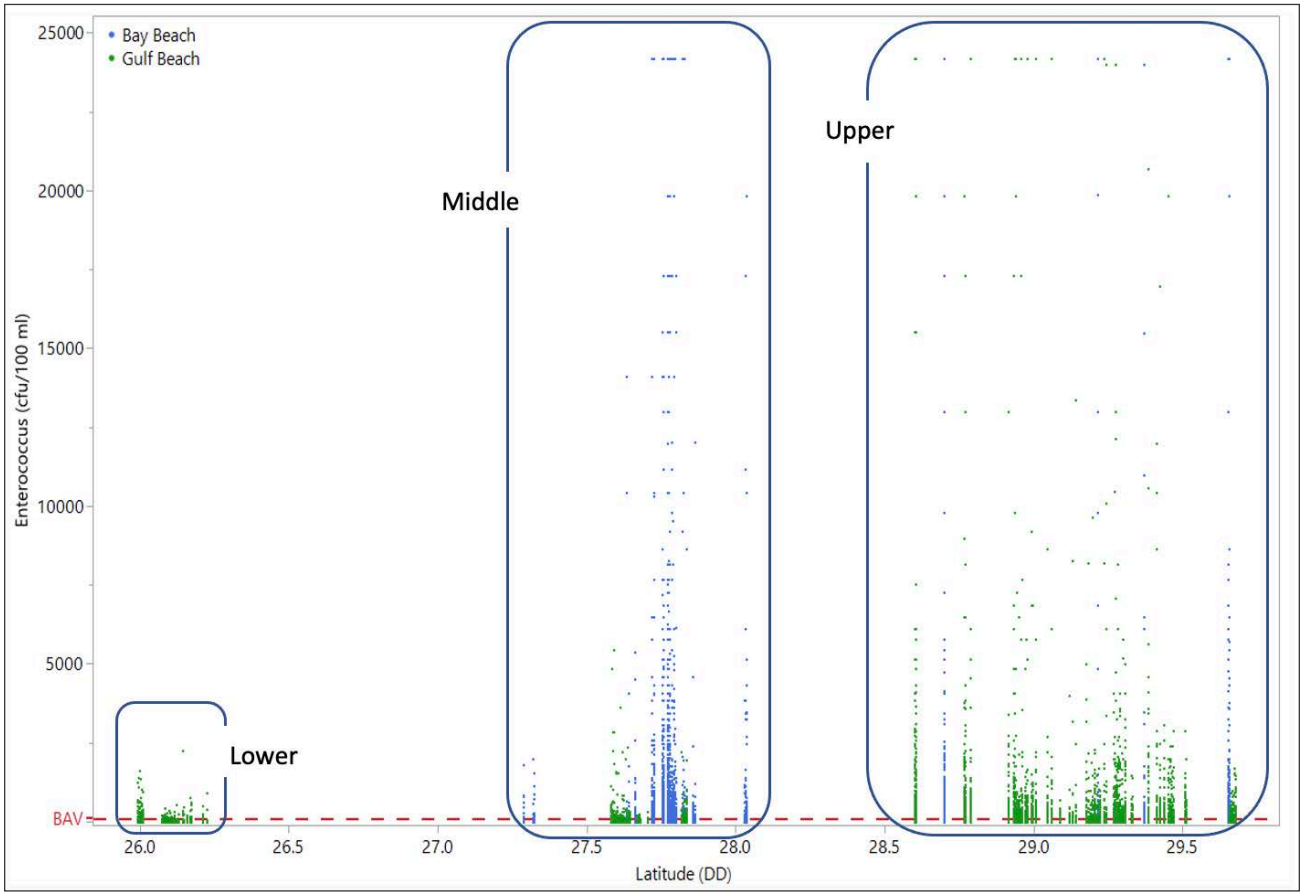

Figure 3. Enterococci concentrations (cfu/100 ml) for bay and gulf sites along the upper, middle, and lower Texas Gulf coast (January 2009 – December2019, n=73,187).

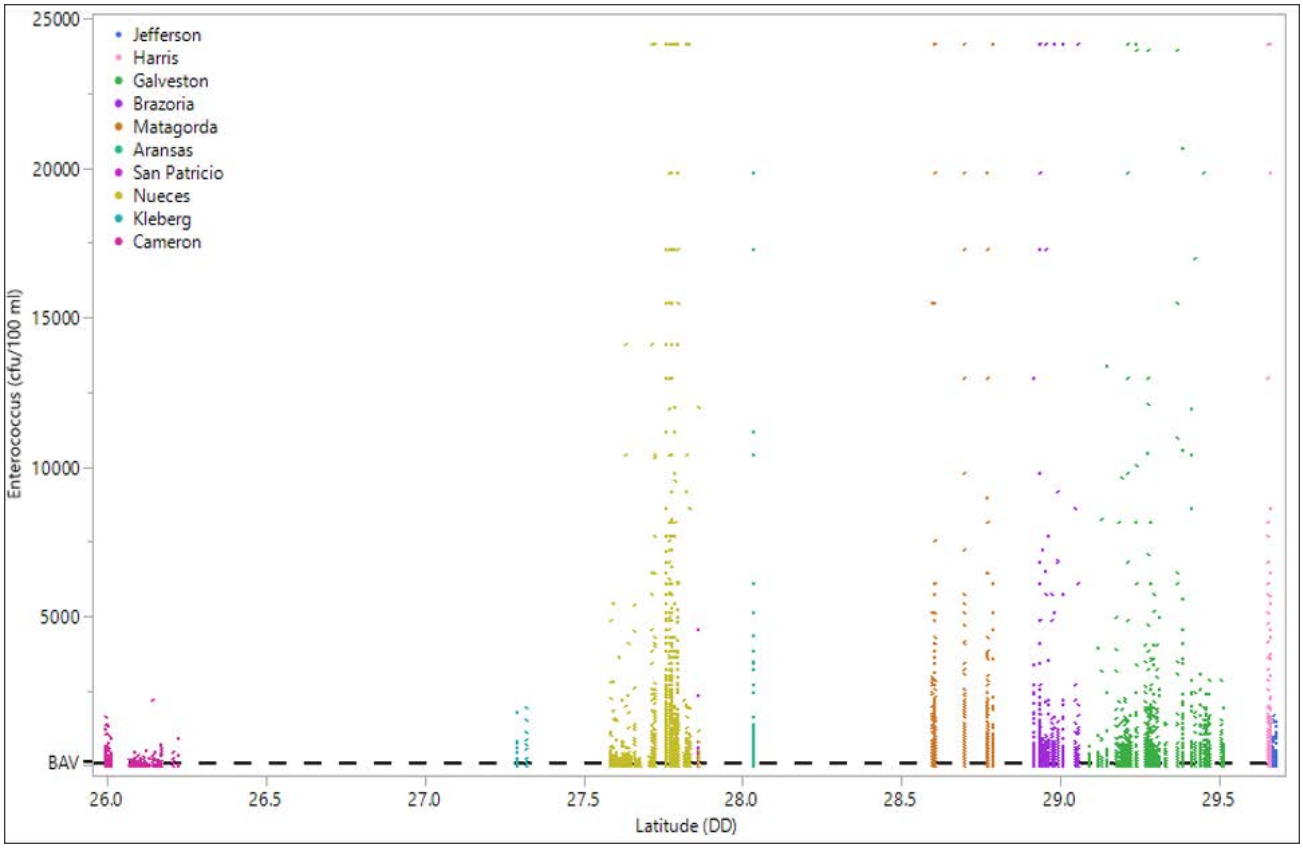

Figure 4. Enterococci concentrations (cfu/100 ml) by county for all sites along Texas Gulf coast (January 2009 - December 2019).

Table 2. Summary statistics of enterococci concentrations (cfu/100 ml) data for upper, middle, and lower coast (January 2009 - December 2019).

Statistic	Upper - Enterococcus (cfu/100 ml)	Middle - Enterococcus (cfu/100 ml)	Lower - Enterococcus (cfu/100 ml)
N	39,324	23,000	10,862
Arithmetic Mean	103.7	195.1	11.9
Geometric Mean	13.8	13.6	6.2
Median	5.0	5.0	5.0
Minimum	5.0	5.0	5.0
Maximum	24,196.0	24,196.0	2,250.5
Std. Deviation	860.2	1,528.7	53.4
Variance	739,902.8	2,337,011.4	2,850.9
No. BAV Exceedances	3,849	2,541	129
% BAV Exceedances	9.8%	11%	1.2%

BEACH TYPE ANALYSIS

Based on the physical location of the monitoring site, TBW data were categorized according to beach type (i.e., bay or gulf). Sites located within a semi-enclosed embayment were categorized as bay beaches and sites located on the shoreline of the Gulf of Mexico were classified as gulf beaches. Thirty-eight sites were located on bay beaches and 131 sites on gulf beaches. Summary statistics for enterococci data from all sites for the two categories are presented in Table 3.

A one-way ANOVA of transformed enterococci data was performed by beach type to test for differences between means. A significant difference (p-value <0.001) between bay and gulf beach means resulted from the one-way ANOVA. Gulf beaches were sampled the greatest number of times (57,506), as compared to bay beaches (15,681). Bay beaches resulted in higher arithmetic (333.1) and geometric (21.7) means, than gulf beaches, 60.4 and 10.5, respectively. Although gulf beaches had a larger number of BAV exceedances (3,614) than bay beaches (2,908), bay beaches exhibited an almost three-fold higher percent exceedance of the BAV (18.5%) than gulf beaches (6.3%).

A one-way ANOVA of transformed enterococci data was performed by beach type and month to test for differences between group means by month. Significant differences between beach type resulted for all months (p-value<0.05) except August (p-value = 0.35). Monthly analysis of arithmetic (Figure 5) and geometric (Figure 6) means reveal that most bay beaches exhibit higher means than gulf beaches. The highest monthly arithmetic mean in bay sites occurred in September while the highest arithmetic mean in gulf sites occurred in August. The highest geometric mean in bay sites occurred in September and in June for gulf sites. Monthly arithmetic means for all bay sites exceeded the BAV (Figure 5). The monthly geometric mean for bay beaches in September (37 cfu/100 ml) exceeded the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters of 35 cfu/100ml (Figure 6).

A one-way ANOVA of transformed enterococci data was performed by beach type and year to test for differences between group means by year. Significant differences between beach type resulted for all years (p-value <0.05), except 2014 (p-value = 0.24). Annual arithmetic means for all bay beaches exceeded the BAV except in 2014, while all gulf beach annual arithmetic means were below the BAV except in 2019 (Figure 7). The annual geometric mean for bay beaches in 2015 (37.6 cfu/100 ml) exceeded the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters of 35 cfu/100ml (Figure 8).

Temporal correlation analysis of annual percent exceedances of the BAV was conducted by beach type (Figure 9). The correlation coefficients for percent exceedances of the BAV by bay beaches (r = 0.52) and gulf beaches (r = 0.58) over time were comparable, however the corresponding p-values (0.09 and 0.06, respectively) were not significant at the 95% confidence interval.

Table 3. Summary statistics of enterococci concentrations (cfu/100 ml) for Texas Beach Watch (TBW) bay and gulf beaches (January2009 - December 2019).

Statistic	Bay Beach - Enterococcus (cfu/100 ml)	Gulf Beach - Enterococcus (cfu/100) ml)
N	15,681	57,506
Arithmetic Mean	333.1	60.4
Geometric Mean	21.7	10.5
Median	11.0	5.0
Minimum	5.0	5.0
Maximum	24,196	24,196
Standard Deviation	1,988.8	592.7
Variance	3,955,501.2	351,344.1
Number of BAV exceedances	2,908	3,614
Percent of BAV exceedances	18.5%	6.3%

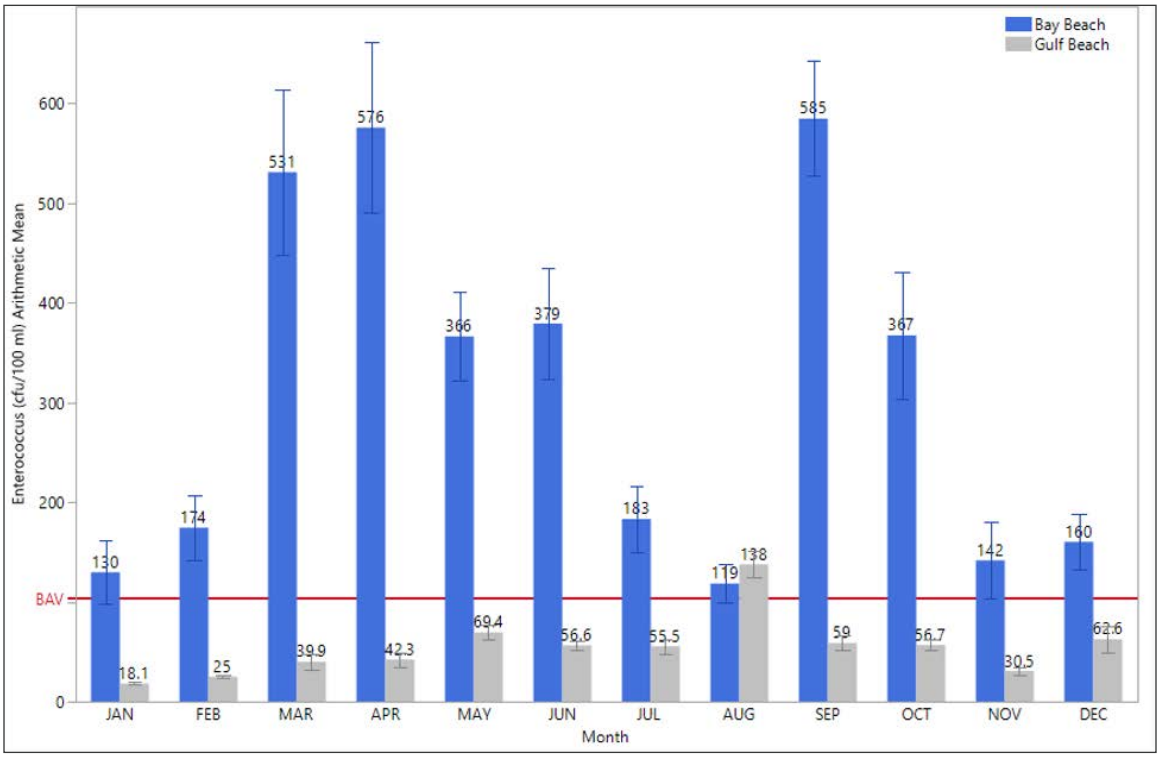

Figure 5. Monthly arithmetic mean of enterococci concentrations (cfu/100 ml) for bay and gulf beaches (January 2009 - December 2019).

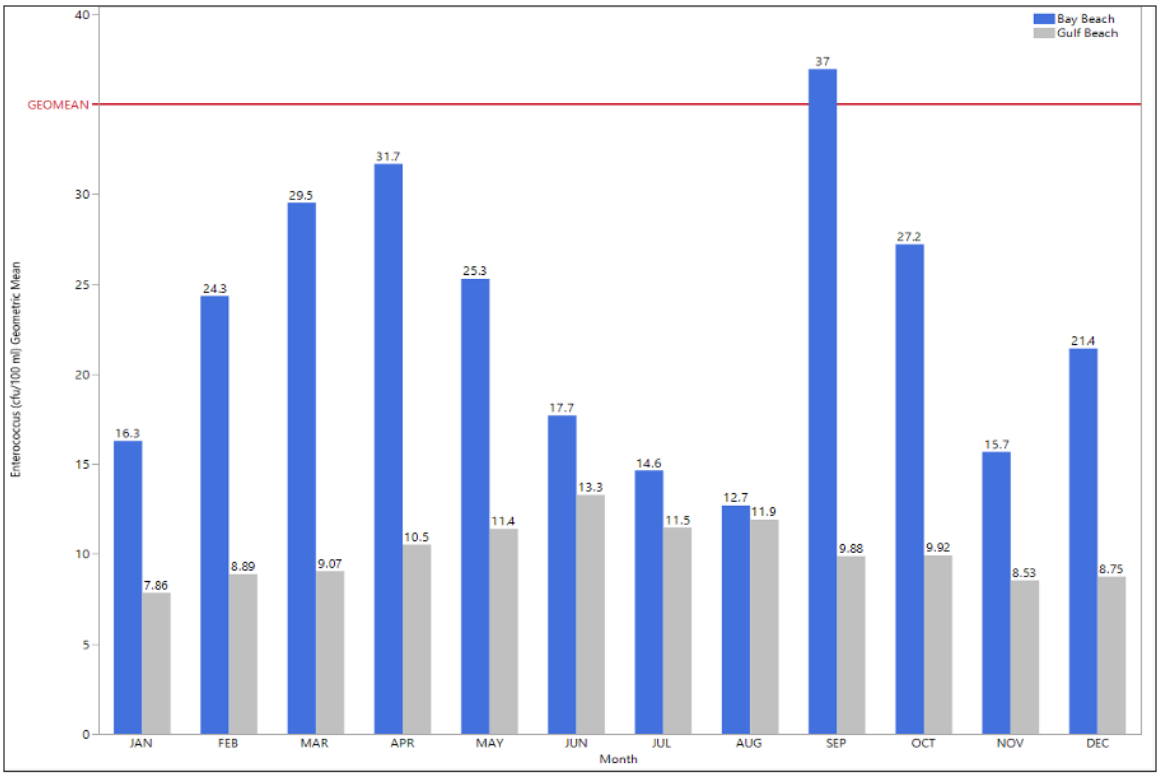

Figure 6. Monthly geometric mean of enterococci concentrations (cfu/100 ml) for bay and gulf beaches (January 2009 - December 2019).

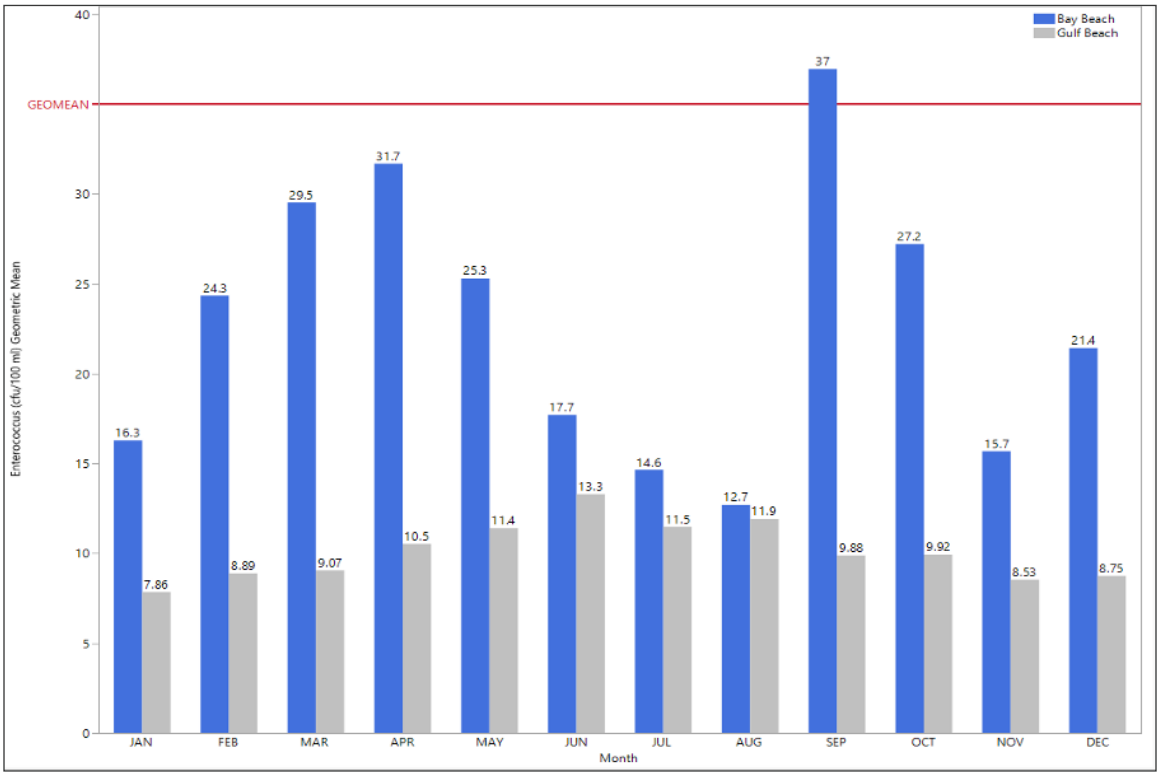

Figure 7. Annual arithmetic mean of enterococci concentrations (cfu/100 ml) for bay and gulf beaches (January 2009 - December 2019).).

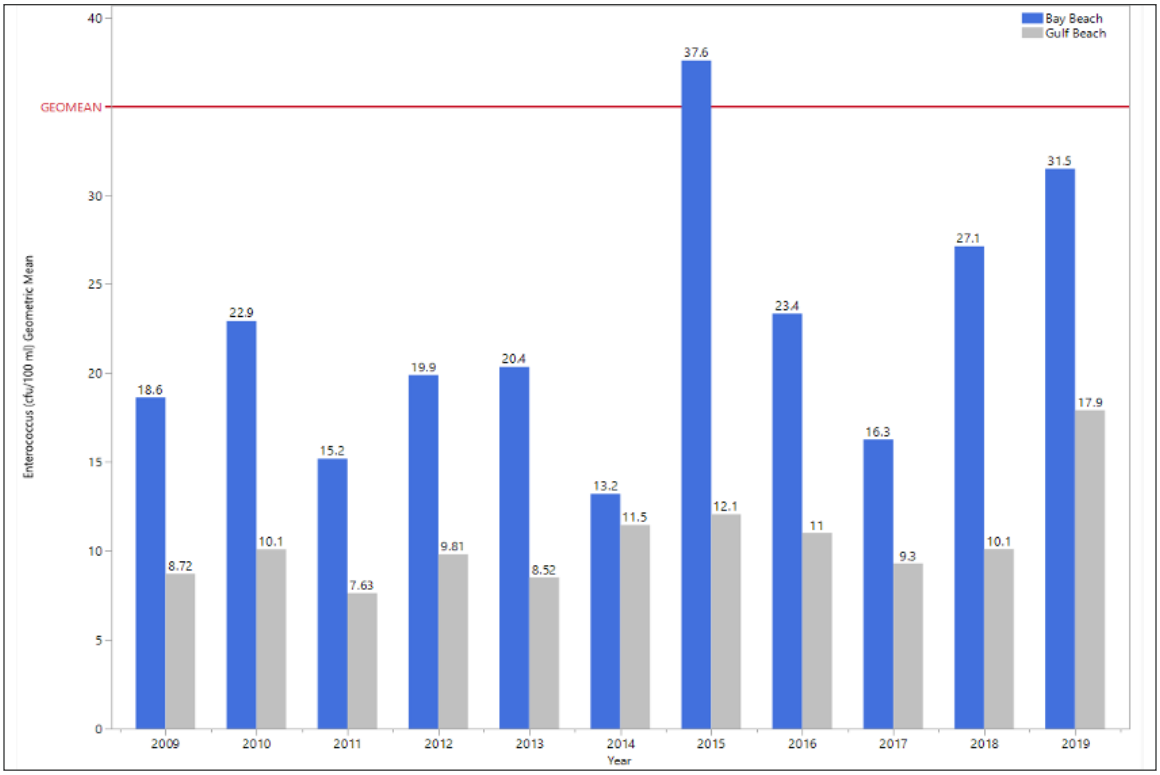

Figure 8. Annual geometric mean enterococci (cfu/100 ml) for all bay and gulf beaches (January 2009 - December 2019).

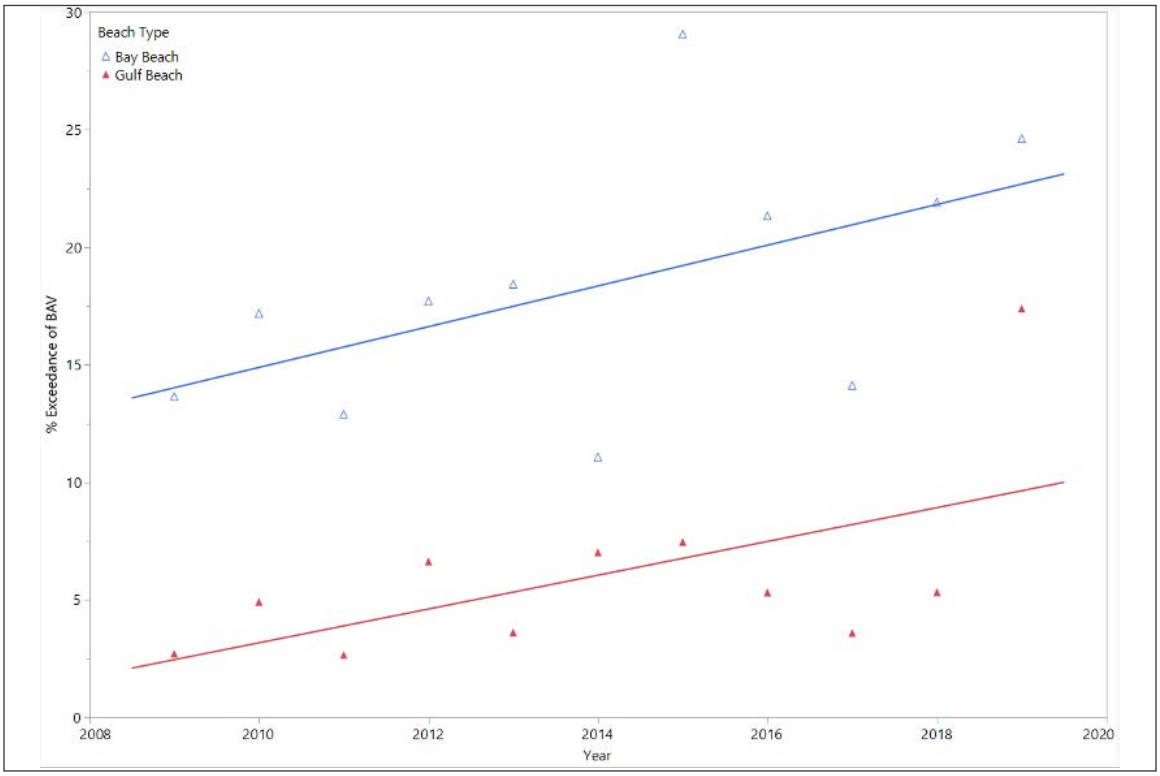

Figure 9. Temporal relationship of annual percent exceedance of BAV for bay and gulf beaches (January 2009 - December 2019).

SEASONAL ANALYSIS

Texas Beach Watch (TBW) water quality sampling frequency differs during peak and non-peak seasons. The peak season consists of weekly sampling from May until September each year in response to peak swim time periods. The non-peak season consists of biweekly sampling at each site from October through April each year in response to non-peak swim time periods. In March of each year, weekly sampling is conducted on all gulf beaches in response to an influx of beachgoers during spring break. Seasonal summary statistics for the enterococci data from all sites are presented in Table 4.

A one-way ANOVA of transformed enterococci data was performed by season to test for differences between season means. A significant difference (p-value < 0.001) between peak and non-peak season means resulted from the one-way ANOVA. A one-way ANOVA was also performed by season for beach type resulting in a seasonal significant difference for gulf beaches, but not for bay beaches.

More samples were collected during the peak season (42,592) than during the non-peak season (30,595). The arithmetic (132.5) and geometric (13.1) means were higher during the peak season than during the non-peak season, 99.7 and 11.2, respectively. The number and percent of BAV exceedances were also higher during the peak season, 4,241 and 10%, as compared to the non-peak season, 2,279 and 7.4%, respectively.

Monthly analysis of arithmetic (Figure 10) and geometric (Figure 11) means by season revealed similar results. Most arithmetic means were greater than the BAV from March through October (Figure 10). None of the peak and non-peak season monthly geometric means exceeded the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters (Figure 11).

Arithmetic (Figure 12) and geometric (Figure 13) means were analyzed for peak and non-peak season by bay and gulf beaches. Bay beaches had higher arithmetic and geometric means than gulf beaches during both seasons. Arithmetic means for bay beaches during peak and non-peak seasons exceeded the BAV (Figure 12). Geometric means during peak and non-peak seasons for both bay and gulf beaches did not exceed the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters (Figure 13).

Table 3. Summary statistics of enterococci concentrations (cfu/100 ml) for Texas Beach Watch (TBW) bay and gulf beaches (January2009 - December 2019).

Statistic	Peak Season – *Enterococcus* (cfu/100ml)	Non-peak Season – *Enterococcus* (cfu/100ml)
N	42,592	30,595
Arithmetic Mean	132.5	99.7
Geometric Mean	13.1	11.2
Median	5.0	5.0
Minimum	5.0	5.0
Maximum	24,196	24,196
Standard Deviation	1,108.1	1,1003.8
Variance	1,227,816.6	1,007,686.8
Number of BAV Exceedances	4,241	2,279
Percent of BAV Exceedances	10%	7.4%

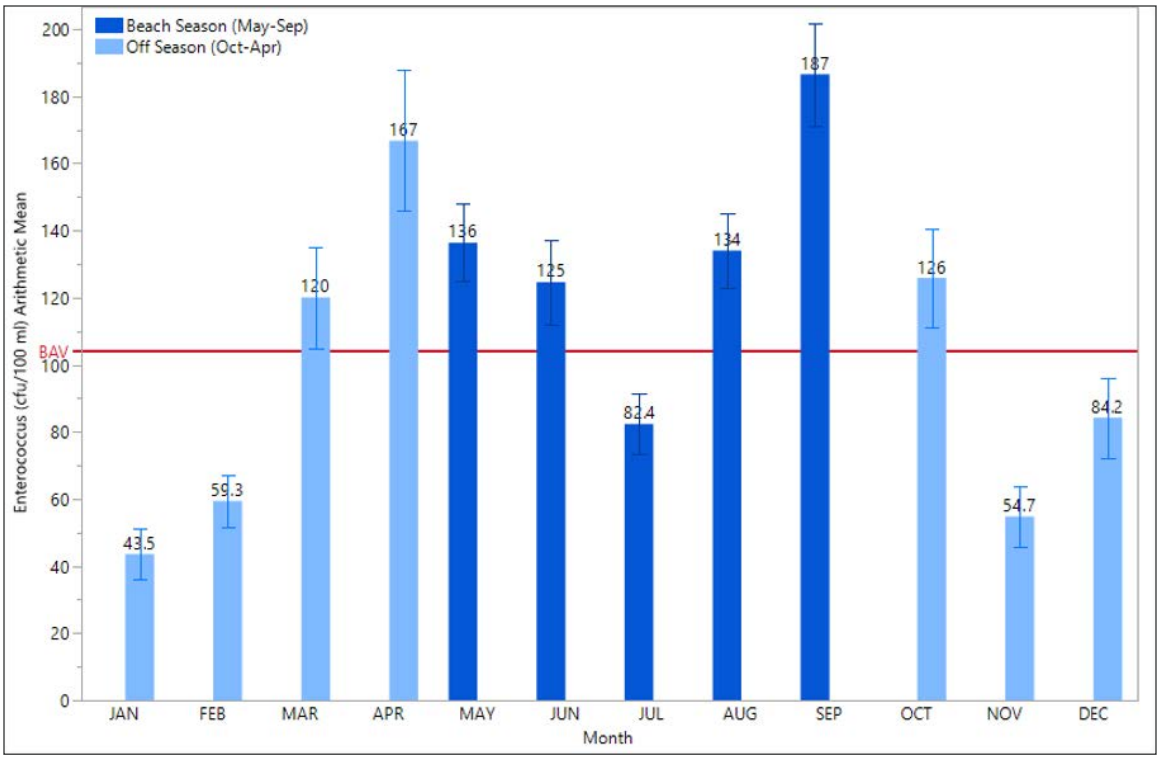

Figure 10. Monthly arithmetic mean of enterococci concentrations (cfu/100 ml) for all sites by season (January 2009 - December 2019).

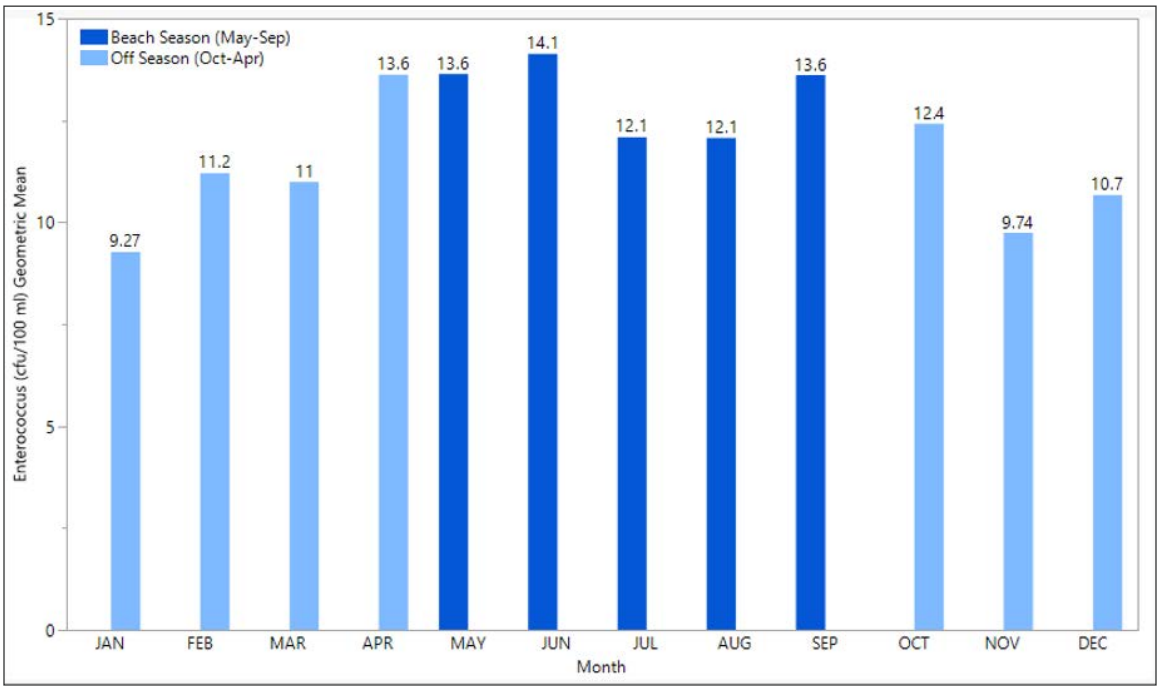

Figure 11. Monthly geometric mean of enterococci concentrations (cfu/100 ml) for all sites by season (January 2009 - December 2019).

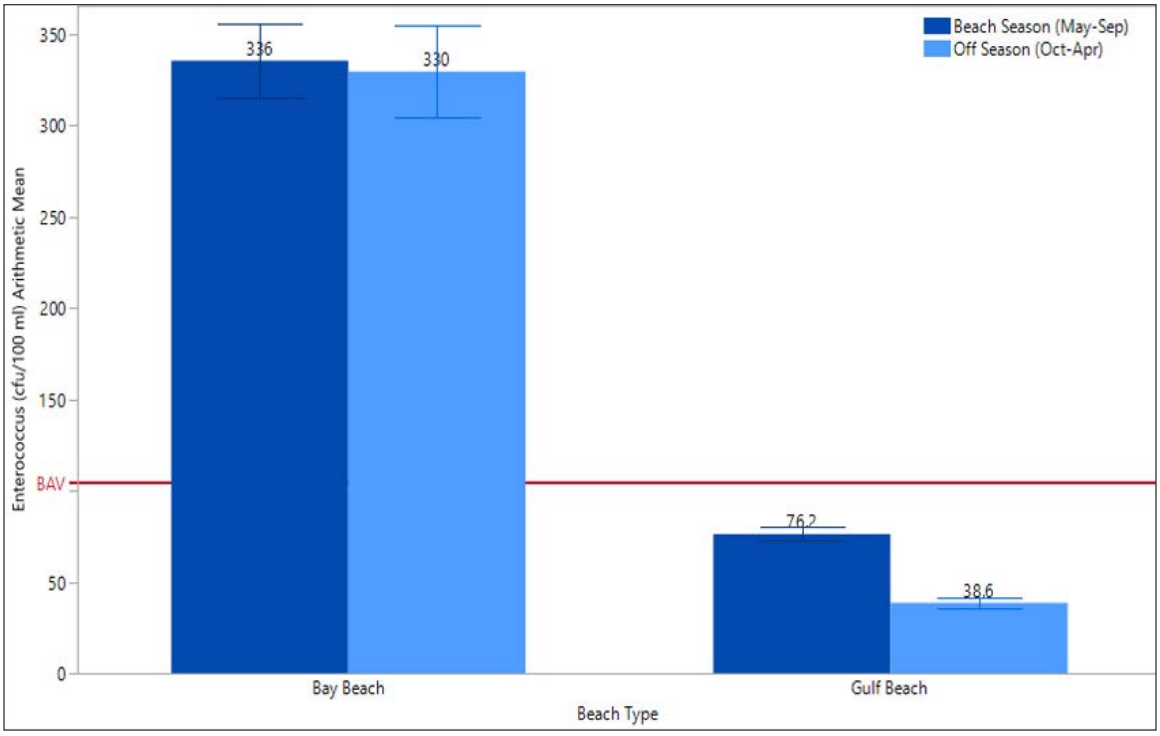

Figure 12. Arithmetic mean of enterococci concentrations (cfu/100 ml) for bay and gulf beaches by season (January 2009 - December 2019). Beach season = May to September and off or non-beach season = October to April.

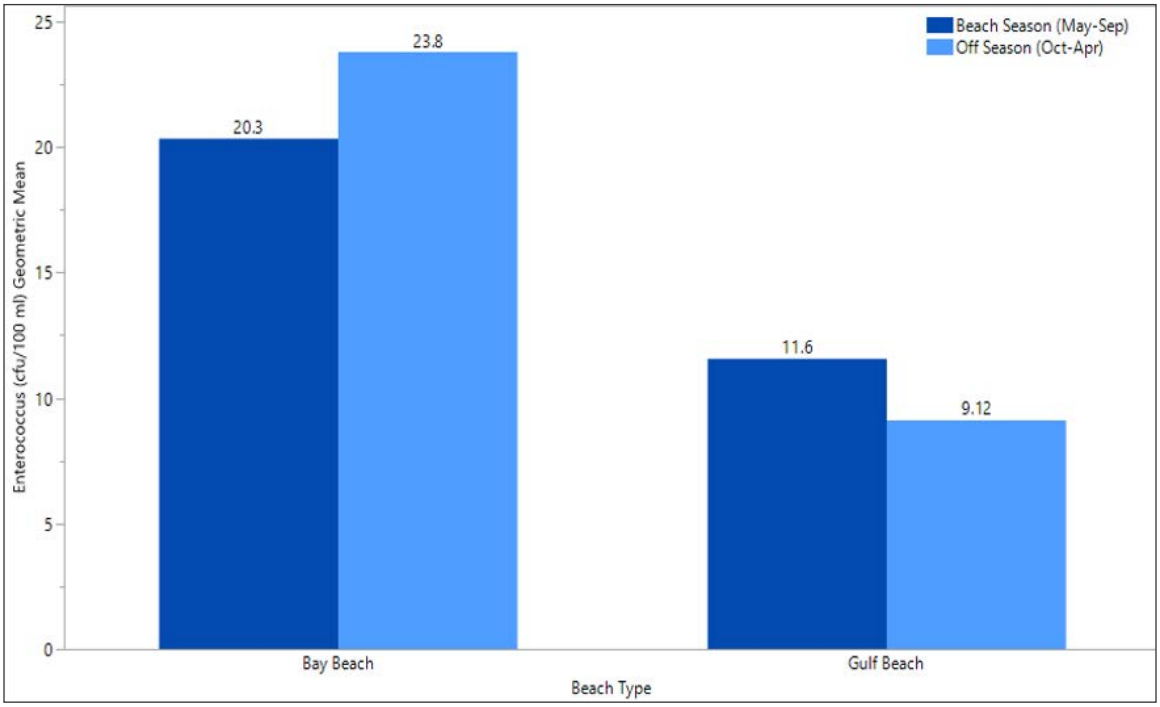

Figure 13. Geometric mean of enterococci concentrations (cfu/100 ml) for bay and gulf beaches by season (January 2009 - December 2019). Beach season = May to September and off or non-beach season = October to April.

STATION ANALYSIS

Stations were analyzed by year and cumulatively for the period of record to determine FIB suitability based on percent exceedance of the BAV (104 cfu/100ml) (Figure 14). A total of 159 (94%) stations met the fully supporting criterion for recreational beaches (<25% exceedance of the BAV), while 6 (3.8%) of the stations met the concern and fully supporting criterion (20-25% exceedance of the BAV) (Table 5). Ten (5.9%) stations did not support the criterion for recreational beach use (>25% exceedance of the BAV) and all were located on bay beaches. Four of the 6 stations that met the concerns and fully supporting criterion were located on gulf beaches. In 2017, 166 or 98% of the stations met the recreational beach criterion, but in 2019 only 136 or 80.5% of the stations met the recreational beach use criterion. Station percent BAV exceedances by year and cumulatively for the period of record are sorted from highest to lowest in Table 6.

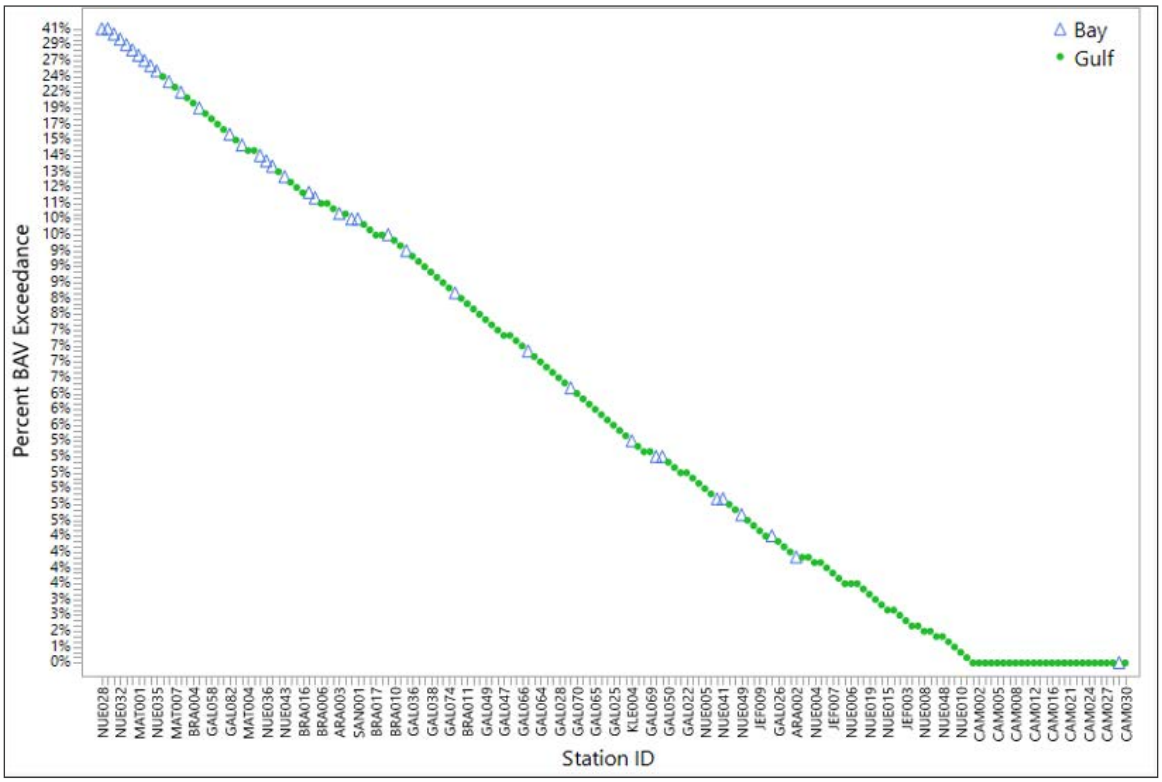

Figure 14. Percent BAV exceedances by station for all years combined (2009-2019).

Table 5. Annual and cumulative station summary of percent BAV exceedance counts and percentages (%) by criterion.

Criterion	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Fully Supporting (<25%)	164 (97)	163 (96)	163 (96)	152 (89)	163 (96)	164 (97)	154 (91)	156 (92)	166 (98)	162 (95.9)	136 (80.5)	159 (94)
Concern and Fully Supporting (20-25%)	4 (2.4)	10 (5.9)	2 (1.2)	7 (4)	4 (2.4)	5 (3)	10 (5.9)	4 (2.4)	3 (1.8)	5 (3)	3 (1.8)	6 (3.6)
Not Supporting (>25%)	5 (3)	6 (3.6)	6 (3.6)	11 (6.5)	6 (3.6)	5 (3)	15 (8.9)	13 (7.7)	3 (1.8)	7 (4)	33 (19.5)	10 (5.9)

Table 6. Station percent BAV exceedances by year and cumulative for the period of record sorted from highest to lowest.

Station	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
NUE028	36%	36%	23%	39%	52%	29%	54%	44%	44%	45%	41%	41%
NUE029	27%	35%	29%	44%	39%	31%	52%	42%	27%	42%	36%	41%
NUE031	28%	27%	28%	34%	37%	35%	56%	34%	24%	51%	35%	38%
NUE032	28%	27%	14%	22%	17%	13%	42%	23%	38%	41%	42%	37%
NUE033	21%	23%	14%	19%	24%	8%	52%	18%	22%	28%	26%	29%
MAT002	22%	36%	30%	36%	18%	20%	26%	29%	14%	20%	51%	29%
MAT001	22%	27%	27%	33%	20%	3%	22%	32%	12%	9%	56%	27%
HAR002	ND	ND	12%	18%	24%	8%	25%	28%	15%	18%	60%	27%
NUE026	29%	24%	32%	31%	25%	17%	23%	29%	10%	41%	3%	25%
NUE035	10%	13%	5%	8%	25%	8%	28%	10%	13%	15%	14%	25%
MAT008	3%	18%	7%	33%	8%	8%	27%	11%	10%	15%	65%	24%
HAR001	ND	ND	5%	8%	13%	10%	23%	29%	13%	18%	55%	24%
MAT007	3%	21%	5%	21%	11%	3%	24%	15%	8%	13%	60%	22%
NUE045	5%	16%	26%	19%	20%	15%	31%	12%	15%	38%	30%	22%
MAT009	5%	18%	5%	35%	12%	9%	14%	20%	8%	15%	51%	21%
BRA004	16%	8%	3%	24%	5%	18%	16%	13%	10%	20%	49%	20%
NUE050	3%	0%	3%	3%	6%	0%	3%	12%	4%	5%	7%	19%
BRA005	16%	8%	5%	33%	5%	6%	14%	19%	5%	9%	44%	18%
GAL058	3%	8%	0%	3%	12%	36%	27%	27%	23%	18%	17%	17%
MAT003	3%	12%	0%	24%	3%	3%	5%	9%	5%	13%	55%	17%
MAT006	5%	12%	5%	27%	5%	10%	5%	7%	5%	7%	52%	16%
GAL082	ND	20%	5%	10%	8%	13%	24%	20%	19%	19%	22%	16%
BRA002	10%	5%	5%	24%	3%	10%	16%	9%	10%	9%	42%	15%
GAL021	17%	5%	7%	10%	12%	19%	16%	18%	19%	19%	20%	15%
MAT004	3%	8%	0%	19%	3%	3%	7%	9%	3%	7%	49%	14%
MAT005	3%	8%	0%	24%	3%	5%	3%	7%	3%	7%	51%	14%
NUE025	8%	16%	5%	27%	15%	3%	27%	12%	3%	23%	5%	14%
NUE036	10%	13%	5%	8%	25%	8%	28%	10%	13%	15%	14%	14%
ARA004	10%	12%	14%	13%	8%	8%	21%	28%	8%	14%	3%	13%
GAL059	6%	5%	0%	3%	10%	18%	25%	27%	14%	10%	18%	13%
NUE043	10%	8%	10%	21%	17%	0%	ND	ND	ND	ND	ND	12%
BRA009	0%	3%	3%	10%	0%	5%	3%	3%	10%	14%	44%	12%
BRA014	0%	3%	5%	13%	0%	8%	3%	3%	5%	7%	46%	12%
BRA016	0%	5%	3%	10%	3%	0%	5%	5%	0%	2%	48%	11%

Table 6 cont. Station percent BAV exceedances by year and cumulative for the period of record sorted from highest to lowest.

Station	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
NUE046	5%	20%	5%	8%	15%	8%	24%	5%	8%	19%	3%	11%
NUE037	8%	15%	8%	8%	11%	5%	18%	10%	5%	21%	12%	11%
BRA006	5%	3%	0%	15%	0%	10%	3%	0%	8%	5%	41%	11%
BRA015	0%	8%	0%	8%	5%	3%	3%	3%	5%	5%	46%	11%
GAL034	12%	8%	3%	0%	8%	26%	21%	11%	8%	7%	10%	11%
ARA003	8%	10%	5%	6%	11%	8%	17%	25%	3%	17%	3%	11%
BRA013	3%	3%	0%	10%	3%	8%	3%	5%	5%	9%	41%	11%
NUE042	20%	19%	22%	13%	8%	3%	11%	0%	0%	5%	5%	10%
SAN001	10%	12%	0%	8%	8%	0%	27%	12%	3%	14%	12%	10%
GAL037	14%	12%	0%	10%	14%	15%	17%	5%	0%	7%	12%	10%
GAL041	15%	7%	5%	3%	8%	16%	19%	14%	3%	10%	9%	10%
BRA017	0%	8%	0%	8%	0%	0%	5%	5%	3%	5%	42%	10%
BRA018	0%	5%	5%	13%	0%	0%	3%	5%	5%	0%	41%	10%
KLE002	5%	14%	11%	ND	ND	ND	ND	ND	ND	ND	ND	10%
BRA010	0%	3%	3%	19%	0%	3%	3%	3%	0%	5%	39%	10%
BRA007	0%	5%	3%	10%	0%	3%	3%	0%	5%	5%	40%	10%
NUE039	3%	14%	5%	10%	3%	3%	14%	29%	0%	8%	3%	9%
GAL036	8%	10%	3%	5%	3%	20%	19%	9%	8%	5%	8%	9%
BRA008	0%	0%	3%	8%	3%	8%	3%	0%	12%	5%	34%	9%
GAL061	8%	3%	0%	3%	5%	10%	18%	16%	12%	3%	18%	9%
GAL038	8%	7%	3%	5%	3%	16%	17%	11%	12%	5%	10%	9%
GAL035	10%	10%	10%	3%	7%	13%	14%	5%	8%	7%	10%	9%
BRA012	3%	5%	0%	8%	3%	3%	3%	3%	3%	2%	38%	9%
GAL074	4%	3%	5%	5%	8%	23%	8%	5%	5%	16%	10%	9%
KLE001	8%	10%	8%	ND	ND	ND	ND	ND	ND	ND	ND	9%
GAL045	5%	7%	5%	3%	3%	19%	16%	7%	5%	8%	10%	8%
BRA011	3%	3%	0%	10%	3%	8%	3%	3%	5%	7%	30%	8%
GAL044	5%	7%	0%	3%	3%	21%	14%	11%	0%	10%	10%	8%
GAL030	3%	0%	7%	3%	10%	14%	12%	11%	10%	5%	10%	8%
GAL049	8%	7%	3%	3%	10%	14%	15%	9%	12%	0%	3%	8%
GAL062	3%	5%	0%	8%	5%	12%	10%	14%	3%	8%	14%	8%
GAL042	11%	7%	0%	0%	3%	17%	17%	5%	5%	5%	10%	7%
GAL047	5%	10%	5%	3%	5%	13%	10%	5%	8%	5%	12%	7%
GAL048	5%	10%	5%	3%	16%	11%	8%	5%	12%	3%	3%	7%

Table 6 cont. Station percent BAV exceedances by year and cumulative for the period of record sorted from highest to lowest.

Station	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
GAL013	3%	0%	0%	5%	10%	11%	12%	9%	10%	5%	12%	7%
GAL066	3%	5%	5%	3%	5%	8%	10%	16%	5%	5%	12%	7%
KLE003	5%	7%	11%	ND	ND	ND	ND	ND	ND	ND	ND	7%
GAL040	8%	7%	5%	0%	5%	14%	19%	5%	0%	3%	10%	7%
GAL064	0%	3%	3%	3%	5%	12%	8%	12%	8%	5%	16%	7%
GAL032	5%	0%	3%	8%	8%	10%	8%	7%	10%	10%	8%	7%
GAL039	8%	5%	3%	3%	0%	12%	19%	7%	8%	3%	7%	7%
GAL028	3%	0%	5%	8%	5%	7%	14%	5%	10%	10%	8%	7%
GAL023	3%	0%	3%	8%	3%	20%	14%	7%	5%	8%	0%	7%
NUE038	3%	10%	3%	10%	0%	0%	16%	20%	0%	5%	0%	7%
GAL070	0%	3%	0%	0%	5%	10%	8%	12%	3%	3%	23%	6%
NUE024	3%	3%	12%	3%	3%	10%	3%	7%	5%	5%	14%	6%
GAL046	10%	3%	3%	3%	3%	12%	8%	10%	5%	3%	10%	6%
GAL065	0%	5%	3%	0%	5%	10%	10%	11%	0%	8%	12%	6%
NUE023	0%	5%	7%	3%	3%	12%	8%	7%	3%	5%	12%	6%
GAL014	0%	3%	5%	10%	14%	5%	10%	5%	8%	3%	3%	6%
GAL025	0%	3%	3%	5%	5%	7%	18%	3%	3%	8%	8%	6%
GAL024	3%	0%	3%	5%	3%	14%	12%	7%	3%	8%	3%	6%
GAL003	0%	3%	7%	5%	3%	5%	7%	7%	5%	10%	8%	5%
KLE004	5%	5%	7%	ND	ND	ND	ND	ND	ND	ND	ND	5%
GAL019	0%	0%	5%	10%	3%	12%	5%	5%	8%	5%	5%	5%
GAL068	0%	0%	0%	3%	3%	8%	10%	9%	0%	5%	16%	5%
GAL069	0%	5%	3%	0%	5%	10%	5%	0%	5%	7%	14%	5%
ARA001	10%	8%	0%	8%	3%	0%	3%	12%	0%	10%	0%	5%
NUE047	3%	12%	3%	8%	6%	0%	10%	0%	3%	10%	0%	5%
GAL050	11%	5%	3%	3%	8%	7%	10%	5%	5%	0%	0%	5%
GAL027	3%	0%	3%	10%	5%	7%	14%	3%	3%	3%	5%	5%
GAL007	0%	3%	5%	5%	8%	5%	8%	5%	5%	10%	3%	5%
GAL022	0%	0%	3%	8%	3%	7%	12%	7%	5%	5%	5%	5%
GAL017	0%	0%	3%	12%	5%	5%	12%	3%	5%	5%	5%	5%
GAL053	7%	7%	0%	8%	10%	5%	10%	5%	0%	3%	0%	5%
NUE005	7%	3%	3%	3%	5%	5%	0%	7%	0%	16%	3%	5%
GAL005	0%	0%	7%	3%	3%	14%	7%	5%	3%	7%	3%	5%
NUE040	3%	10%	3%	5%	0%	0%	10%	12%	0%	8%	0%	5%

Table 6 cont. Station percent BAV exceedances by year and cumulative for the period of record sorted from highest to lowest.

Station	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
NUE041	0%	14%	3%	5%	3%	0%	5%	7%	0%	10%	3%	5%
JEF008	0%	3%	0%	10%	0%	0%	16%	0%	0%	20%	0%	5%
GAL067	0%	0%	3%	5%	5%	10%	5%	3%	5%	3%	12%	5%
NUE049	3%	0%	0%	0%	3%	3%	0%	3%	3%	0%	0%	5%
GAL077	4%	0%	5%	3%	3%	5%	12%	7%	3%	5%	3%	5%
GAL001	0%	3%	0%	3%	8%	3%	5%	7%	3%	10%	8%	4%
JEF009	0%	0%	0%	10%	3%	5%	11%	0%	0%	13%	3%	4%
NUE020	0%	8%	5%	10%	8%	8%	0%	5%	0%	0%	5%	4%
NUE044	0%	3%	0%	3%	6%	3%	3%	3%	0%	5%	19%	4%
GAL026	0%	0%	3%	8%	3%	7%	5%	3%	5%	5%	10%	4%
JEF005	3%	3%	0%	10%	0%	0%	21%	3%	0%	7%	3%	4%
GAL055	3%	3%	0%	8%	5%	10%	8%	5%	0%	3%	3%	4%
ARA002	5%	8%	10%	6%	3%	0%	3%	3%	0%	8%	0%	4%
NUE017	0%	10%	5%	3%	3%	3%	0%	3%	5%	7%	7%	4%
NUE022	5%	8%	12%	3%	5%	5%	0%	3%	0%	3%	0%	4%
NUE004	7%	7%	3%	3%	5%	5%	3%	7%	0%	3%	0%	4%
NUE021	0%	0%	5%	8%	3%	8%	3%	7%	0%	0%	10%	4%
JEF004	0%	0%	0%	10%	0%	0%	21%	3%	0%	5%	3%	4%
JEF007	3%	0%	0%	13%	0%	5%	13%	0%	0%	7%	0%	4%
GAL076	4%	0%	3%	5%	3%	5%	3%	7%	3%	5%	3%	4%
NUE001	3%	7%	0%	8%	3%	5%	3%	3%	3%	5%	0%	4%
NUE006	3%	3%	5%	3%	3%	0%	8%	3%	0%	10%	3%	4%
NUE016	3%	3%	7%	5%	5%	3%	0%	5%	5%	0%	3%	4%
GAL075	0%	0%	5%	3%	3%	10%	8%	3%	0%	5%	0%	3%
NUE019	0%	5%	7%	5%	5%	3%	5%	0%	0%	0%	5%	3%
JEF006	5%	0%	0%	10%	0%	3%	11%	0%	0%	2%	0%	3%
NUE002	3%	0%	3%	3%	0%	3%	3%	3%	5%	7%	3%	3%
NUE015	0%	0%	7%	3%	3%	3%	8%	3%	0%	3%	0%	3%
NUE018	0%	5%	3%	3%	3%	3%	0%	3%	8%	3%	0%	3%
JEF002	0%	0%	0%	8%	0%	0%	8%	0%	0%	13%	0%	3%
JEF003	0%	0%	0%	8%	0%	0%	11%	0%	0%	5%	3%	2%
NUE003	3%	0%	0%	0%	3%	3%	3%	3%	0%	7%	0%	2%
NUE013	3%	0%	7%	0%	3%	5%	0%	3%	0%	0%	0%	2%
NUE008	0%	0%	5%	3%	0%	0%	6%	3%	0%	0%	3%	2%

Table 6 cont. Station percent BAV exceedances by year and cumulative for the period of record sorted from highest to lowest.

Station	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
NUE014	0%	3%	3%	5%	5%	0%	0%	2%	0%	0%	0%	2%
NUE009	0%	0%	0%	3%	5%	0%	0%	3%	0%	0%	3%	1%
NUE048	3%	12%	3%	8%	6%	0%	10%	0%	3%	10%	0%	1%
JEF001	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%	0%	1%
NUE012	0%	0%	0%	3%	5%	0%	0%	0%	0%	0%	0%	1%
NUE010	0%	0%	3%	0%	0%	0%	0%	3%	0%	0%	0%	1%
NUE007	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%
CAM001	0%	22%	3%	0%	0%	0%	0%	0%	0%	8%	0%	0%
CAM002	0%	21%	0%	0%	0%	0%	0%	0%	0%	8%	0%	0%
CAM003	0%	21%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%
CAM004	0%	21%	0%	3%	0%	0%	0%	0%	0%	8%	0%	0%
CAM005	3%	20%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%
CAM006	0%	18%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%
CAM007	0%	3%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CAM008	0%	3%	5%	3%	3%	0%	0%	0%	0%	0%	0%	0%
CAM010	3%	3%	0%	0%	0%	0%	0%	3%	0%	0%	0%	0%
CAM011	0%	3%	0%	3%	0%	0%	0%	3%	0%	0%	0%	0%
CAM012	0%	3%	0%	3%	0%	0%	0%	3%	0%	0%	0%	0%
CAM013	0%	3%	0%	0%	0%	3%	0%	3%	0%	0%	0%	0%
CAM014	0%	3%	0%	0%	0%	0%	0%	3%	0%	0%	0%	0%
CAM016	0%	3%	3%	0%	0%	0%	0%	3%	0%	0%	0%	0%
CAM017	0%	3%	0%	0%	0%	0%	0%	3%	0%	0%	0%	0%
CAM019	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CAM021	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CAM022	0%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CAM023	0%	3%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CAM024	0%	3%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CAM025	0%	10%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CAM026	0%	7%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CAM027	3%	3%	3%	0%	0%	0%	0%	0%	0%	3%	0%	0%
CAM028	0%	3%	0%	0%	0%	0%	0%	3%	0%	0%	0%	0%
CAM029	8%	5%	3%	3%	0%	0%	0%	0%	0%	0%	0%	0%
CAM030	0%	3%	0%	3%	0%	3%	0%	3%	0%	0%	0%	0%

COUNTY ANALYSIS

The TBW program spans 10 counties along the Texas Gulf coast. Background information for each of the 10 counties including number of beaches, stations, samples, stations per beach type, and period of record are summarized in Table 7. Galveston and Nueces counties have the highest number of beaches monitored within their jurisdictions, 23 and 18 respectively, the highest number of stations, 52 and 46, and the highest number of samples collected, 22,683 and 20,416. The period of record for most counties was January 2009 through December 2019, with two exceptions, Kleberg County was January 2009 through August 2011, and Harris County was January 2011 through December 2019.

A Tukey-Kramer test was used to analyze the transformed means of enterococci concentrations among the ten counties to determine if the county means were statistically significantly different. Three counties, Harris (Level 6), Matagorda (Level 5), and Cameron (Level 1), were identified as significantly different (p-value< 0.05) from all other counties (Table 8).

The TBW enterococci data were analyzed by county and ordered from highest to lowest by percent BAV exceedances (Table 9). All county beaches exhibited single sample BAV exceedances at some point during the period of record. Five counties (i.e., Harris, Matagorda, Nueces, Brazoria, and Aransas), have arithmetic means that exceed the BAV. Harris (25.1%) and Matagorda (20.8 %) counties had the highest percent exceedances of the BAV for the entire period of record (Figure 15). Harris County did not support the recreational beach use criterion (>25% BAV exceedances) and Matagorda County met the concern and fully supporting criterion (20-25% BAV exceedances).

The percent BAV exceedance data were analyzed collectively for all counties by year (Figure 16). A strong (r = 0.61) and statistically significant (p-value = 0.04) positive correlation was observed for percent BAV exceedances over time. The percent exceedance of values at the upper detection limit (values ≥ 24,196 cfu/100 ml) for all counties per year was also analyzed (Figure 17). A strong (r = 0.67) and statistically significant (p-value = 0.03) positive correlation was also observed for the upper detection limit analysis.

The remainder of the county analysis section includes a more in-depth investigation of the four counties, Harris, Matagorda, Brazoria, and Nueces, with the highest percent BAV exceedances. Summary statistics of enterococci data for each of the four counties include arithmetic and geometric means by month, year, and site, number and percent BAV exceedances using the TCEQ seven-year assessment period approach and annually for each site for the project period.

Multivariate data analysis or a one-way MANOVA was conducted for select stations with available data corresponding to the TBW enterococci period of record to determine correlations with hydrodynamic alterations and other water quality parameters. The analysis focused on the ten stations that did not support the recreational beach criterion (>25% BAV exceedances) and the 6 stations that met the concern and fully supporting criterion (20 - 25% BAV exceedances) resulting from the station analysis. These stations were all in Harris, Brazoria, Matagorda, and Nueces counties, the top four counties with the greatest number of percent BAV exceedances from the county analysis. The ten stations that did not support the recreational beach criterion were all located on bay beaches, while 4 of the 6 stations that exceeded the concerns and fully supporting criterion are located on gulf beaches. Data sources for the stations included in the multivariate analysis are provided in Table 10.

Table 7. Summary of Texas Beach Watch beaches, stations, samples, stations per beach type, and period of record by county.

County	Number of Beaches	Number of Stations	Number of Samples (n)	Number of Stations per Beach Type		Period of Record
				Bay	Gulf	
Jefferson	2	9	3,496	0	9	Jan 2009 – Dec 2019
Harris	1	2	838	2	0	Jan 2011 – Dec 2019
Galveston	23	52	22,683	2	50	Jan 2009 – Dec 2019
Brazoria	4	16	7,605	0	16	Jan 2009 – Dec 2019
Matagorda	3	9	4,702	2	7	Jan 2009 – Dec 2019
Aransas	1	4	1,704	4	0	Jan 2009 – Dec 2019
San Patricio	1	1	439	1	0	Jan 2009 – Dec 2019
Nueces	18	46	20,416	21	25	Jan 2009 – Dec 2019
Kleberg	4	4	443	4	0	Jan 2009 – Aug 2011
Cameron	9	26	10,861	1	25	Jan 2009 – Dec 2019
Total	66	169	73,187	37	132	

Table 8. Texas Beach Watch data for enterococci concentrations per county connecting numbers report from the Tukey-Kramer analysis. Enterococci concentrations at sites with different levels are significantly different (JMP Pro 15.1.0, 2019).

County	Level						Mean *Enterococcus* (ln(y))
Harris	6						3.53
Matagorda		5					3.25
San Patricio			4	3			2.69
Brazoria			4				2.66
Aransas			4	3			2.63
Nueces			4				2.60
Kleberg			4	3	2		2.55
Jefferson				3	2		2.52
Galveston					2		2.47
Cameron						1	1.83

Table 9. Summary statistics of Texas Beach Watch enterococci concentrations (cfu/100 ml) by county (January 2009 - December 2019).

County	Number of Samples	Arithmetic Mean	Geometric Mean	Median	Min.	Max	Number of BAV Exceedances (%)
Harris	838	453.2	34.3	30.0	5.0	24,196.0	210 (25.1%)
Matagorda	4,702	234.1	25.9	20.0	5.0	24,196.0	979 (20.8%)
Brazoria	7,605	120.4	14.3	5.0	5.0	24,196.0	884 (11.6%)
Nueces	20,416	209.5	13.6	5.0	5.0	24,196.0	2,320 (11.4%)
San Patricio	439	59.7	14.8	5.0	5.0	4,611.0	44 (10.0%)
Aransas	1,704	107.7	13.9	5.0	5.0	19,863.0	142 (8.3%)
Kleberg	443	50.9	12.9	5.0	5.0	1,995.0	33 (7.4%)
Galveston	22,683	68.6	11.8	5.0	5.0	24,196.0	1,649 (7.3%)
Jefferson	3,496	30.3	12.5	5.0	5.0	1,723.0	122 (3.5%)
Cameron	10,861	11.9	6.2	5.0	5.0	2,252.5	129 (1.2%)
Total	73,187	118.8	12.2	5.0	5.0	24,196.0	6,521 (8.9%)

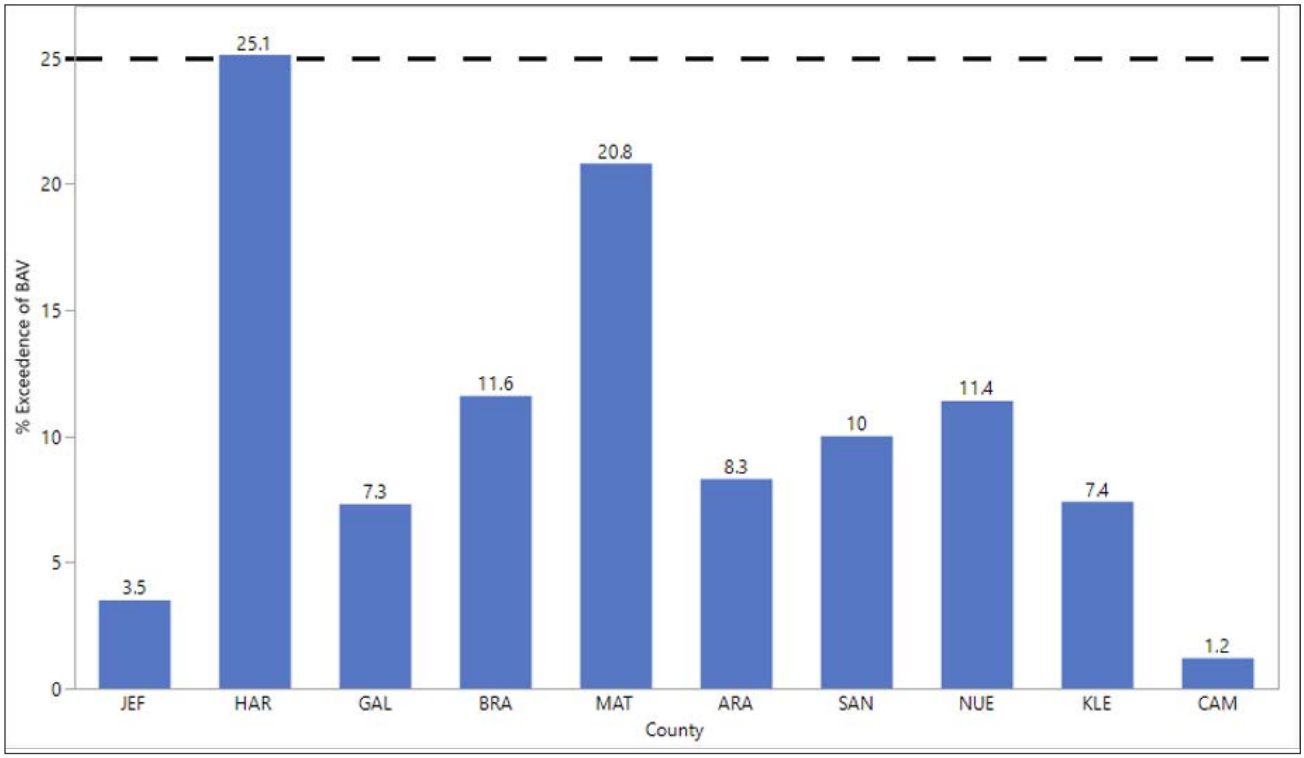

Figure 15. Texas Beach Watch program percent exceedance of BAV by county (January 2009 -December 2019). Dashed line denotes TCEQ assessment criteria threshold for nonsupport (see Table 1).

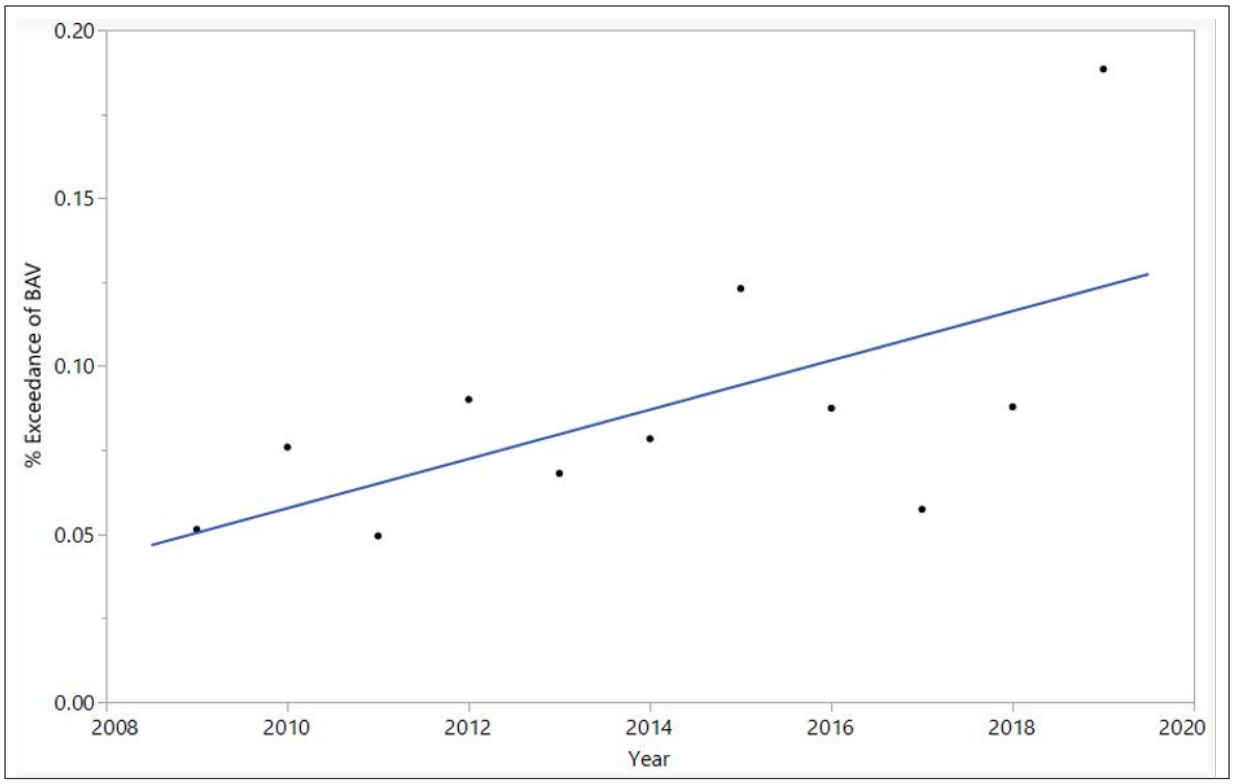

Figure 16. Texas Beach Watch percent exceedance of BAV for all counties per year (2009 - 2019).

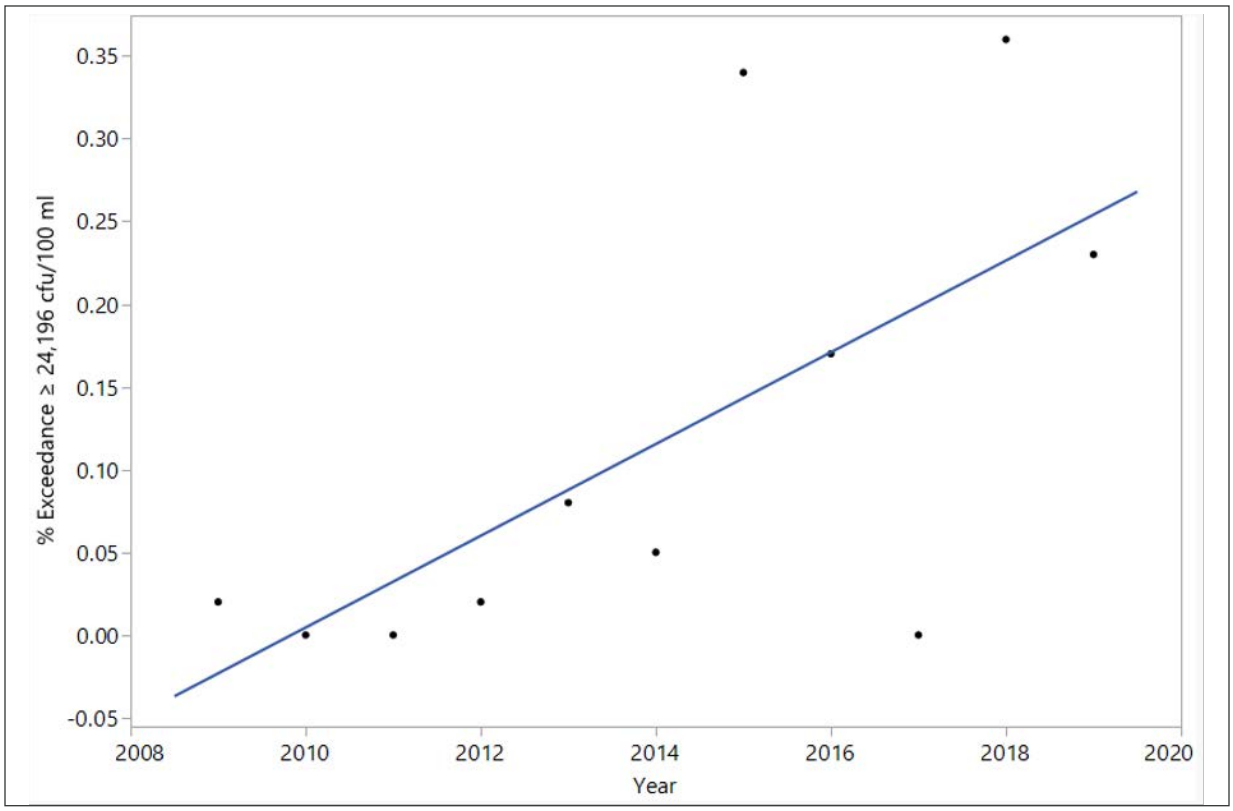

Figure 17. Texas Beach Watch program percent exceedance of values at the upper detection limit (values ≥ 24,196 cfu/100 ml) for all counties by year (2009 - 2019).

Table 10. Data sources aggregated with Texas Beach Watch stations for multivariate analysis. NA = not applicable

Beach Watch Station ID	TCEQ SWQM Station ID	USGS Flow Gauge ID	TexMesoNet Precipitation Station ID	NOAA Coops Tides and Currents
HAR001	15904 - Upper Galveston Bay at 96GB009 15907 – Upper Galveston Bay at 96GB012 15244 – Upper Galveston Bay at 95GB006	NA	Pearland Municipal Airport (KLVJ)	Morgans Point, Barbours Cut, TX
HAR002				
BRA004	11498 - Old Brazos River Channel	8079120 – Old Brazos Rv nr Freeport, TX	Brazoria NWR (BZRT2)	Freeport, TX
BRA005				
MAT001	18398- Tres Palacios Bay S Palacios	08162600 - Tres Palacios River near Midfield, TX	Palacios Municipal Airport (KPSX)	Freeport, TX
MAT002				
MAT007	12148-Caney Creek at Chambless Rd. 12149-Caney Creek tidal at Stevens Rd.	08162000 – Colorado River at Wharton, TX	San Bernard NWR (SRDT2)	Freeport, TX
MAT008				
MAT009				
NUE028	Ropes Park: 13411, 20958, 20959, 20960	08211520 -Oso Ck at Corpus Christi, TX	Corpus Christi NAS (USW00012926)	Bob Hall Pier
NUE029				

Goose Creek in Baytown, Texas © BaytownBert

HARRIS COUNTY

Harris County extends along the Galveston Bay shoreline and includes Sylvan Beach Park (TGLO, 2019). Two TBW sites at one recreational bay beach are sampled in the City of LaPorte (Figure 18, Table 11). No gulf beaches are monitored in Harris County.

Summary statistics for the two sites monitored in Harris County are provided in Table 12. Approximately equal number of sampling events occurred at both sites. The arithmetic mean was higher (512.4 cfu/100 ml) at HAR001 than HAR002 (394.6 cfu/100 ml), but the geometric mean at HAR001 was lower (32.5 cfu/100 ml) than HAR002 (36.0 cfu/100 ml). The number and percent BAV exceedances were higher at the HAR002 site (114 cfu/100 ml, 26.8%) than at the HAR001 site (97 cfu/100 ml, 23.5%).

A one-way ANOVA with transformed enterococci concentrations revealed no significant differences in enterococci concentrations between sites (p-value = 0.77).

Percent BAV exceedances for both sites, using a rolling seven-year assessment period, fully supported the recreational beach use criterion (< 25% BAV exceedances) for the 2009 to 2015 and 2010 to 2016 assessment periods (Table 13). For the remaining assessment periods, both sites either did not support (>25%) or had a concern and fully supported (20-25%) the recreational beach use assessment criteria (Table 13).

The annual percent BAV exceedances by site showed mixed results for the period of record (Table 14). Both sites fully supported (<25% BAV exceedances) the recreational beach use in 2011, 2012, 2014, 2017 and 2018. The

criterion for concern and fully supporting (20-25% BAV exceedances) was met at HAR001 in 2015 and at HAR002 in 2013. The recreational beach use was not supported (>25%) in 2016 and 2019 at either site or in 2015 at HAR002. (Table 14).

Monthly analysis of enterococci arithmetic means resulted in exceedances of the BAV every month except for March (Figure 19). Monthly analysis of enterococci geometric means revealed exceedances of the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters of 35 cfu/100ml in January, April, June, August, and October (Figure 20).

Annual analysis of enterococci arithmetic means revealed the BAV was exceeded in most years except for 2012, 2014 and 2017 (Figure 21), while the geometric mean exceeded the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters in 2015, 2016 and 2019 (Figure 22).

Site analysis of enterococci arithmetic means revealed the highest values at HAR001, but both sites exceeded the BAV (Figure 23). Site analysis of the geometric mean revealed a slightly higher value at HAR002 and exceedance of the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters of 35 cfu/100ml (Figure 24).

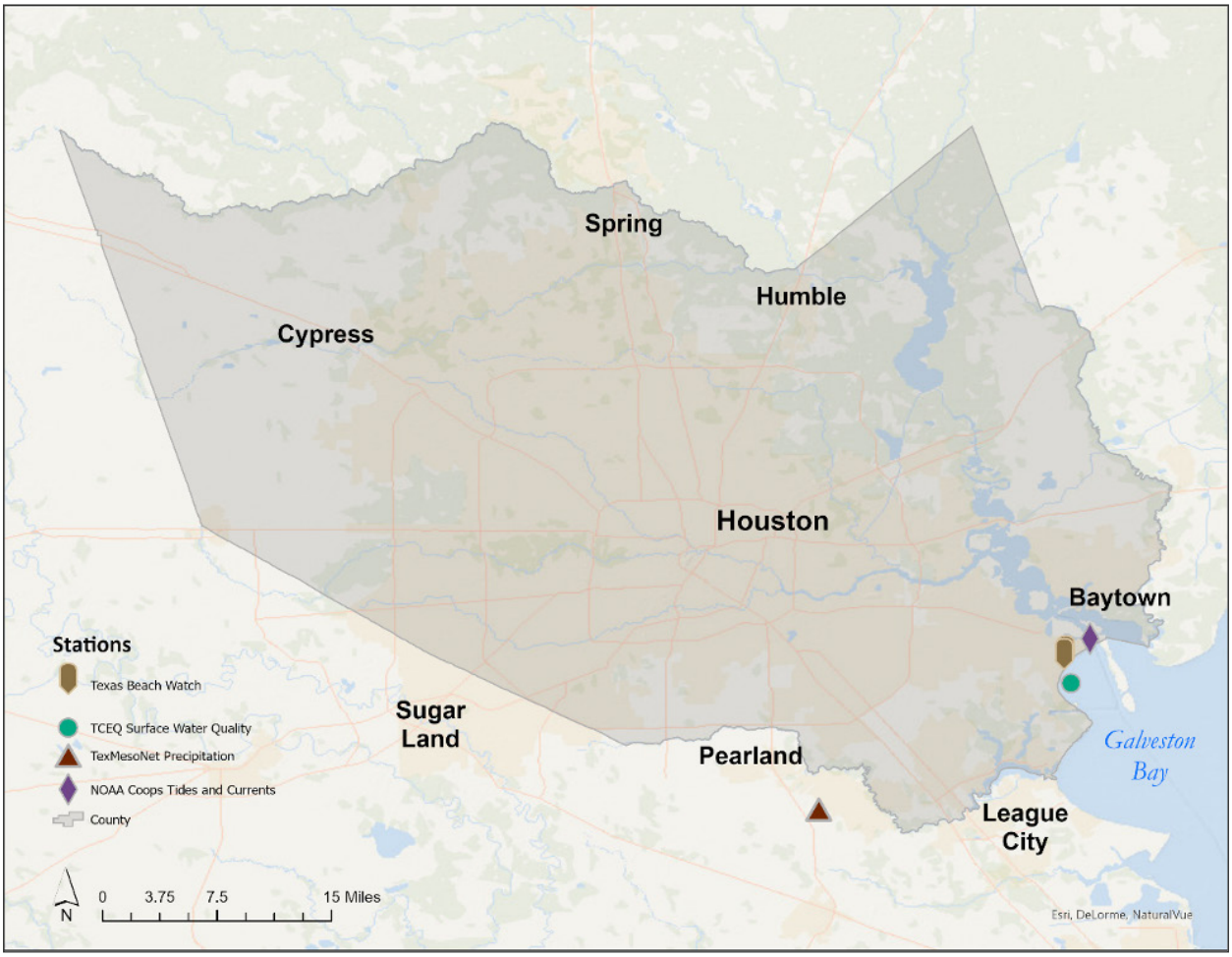

Figure 18. Environmental monitoring stations in Harris County.

Table 11. Texas Beach Watch (TBW) beaches and sites in Harris County.

County	Beach ID	Beach Name	Station ID
Harris	TX412536	Sylvan Beach Park	HAR001
			HAR002

Table 12. Summary statistics of Texas Beach Watch (TBW) enterococci concentration (cfu/100 ml) data by site in Harris County (January 2011 - December 2019).

Site	Statistic							
	N	Arithmetic Mean	Geometric Mean	Median	Min.	Max	Standard Deviation	# BAV Exceedances (%)
HAR001	413	513.4	32.5	20.0	5.0	24,196.0	2,445.9	97 (23.5)
HAR002	425	394.6	36.0	30.0	5.0	24,196.0	1,652.8	114 (26.8)

Table 13. Percent BAV (104 cfu/100 ml) exceedances in Harris County for each seven-year assessment period from January 2011 to December 2019. Note: First two assessment periods have missing data due to difference in period of record.

Site ID	Assessment Period				
	2009-2015	2010-2016	2011-2017	2012-2018	2013-2019
HAR001	14.6%	16.4%	23.0%	24.5%	26.9%
HAR002	18.5%	19.3%	25.3%	25.6%	28.6%

Table 14. Annual percent BAV (104 cfu/100 ml) exceedances in Harris County per site from January 2009 to December 2019. ND = no data available.

Site	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
HAR001	ND	ND	5.3%	8.3%	13.2%	10.3%	23.4%	29.2%	12.5%	17.8%	136 (80.5)
HAR002	ND	ND	12.2%	17.5%	24.4%	7.9%	25.0%	27.7%	14.6%	17.8%	3 (1.8)

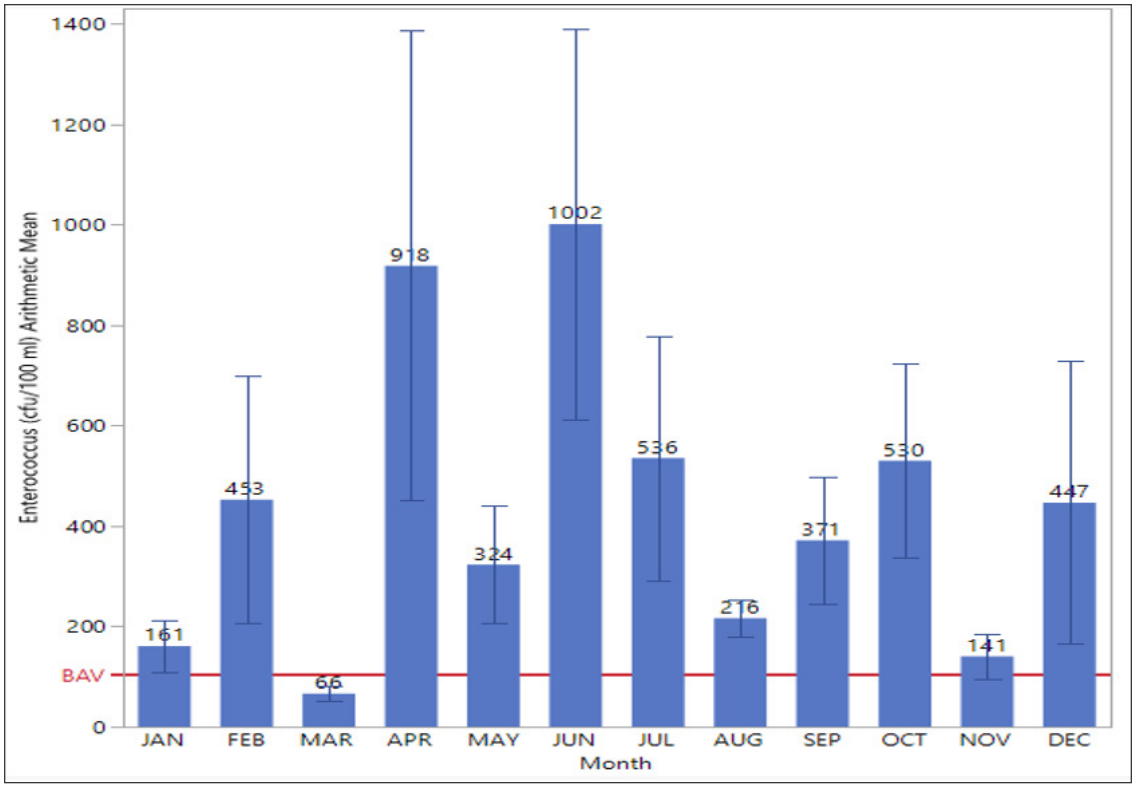

Figure 19. Annual arithmetic mean of enterococci concentration for Harris County bay beaches (January 2011 - December 2019). No gulf beaches sampled in Harris County.

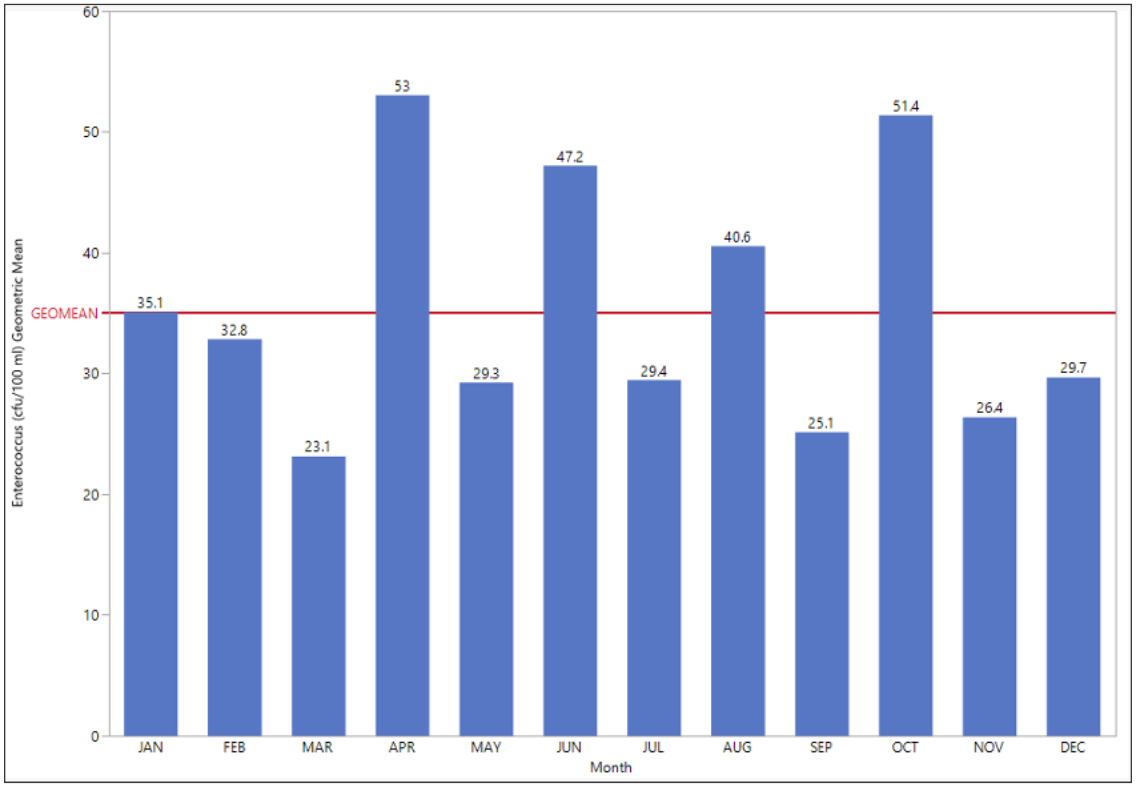

Figure 20. Monthly geometric mean of enterococci concentrations for Harris County bay beaches (January 2011 - December 2019). No gulf beaches sampled in Harris County.

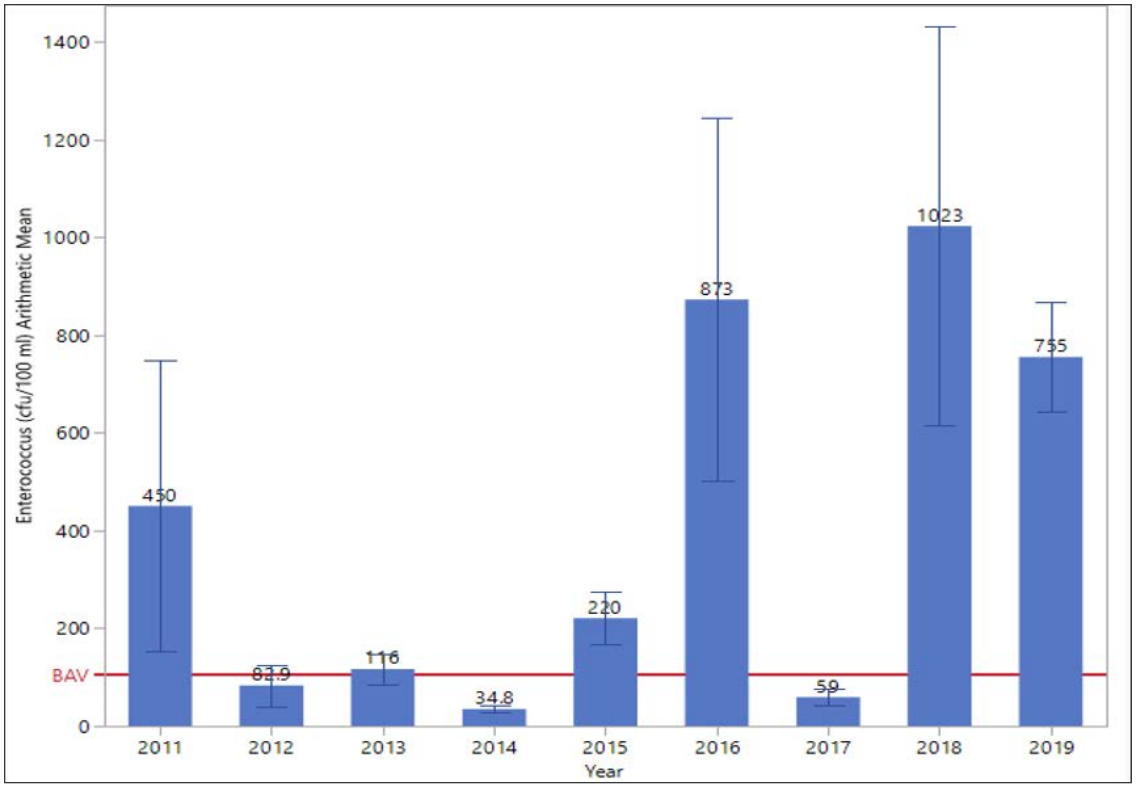

Figure 21. Annual mean enterococci concentrations for Harris County bay beaches (January 2011 - December 2019). No gulf beaches sampled in Harris County.

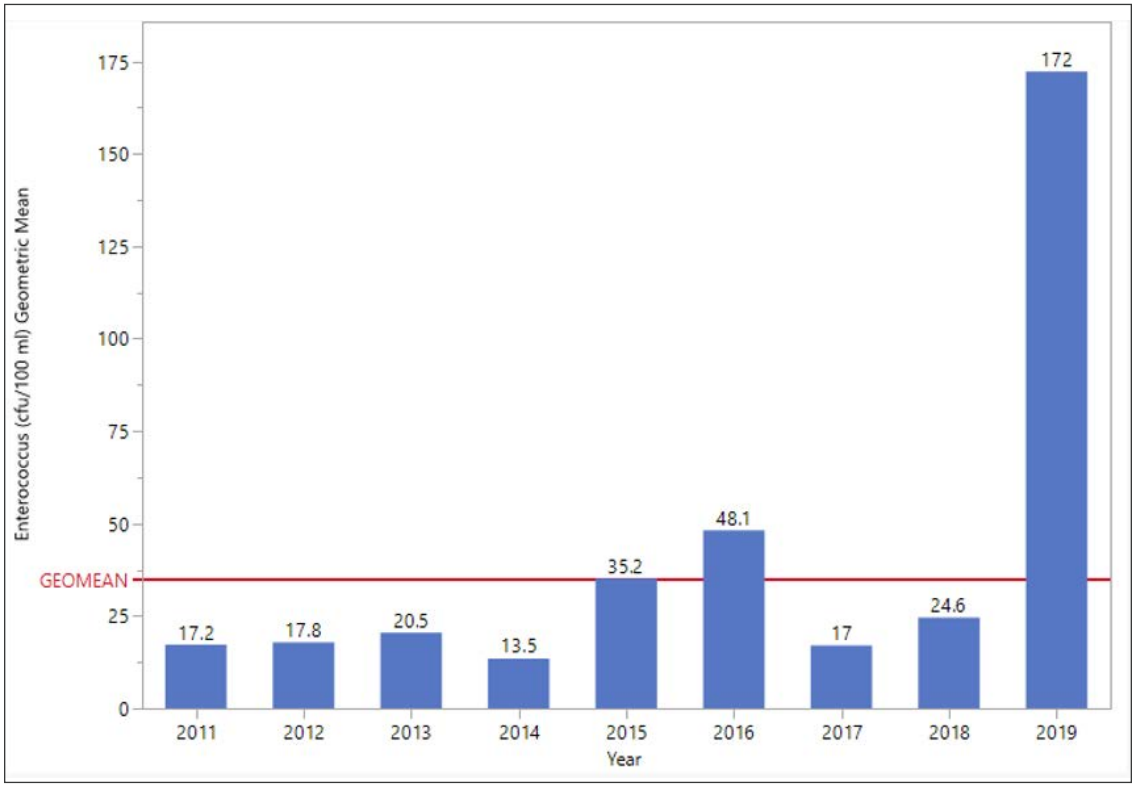

Figure 22. Annual geometric mean of enterococci concentrations for Harris County bay beaches (January 2011 - December 2019). No gulf beaches sampled in Harris County.

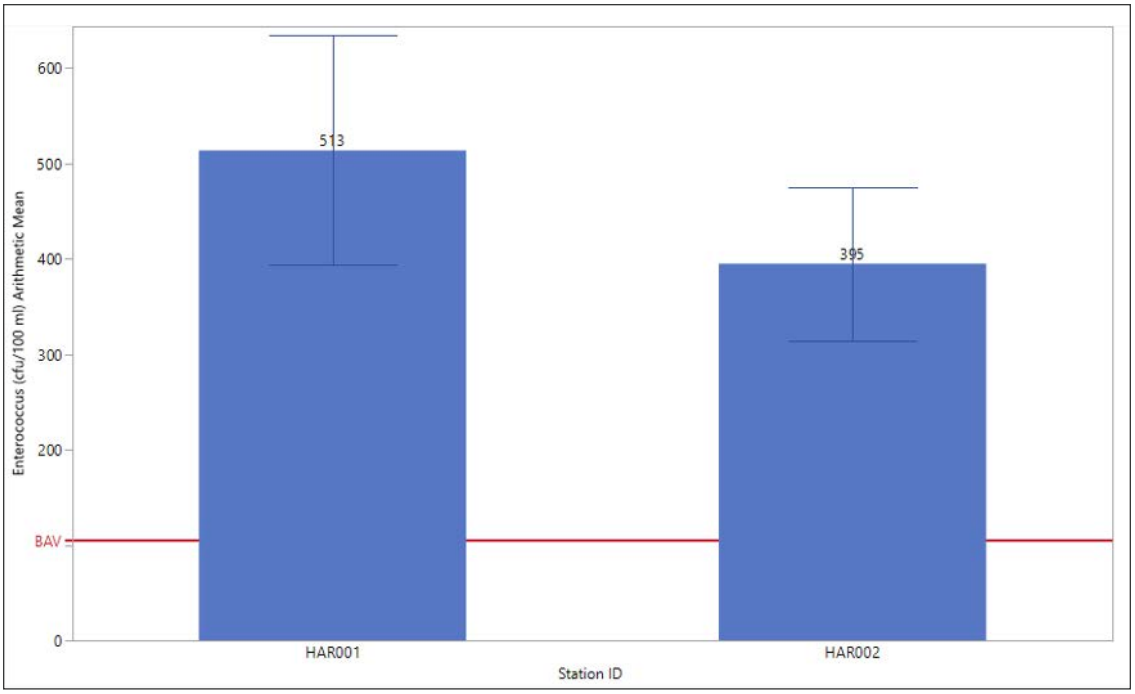

Figure 23. Arithmetic mean of enterococci concentrations by site in Harris County bay beaches (January 2011-December 2019).

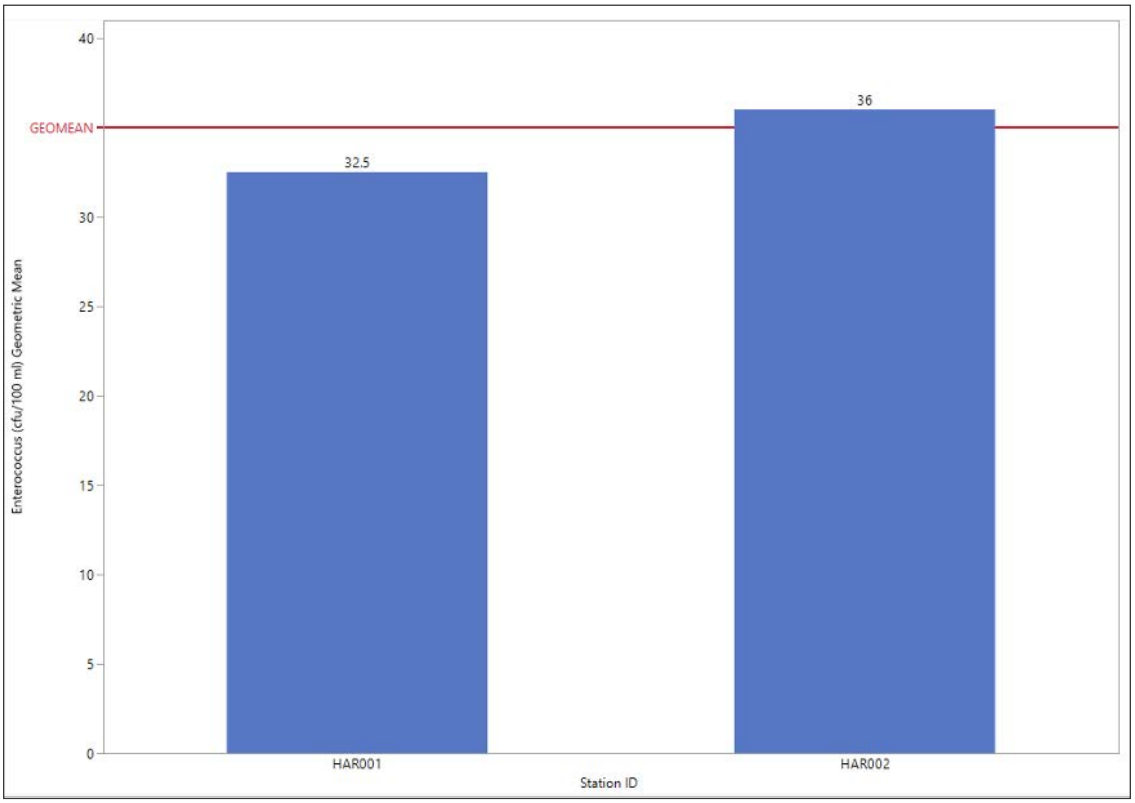

Figure 24. Geometric mean enterococci concentrations by site in Harris County bay beaches (January 2011-December 2019).

A one-way MANOVA with log transformed TBW enterococci data was performed to assess correlation with hydrodynamic alterations and other physical and chemical parameters. Precipitation was the only parameter with a p-value <0.05 and a positive correlation (0.19) at the two combined bay sites in Harris County (Table 15).

Table 15. One-way MANOVA with enterococci as the dependent variable in Harris County. Bold parameters denote significant p-value <0.05.

Parameters	Number of Samples	Correlation	Mean	Standard Deviation	P-value
Ammonia-Nitrogen (mg/l)	14	0.45	0.09	0.07	0.1079
Nitrite plus Nitrate-Nitrogen (mg/l)	16	0.36	0.49	0.35	0.1715
Total Fluoride (mg/l)	16	0.33	1.12	1.53	0.2165
Transparency (m)	16	0.23	0.73	0.21	0.3815
Precipitation (in)	**108**	**0.19**	**4.23**	**4.06**	**0.0436**
Tidal Amplitude (ft)	108	0.17	3.68	0.88	0.0715
Temperature (°C)	16	0.11	23.56	7.01	0.6741
Total Kjeldahl Nitrogen (TKN) (mg/l)	13	-0.50	0.78	0.28	0.0807
Dissolved Oxygen (mg/l)	14	-0.47	9.10	3.83	0.0927
pH (s.u.)	15	-0.47	8.28	0.37	0.0793
Total Suspended Solids (mg/l)	15	-0.39	20.77	8.10	0.1489
Alkalinity (mg/l)	16	-0.37	102.63	8.25	0.1605
Total Organic Carbon (TOC) (mg/l)	15	-0.36	5.70	1.87	0.1917
Total Phosphorus (TP) (mg/l)	14	-0.29	0.23	0.09	0.3114
Specific Conductance (µS/cm)	16	-0.25	28,059.38	6,277.88	0.3480
Salinity (ppt)	16	-0.24	17.34	4.22	0.3678
Chloride (mg/l)	16	-0.16	11,038.13	4,156.11	0.5570
Sulfate (mg/l)	16	-0.09	1,594.25	710.92	0.7294

Matagorda County

In Matagorda County, nine sites at three beaches were sampled from January 2009 to December 2019 (Figure 25, Table 16). Summary statistics for all sites in Matagorda County are provided in Table 17. When compared to the gulf sites, the two bay sites, MAT001 and MAT002, consistently had the highest arithmetic and geometric means, as well as medians and percent BAV exceedances (Table 17).

A Tukey-Kramer test was used to analyze enterococci transformed means among the nine sites to determine if the interaction was mutually statistically significant (Table 18). The two bay sites, MAT002 and MAT001, are significantly different from the remaining sites, as are the three gulf sites MAT003, MAT004, and MAT005. The gulf sites, MAT006, MAT007, MAT008, and MAT009, were connected at varying levels and share some characteristics.

Percent BAV exceedances for most sites using a rolling seven-year assessment period fully supported the recreational beach use criterion (<25% BAV exceedances), except for MAT002 (Table 19). The two bay sites exceeded the TCEQ recreational beach use criterion (>25% BAV exceedances) and the concern criterion (20-25% exceedances) during four of the five assessment periods. The gulf site MAT008 only exceeded the concern criterion during one assessment period (2013 - 2019).

The annual percent BAV exceedances by site revealed mixed results with consistently higher percent exceedances at the two bay sites (Table 20). Most sites had high percent BAVs during 2012 and 2019 (Table 20).

Monthly analysis of the arithmetic means of enterococci concentrations resulted in exceedances of the BAV in bay beaches throughout the year except for February, October, and November (Figure 26). Monthly analysis of exceedances of the BAV in gulf beaches resulted in exceedances in May, June, July, August, and December (Figure 26). Monthly analysis of enterococci geometric means resulted in exceedances of the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters at bay beaches in March, April, May, June, August, September, and December and gulf beaches in August (Figure 27).

Annual analysis of enterococci concentration arithmetic means (Figure 28) revealed exceedances of the BAV in bay beaches during all years except for 2014, 2017 and 2018. Gulf site exceedances of the BAV occurred during 2012, 2014, 2016, and 2019 (Figure 28). Annual geometric means at bay sites exceeded the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters in 2009, 2010, 2011, 2012, 2015, 2016, and 2019, but the criterion was only exceeded at gulf sites in 2019 (Figure 29).

Site analysis of enterococci concentration arithmetic means revealed that all sites exceeded the BAV (Figure 30). When the geometric mean was used, only the bay beach sites exceeded the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters (Figure 31).

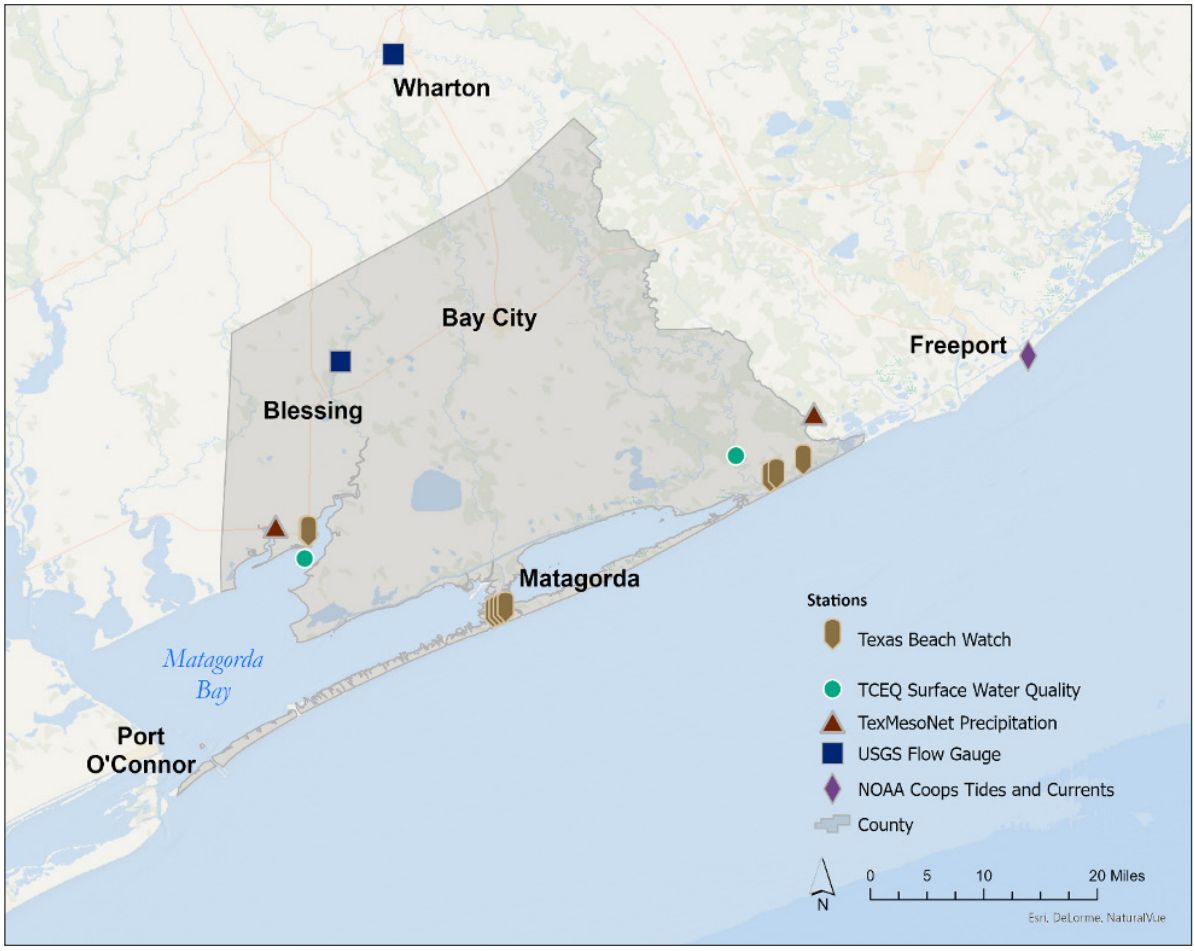

Figure 25. Environmental monitoring stations in Matagorda County.

Table 16. Texas Beach Watch (TBW) beaches and sites in Matagorda County.

County	Beach ID	Beach Name	Station ID
Matagorda	TX78742	Palacios – Palacios Pavilion	MAT001
			MAT002
	TX756029	Matagorda County Jetty Park	MAT003
			MAT004
			MAT005
			MAT006
	TX455545	Sargent Beach	MAT007
			MAT008
			MAT009

A one-way MANOVA with log transformed TBW enterococci data was performed to assess correlation with hydrodynamic alterations and other physical and chemical parameters for bay (MAT001 and MAT002) and gulf (MAT007-MAT009) sites. Six parameters at the Palacios Pavilion bay sites resulted in significant p-values (<0.05) and positive correlations including TKN, temperature, TP, discharge, precipitation and tidal amplitude (Table 21). Two parameters, transparency and dissolved oxygen, resulted in significant p-values (<0.05) and negative correlations. Five parameters at the Sargent Beach gulf sites resulted in significant p-values (<0.05) and positive correlations including TOC, tidal amplitude, discharge, ammonia-nitrogen, and nitrite+nitrate-nitrogen (Table 22). Nine parameters including TDS, salinity, specific conductance, transparency, chloride, sulfate, alkalinity, dissolved oxygen, and pH, resulted in significant p-values (<0.05) and negative correlations.

Table 17. Summary statistics of enterococci (cfu/100 ml) data by site in Matagorda County (January 2009 - December 2019).

Site	Statistic							
	N	Arithmetic Mean	Geometric Mean	Median	Min.	Max	Standard Deviation	# BAV Exceedances (%)
MAT001	574	322.5	39.3	41.0	5.0	24,196.0	1,595.5	156 (27)
MAT002	594	279.8	45.2	41.5	5.0	19,863.0	1,361.2	175 (29)
MAT003	496	161.2	18.6	5.0	5.0	15,530.0	820.3	82 (17)
MAT004	481	169.7	16.5	5.0	5.0	24,196.0	1,193.4	65 (14)
MAT005	486	219.8	18.5	12.5	5.0	24,196.0	1,394.1	70 (14)
MAT006	498	243.8	19.2	5.0	5.0	24,196.0	1,394.1	82 (16)
MAT007	519	205.7	27.4	20.0	5.0	19,860.0	1,059.4	112 (22)
MAT008	533	240.5	29.5	20.0	5.0	17,320.0	1,120.2	129 (24)
MAT009	521	239.3	26.9	20.0	5.0	24,196.0	1,570.1	109 (21)

Table 18. Texas Beach Watch (TBW) data for enterococci concentrations for Matagorda County connecting numbers report from the Tukey-Kramer analysis enterococci concentrations at sites with different levels are significantly different (JMP Pro 15.1.0, 2019).

County	Level					Mean *Enterococcus* (ln(y))
MAT002	5					3.81
MAT001	5					3.67
MAT008		4	3			3.39
MAT007			3			3.31
MAT009			3	2		3.29
MAT006				2	1	2.95
MAT003					1	2.92
MAT005					1	2.92
MAT004					1	2.80

Table 19. Percent BAV (104 cfu/100 ml) exceedances for each seven-year assessment period from January 2009 to December 2019.

Site ID	Assessment Period				
	2009-2015	2010-2016	2011-2017	2012-2018	2013-2019
MAT001	21.9	23.3	21.2	18.6	22.0
MAT002	26.8	27.7	24.6	23.2	25.3
MAT003	6.9	7.9	7.0	8.8	13.3
MAT004	5.9	6.9	6.2	7.2	11.5
MAT005	6.4	7.0	6.4	7.3	11.2
MAT006	9.9	10.2	9.3	9.5	13.1
MAT007	12.4	14.2	12.3	13.4	19.0
MAT008	14.8	16.1	15.0	16.0	20.6
MAT009	13.9	16.1	14.7	16.0	18.3

Table 20. Annual percent BAV (104 cfu/100 ml) exceedances by site from January 2009 to December 2019.

Site	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
MAT001	22.0	26.5	26.9	32.7	20.0	2.6	22.4	31.6	11.9	8.7	56.4
MAT002	22.4	35.7	29.8	36.4	18.2	19.6	25.5	28.6	14.0	20.4	51.1
MAT003	2.6	11.6	0.0	23.9	2.7	2.8	5.0	9.3	5.3	12.8	55.1
MAT004	2.6	7.5	0.0	18.6	2.7	2.8	7.3	9.3	2.7	6.7	48.8
MAT005	2.6	7.5	0.0	23.9	2.7	5.4	2.6	7.1	2.7	6.7	51.2
MAT006	4.9	11.9	5.0	27.1	5.3	10.3	5.0	7.1	5.3	6.7	51.8
MAT007	2.6	21.3	5.0	20.5	10.5	2.9	24.0	15.2	7.7	12.8	60.0
MAT008	2.6	17.8	7.3	32.7	8.1	8.3	26.9	11.4	10.0	14.6	64.6
MAT009	5.0	17.8	5.0	35.2	12.2	8.6	13.6	20.4	7.7	14.6	51.2

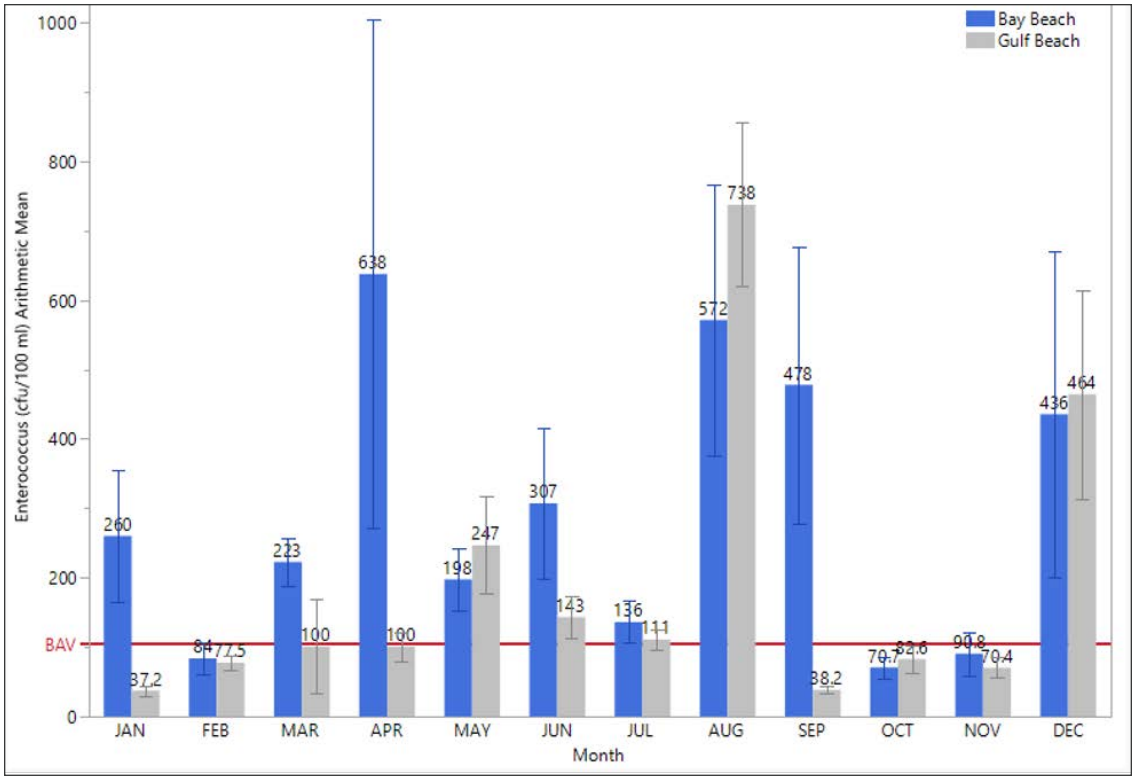

Figure 26. Monthly arithmetic mean enterococci concentrations (cfu/100 ml) for Matagorda County bay and gulf beaches (January 2009 - December 2019).

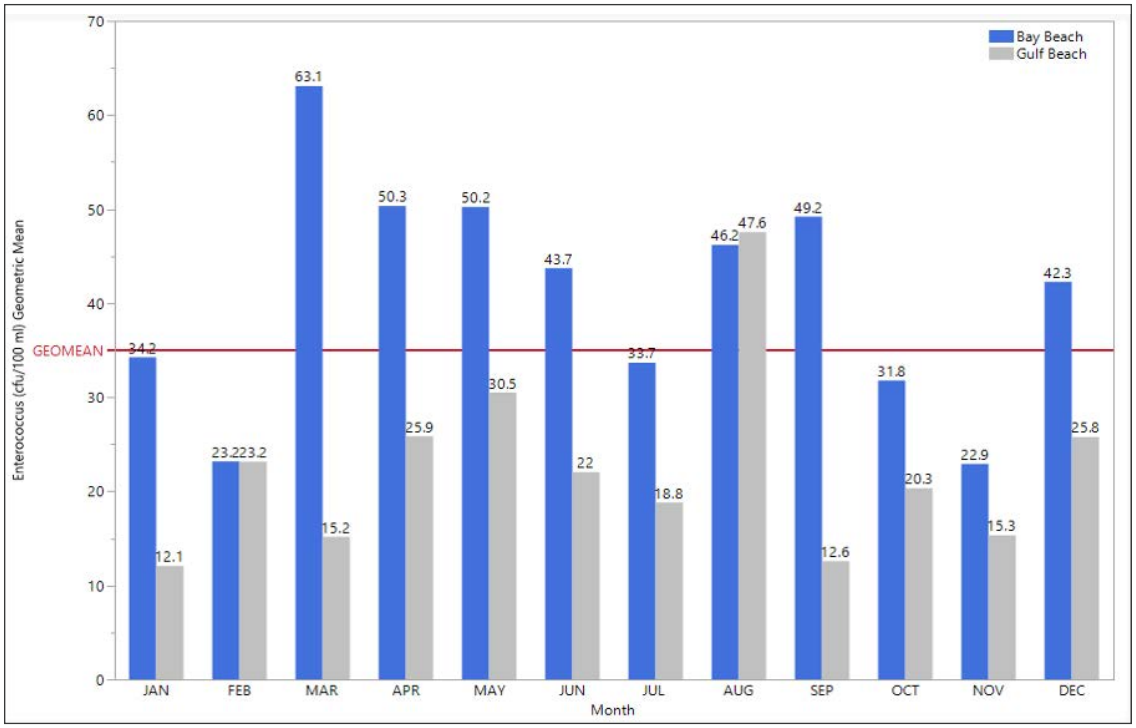

Figure 27. Monthly geometric mean enterococci (cfu/100 ml) for Matagorda County bay and Gulf beaches (Jan 2009 - Dec 2019).

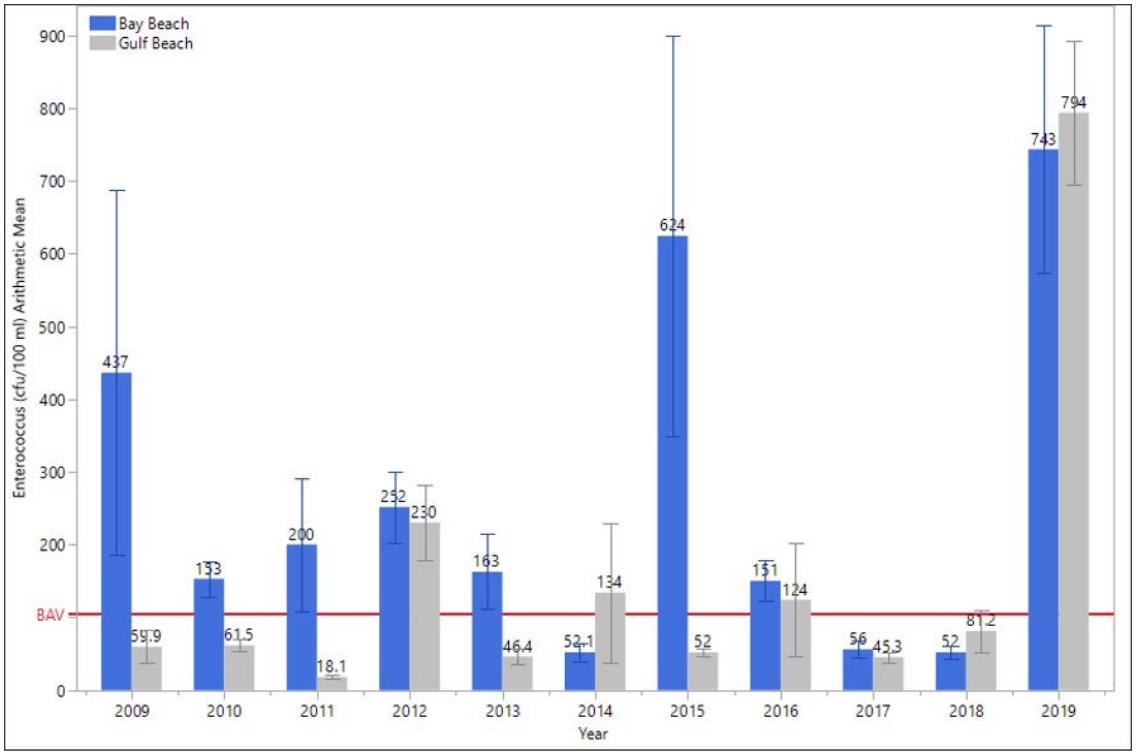

Figure 28. Annual arithmetic mean of enterococci concentrations (cfu/100 ml) for Matagorda County bay and gulf beaches (January 2009 – December 2019).

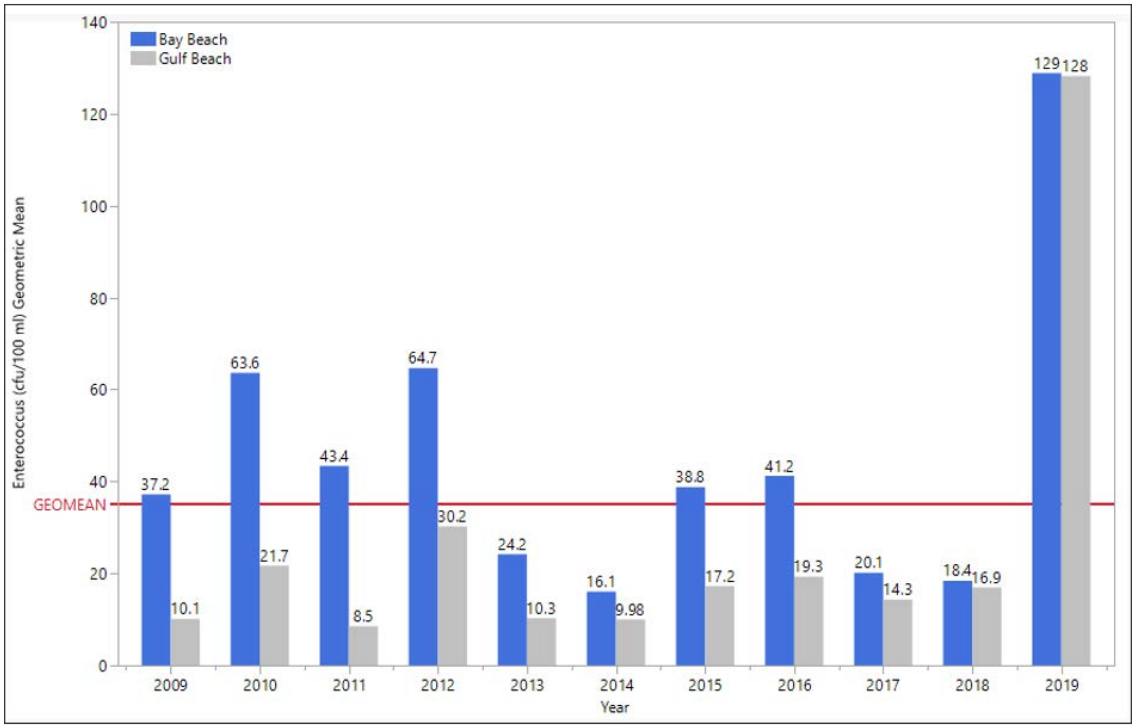

Figure 29. Annual geometric mean of enterococci concentrations (cfu/100 ml) for Matagorda County bay and Gulf beaches (January 2009 - December 2019).

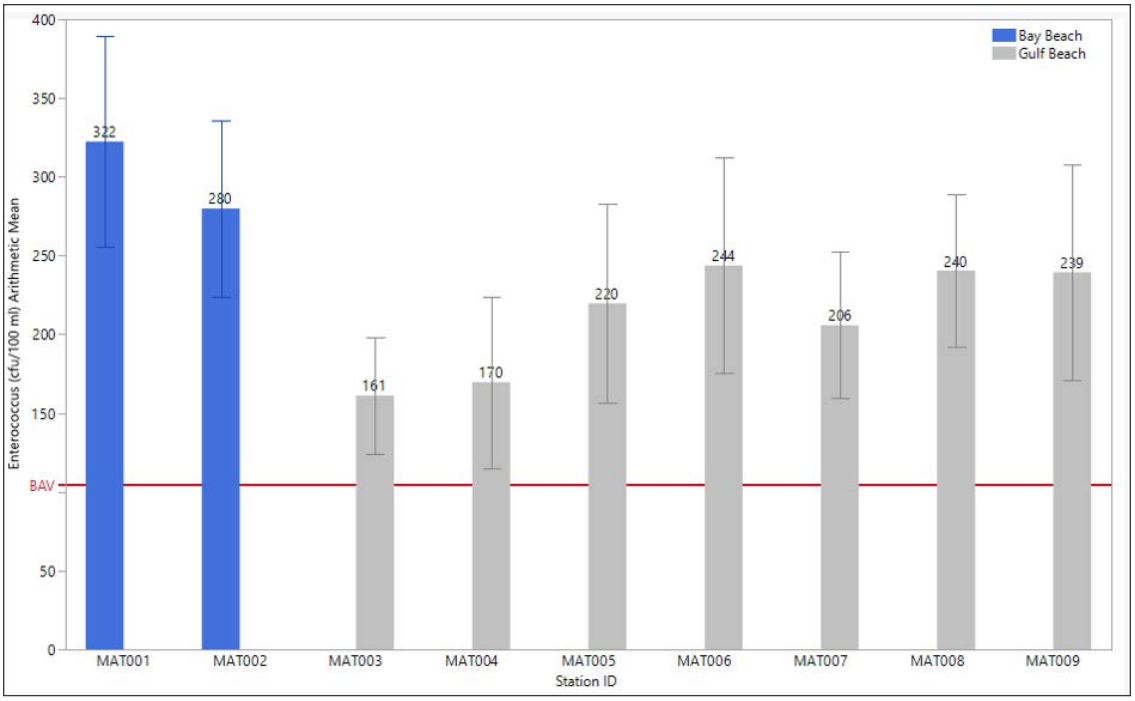

Figure 30. Station arithmetic mean of enterococci concentrations (cfu/100 ml) for Matagorda County bay and gulf beaches (January 2009 - December 2019).

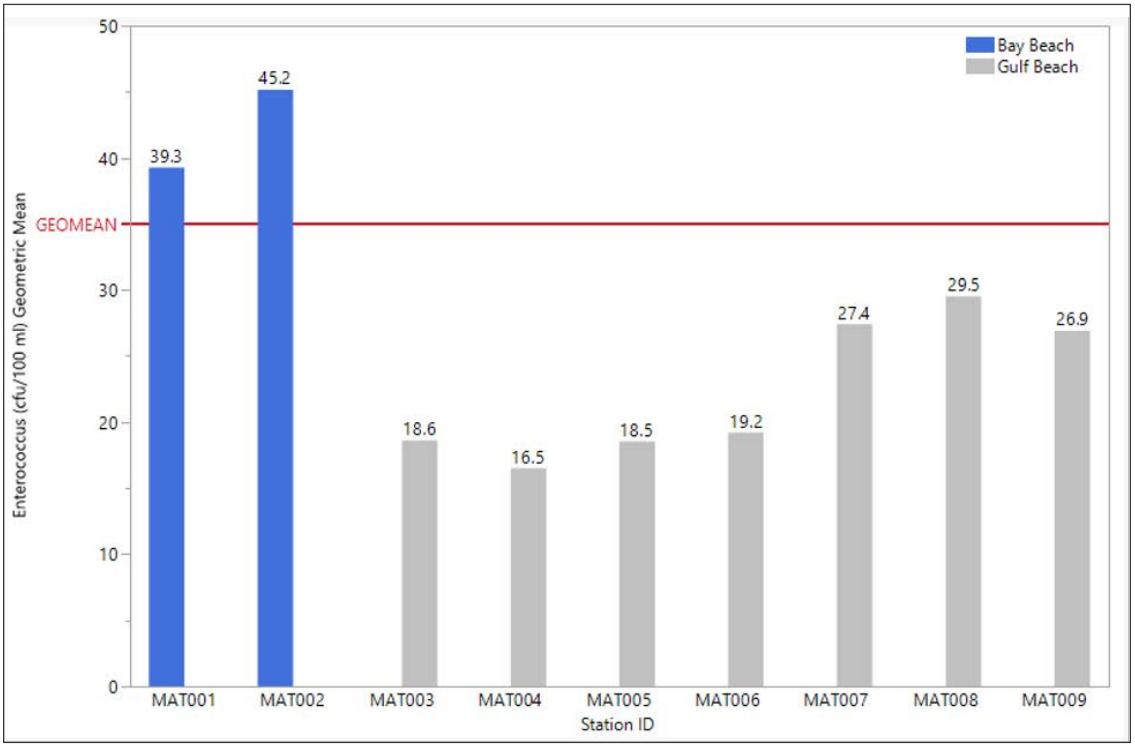

Figure 31. Station geometric mean of enterococci concentrations (cfu/100 ml) for Matagorda County bay and gulf beaches (January 2009 - December 2019).

Table 21. One-way MANOVA with enterococci as the dependent variable in Matagorda County at the Palacios Pavilion bay sites (MAT001-002). Bold parameters denote significant p-value <0.05.

Parameters	Number of Samples	Correlation	Mean	Standard Deviation	P-value
Total Kjeldahl Nitrogen (TKN) (mg/l)	**33**	**0.59**	**0.76**	**0.47**	**0.003**
Temperature (°C)	**34**	**0.43**	**24.71**	**5.74**	**0.0115**
Total Phosphorus (TP) (mg/l)	**32**	**0.36**	**0.09**	**0.05**	**0.0451**
Discharge (cfs)	**131**	**0.23**	**111.81**	**185.26**	**0.0073**
Precipitation (in)	**131**	**0.21**	**3.35**	**2.94**	**0.0181**
Tidal Amplitude (ft)	**130**	**0.19**	**2.90**	**0.54**	**0.0351**
Chlorophyll a (µg/l)	31	0.21	11.09	7.47	0.2582
Total Fluoride (mg/l)	34	0.19	1.47	2.37	0.2812
Total Suspended Solids (mg/l)	35	0.11	23.30	13.55	0.5246
Nitrite plus Nitrate-Nitrogen (mg/l)	35	0.03	0.06	0.08	0.8823
Transparency (m)	**34**	**-0.57**	**0.65**	**0.39**	**0.0005**
Dissolved Oxygen (mg/l)	**34**	**-0.40**	**7.86**	**1.57**	**0.0175**
Total Organic Carbon (TOC) (mg/l)	31	-0.35	4.67	2.00	0.0515
Ammonia-Nitrogen (mg/l)	34	-0.32	0.05	0.02	0.0646
Specific Conductance (µS/cm)	34	-0.26	35,787.71	11,800.49	0.1355
Salinity (ppt)	34	-0.25	22.79	8.06	0.1519
Chloride (mg/l)	34	-0.23	14,351.14	5,919.90	0.1898
Sulfate (mg/l)	35	-0.21	2,024.81	986.76	0.2297
Alkalinity (mg/l)	35	-0.13	115.58	15.40	0.4490
pH (s.u.)	34	-0.12	8.18	0.19	0.5011

Table 22. One-way MANOVA with enterococci as the dependent variable in Matagorda County at the Sargent Beach gulf sites (MAT008-009). Bold parameters denote significant p-value <0.05.

Parameters	Number of Samples	Correlation	Mean	Standard Deviation	P-value
Total Organic Carbon (TOC) (mg/l)	**55**	**0.46**	**7.85**	**3.07**	**0.0004**
Tidal Amplitude (ft)	**130**	**0.39**	**2.90**	**0.54**	**<0.0001**
Discharge (cfs)	**131**	**0.36**	**2,202.82**	**3,236.86**	**<0.0001**
Ammonia-Nitrogen (mg/l)	**54**	**0.31**	**0.07**	**0.06**	**0.0210**
Nitrite plus Nitrate-Nitrogen (mg/l)	**57**	**0.26**	**0.32**	**0.54**	**0.0497**
Precipitation (in)	131	0.16	3.71	3.71	0.0702
Total Phosphorus (TP) (mg/l)	56	0.14	0.37	0.17	0.3115
Temperature (°C)	57	0.09	22.80	5.89	0.5128
Chlorophyll a (µg/l)	56	0.01	12.91	13.68	0.9473
Total Dissolved Solids (mg/l)	**22**	**-0.56**	**4,274.41**	**5,798.70**	**0.0065**
Total Suspended Solids (mg/l)	9	-0.56	7,327.00	8,275.24	0.1154
Salinity (ppt)	**43**	**-0.52**	**8.82**	**6.86**	**0.0004**
Specific Conductance (µS/cm)	**57**	**-0.48**	**12,425.20**	**11,334.97**	**0.0002**
Transparency (m)	**57**	**-0.43**	**0.30**	**0.17**	**0.0009**
Chloride (mg/l)	**57**	**-0.42**	**3,365.92**	**3,966.18**	**0.0012**
Sulfate (mg/l)	**57**	**-0.41**	**456.02**	**541.88**	**0.0014**
Alkalinity (mg/l)	**57**	**-0.39**	**135.63**	**46.84**	**0.0029**
Dissolved Oxygen (mg/l)	**57**	**-0.33**	**5.31**	**2.03**	**0.0126**
pH (s.u.)	**57**	**-0.30**	**7.67**	**0.32**	**0.0227**
Total Fluoride (mg/l)	42	-0.09	0.63	1.05	0.5598
Total Kjeldahl Nitrogen (TKN) (mg/l)	51	-0.01	1.16	0.66	0.9606

Brazoria County

Brazoria County borders the Texas Gulf coast and lies south of the Houston-Galveston metroplex (TGLO, 2019). The TBW monitors four recreational gulf beaches and 16 sites within Brazoria County (Figure 32, Table 23).

Summary statistics for all sites are presented in Table 24. Half of the sites had arithmetic means that exceeded the BAV and none of the sites had geometric means that exceeded the TCEQ primary contact recreation numeric criterion. Only one site (BRA004) exceeded the concern criterion (20-25% BAV exceedances) of all 16 sites in Brazoria County.

A Tukey-Kramer test was used to analyze the transformed mean enterococci concentrations among the 16 sites to determine if the interaction was mutually statistically significant. Two groups of sites emerged as being significantly different (p-value < 0.05) from each other (Table 25). Sites with a Level 1 designation consisted of 13 sites located in Surfside and Follets Island. Sites with a Level 2 designation consisted of three sites (BRA004, BRA005, and BRA002) located in Quintana and Bryan Beach.

Percent BAV exceedances by site using a rolling seven-year assessment period supported the recreational beach use for all assessment periods (Table 26).

Annual percent BAV exceedances by site revealed most sites fully supported the recreational beach use (Table 27). However, in 2012 two sites (BRA002 and BRA004) exceeded the concern criterion (20-25% BAV exceedances) and BRA005 did not meet (> 25% exceedance) the recreational beach use criterion. In 2019 all sites exceeded the nonsupport criterion (> 25% exceedance) for recreational beaches.

Monthly analysis of enterococci concentration arithmetic means resulted in exceedance of the BAV in March, May, July, and August (Figure 33). Monthly geometric means were highest in August, but none exceeded the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters (Figure 34).

Annual analysis of enterococci concentration arithmetic means revealed exceedances of the BAV in 2012, 2016, and 2019 (Figure 35). The highest geometric means were observed in 2019 and it exceeded the the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters (Figure 36).

Site analysis of enterococci concentration arithmetic means revealed that eight (BRA002, BRA004, BRA005, BRA006, BRA009, BRA013, BRA016 and BRA018) of the 16 sites exceeded the BAV (Figure 37). None of the geometric means exceeded the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters (Figure 38).

A one-way MANOVA with log transformed TBW enterococci data was performed to assess correlation with hydrodynamic alterations and other physical and chemical parameters at two gulf Quintana Beach sites (BRA004 and 005) in Brazoria County. Two parameters at the Quintana Beach gulf sites resulted in significant p-values (<0.05) and positive correlations including nitrite+nitrate-nitrogen and tidal amplitude (Table 28). Five parameters resulted in significant p-values (<0.05) and negative correlations including chloride, sulfate, alkalinity, specific conductance, and salinity.

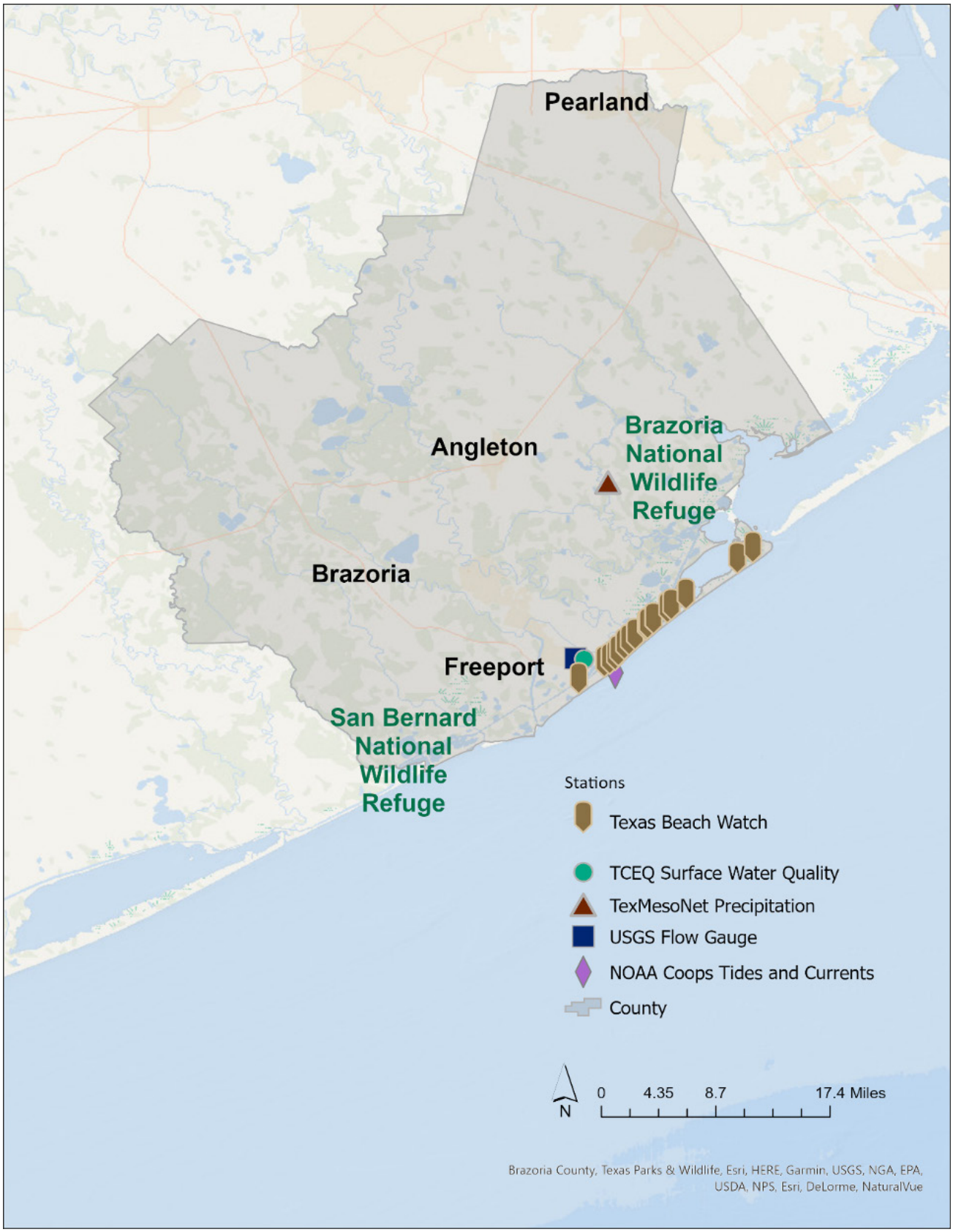

Figure 32. Environmental monitoring stations in Brazoria County.

Table 23. Texas Beach Watch program beaches and sites in Brazoria County.

County	Beach ID	Beach Name	Station ID
Brazoria	TX647885	Surfside	BRA006
			BRA007
			BRA008
			BRA009
			BRA010
			BRA011
			BRA012
			BRA013
	TX646145	Follets Island	BRA014
			BRA015
			BRA016
			BRA017
			BRA018
	TX728060	Quintana	BRA004
			BRA005
	TX384318	Bryan Beach	BRA002

Table 24. Summary statistics of enterococci concentration (cfu/100 ml) data by site in Brazoria County (Jan 2009 – Dec 2019).

Site	Statistic							
	N	Arithmetic Mean	Geometric Mean	Median	Min.	Max	Standard Deviation	# BAV Exceedances (%)
BRA002	499	136.9	20.5	20.0	5.0	12997	674.4	77 (14.9)
BRA004	516	174.7	24.3	20.0	5.0	17329	935.3	101 (19.6)
BRA005	502	365.1	24.2	20.0	5.0	24196	2454.1	89 (17.7)
BRA006	476	160.5	13.6	5.0	5.0	24196	1459.4	52 (10.9)
BRA007	464	61.8	12.4	5.0	5.0	7270	356.2	44 (9.5)
BRA008	464	57.6	12.8	5.0	5.0	6524	330.8	42 (9.1)
BRA009	476	147.4	13.6	5.0	5.0	24196	1389.9	56 (11.8)
BRA010	467	80.6	13.1	5.0	5.0	7701	436.2	45 (9.6)
BRA011	461	53.8	11.3	5.0	5.0	4884	263.9	38 (8.2)
BRA012	464	57.6	12.4	5.0	5.0	5794	298.4	41 (8.8)
BRA013	471	111.3	12.6	5.0	5.0	24196	1145.9	50 (10.6)
BRA014	477	88.2	12.8	5.0	5.0	9208	545.3	56 (11.7)
BRA015	469	73.1	13.6	5.0	5.0	6867	353.1	51 (10.9)
BRA016	470	127.5	12.9	5.0	5.0	24196	1163.5	53 (11.3)
BRA017	465	79.0	12.3	5.0	5.0	8664	455.6	45 (9.7)
BRA018	464	122.9	12.2	5.0	5.0	24196	1172.6	45 (9.7)

Table 25. Texas Beach Watch (TBW) data for enterococci concentrations for Brazoria County connecting letters report from Tukey-Kramer analysis. Enterococci concentrations at sites with different levels are significantly different. (JMP Pro 15.1.0, 2019).

County	Level		Mean *Enterococcus* (ln(y))
BRA004	2		3.19
BRA005	2		3.18
BRA002	2		3.02
BRA015		1	2.61
BRA009		1	2.61
BRA006		1	2.61
BRA010		1	2.57
BRA016		1	2.56
BRA008		1	2.55
BRA014		1	2.55
BRA013		1	2.53
BRA007		1	2.52
BRA012		1	2.52
BRA017		1	2.51
BRA018		1	2.50
BRA011		1	2.43

Table 26. Percent BAV (104 cfu/100 ml) exceedances in Brazoria County for each seven-year assessment period from January 2009 to December 2019.

Site ID	Assessment Period				
	2009-2015	2010-2016	2011-2017	2012-2018	2013-2019
BRA002	10.3	10.3	11.0	11.5	14.0
BRA004	12.6	12.3	12.7	15.1	18.6
BRA005	12.4	12.8	12.5	13.0	14.5
BRA006	4.9	4.2	4.9	5.6	9.3
BRA007	3.3	3.3	3.3	3.6	7.9
BRA008	3.4	3.4	5.1	5.4	9.1
BRA009	3.3	3.7	4.7	6.4	11.2
BRA010	4.2	4.5	4.1	4.4	7.3
BRA011	4.1	4.0	4.4	5.4	8.3
BRA012	3.4	3.3	3.0	3.3	7.7
BRA013	4.0	4.4	4.7	6.0	10.3
BRA014	4.3	4.7	5.0	5.3	10.0
BRA015	3.7	4.1	3.7	4.4	9.8
BRA016	3.7	4.4	3.6	3.6	9.0
BRA017	2.9	3.6	2.9	3.6	8.4
BRA018	3.6	4.3	4.3	3.6	7.7

Table 27. Annual percent BAV (104 cfu/100 ml) exceedances in Brazoria County by site from January 2009 to December 2019.

Site	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
BRA002	9.5	5.1	5.0	24.4	2.7	10.0	15.6	9.3	10.0	8.7	41.5
BRA004	15.6	7.5	2.6	24.4	5.3	17.5	15.6	13.3	10.0	19.6	48.9
BRA005	15.6	7.5	5.0	33.3	5.3	6.3	13.6	18.8	5.3	8.7	43.8
BRA006	5.0	2.6	0.0	14.6	0.0	9.8	2.6	0.0	7.7	4.5	40.7
BRA007	0.0	5.1	2.6	10.3	0.0	2.7	2.6	0.0	5.3	4.7	40.3
BRA008	0.0	0.0	2.6	7.9	2.7	7.7	2.9	0.0	12.2	4.5	33.8
BRA009	0.0	2.6	2.6	10.3	0.0	5.3	2.6	2.5	10.0	14.3	43.8
BRA010	0.0	2.6	2.6	18.6	0.0	2.7	2.6	2.5	0.0	4.5	39.0
BRA011	2.6	2.6	0.0	10.3	2.7	7.7	2.6	2.5	5.3	6.7	30.4
BRA012	2.6	5.1	0.0	7.9	2.7	2.6	2.6	2.5	2.7	2.3	38.2
BRA013	2.6	2.6	0.0	10.3	2.7	7.5	2.6	4.9	5.3	8.7	40.8
BRA014	0.0	2.6	5.0	12.5	0.0	7.5	2.6	2.5	5.3	6.7	45.8
BRA015	0.0	7.5	0.0	7.9	5.3	2.7	2.6	2.5	5.3	4.5	45.6
BRA016	0.0	5.1	2.6	10.3	2.7	0.0	5.0	5.0	0.0	2.3	48.2
BRA017	0.0	7.5	0.0	7.9	0.0	0.0	5.0	4.9	2.7	4.5	41.6
BRA018	0.0	5.1	5.0	12.5	0.0	0.0	2.6	5.0	5.3	0.0	40.8

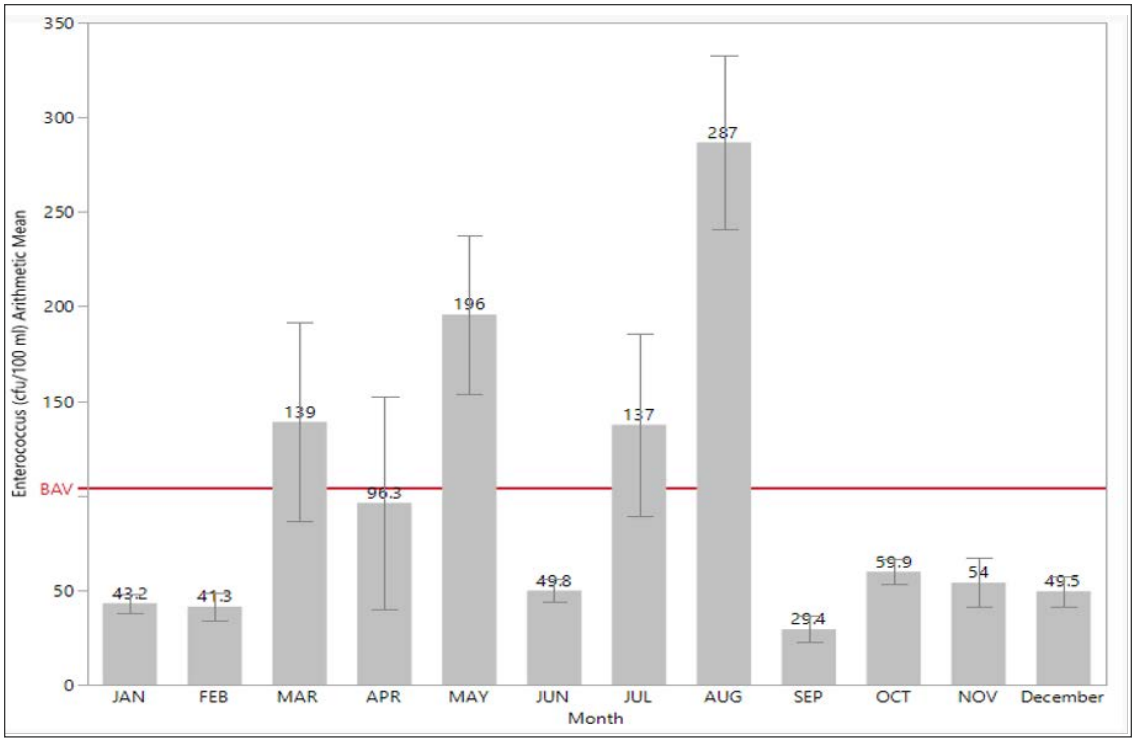

Figure 33. Monthly arithmetic means of enterococci concentration (cfu/100 ml) for Brazoria County gulf beaches (Jan 2009 - Dec 2019). No bay beaches were sampled in Brazoria County.

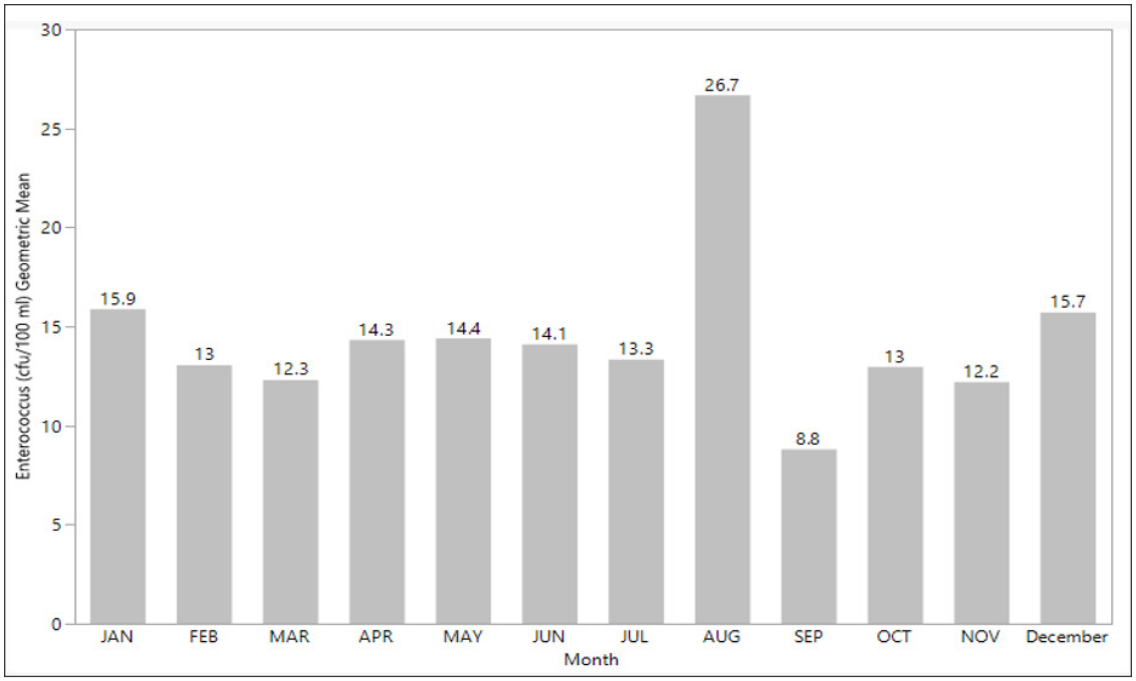

Figure 34. Geometric mean monthly of enterococci concentrations for Brazoria County gulf beaches (January 2009 - December 2019). No bay beaches were sampled in Brazoria County.

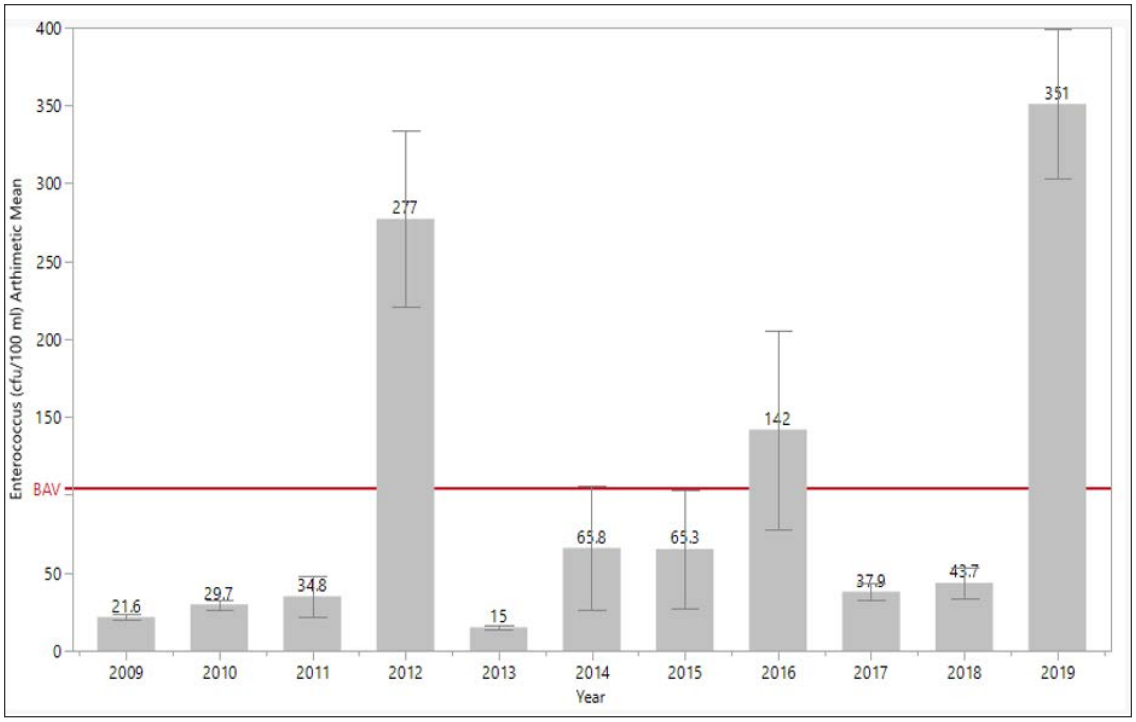

Figure 35. Annual arithmetic means of enterococci concentrations for Brazoria County gulf beaches (January 2009 - December 2019). No bay beaches were sampled in Brazoria County.

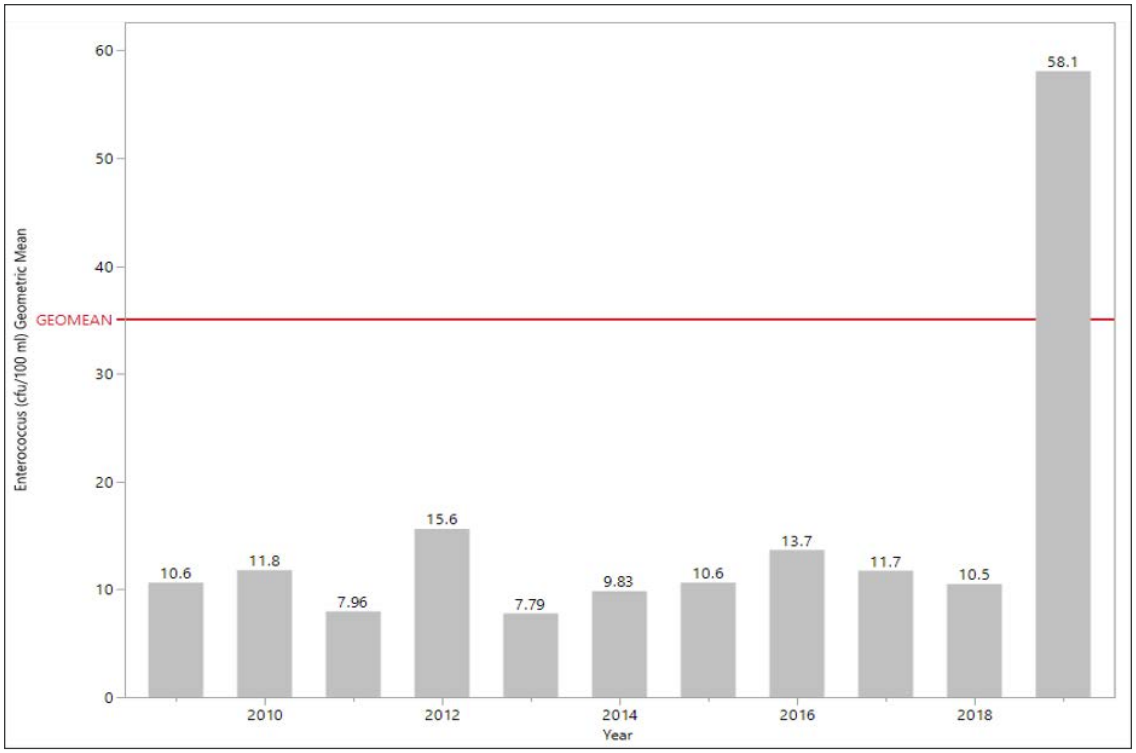

Figure 36. Annual geometric mean of enterococci concentrations for Brazoria County gulf beaches (January 2009 - December 2019). No bay beaches were sampled in Brazoria County.

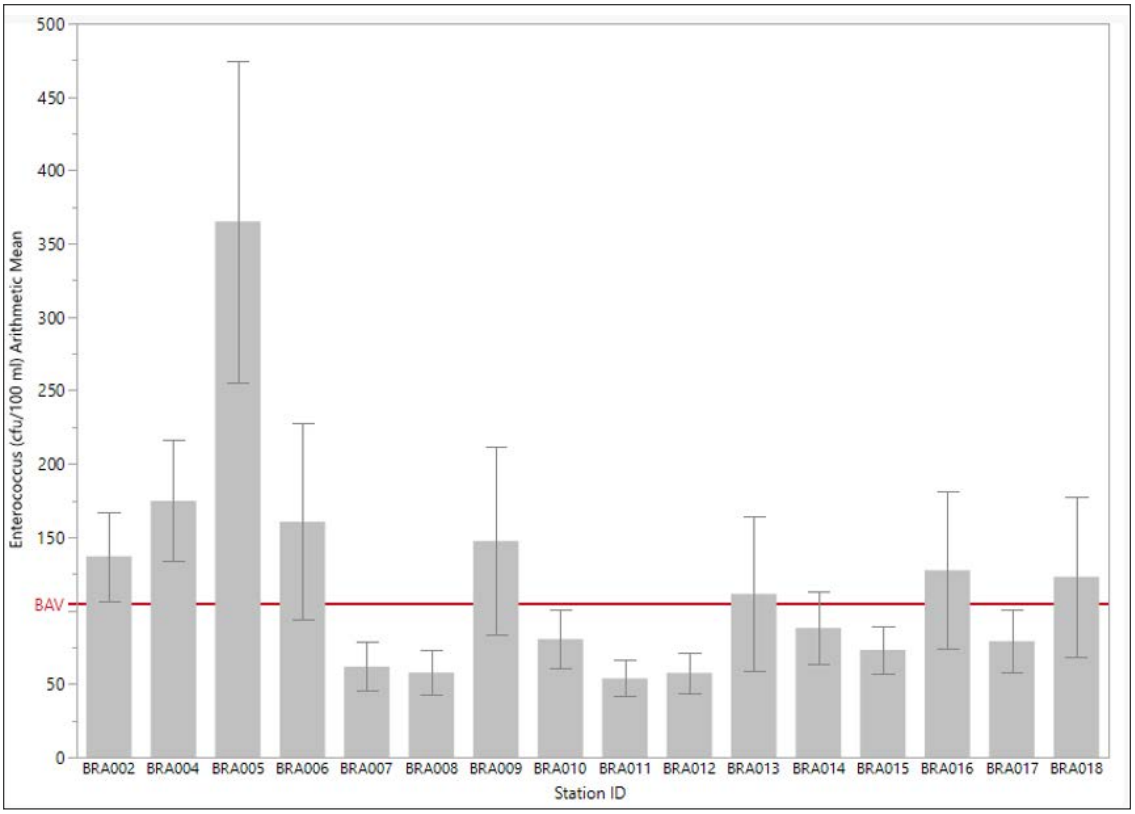

Figure 37. Arithmetic mean of enterococci concentrations by site in Brazoria County beaches (January 2009 - December 2019).

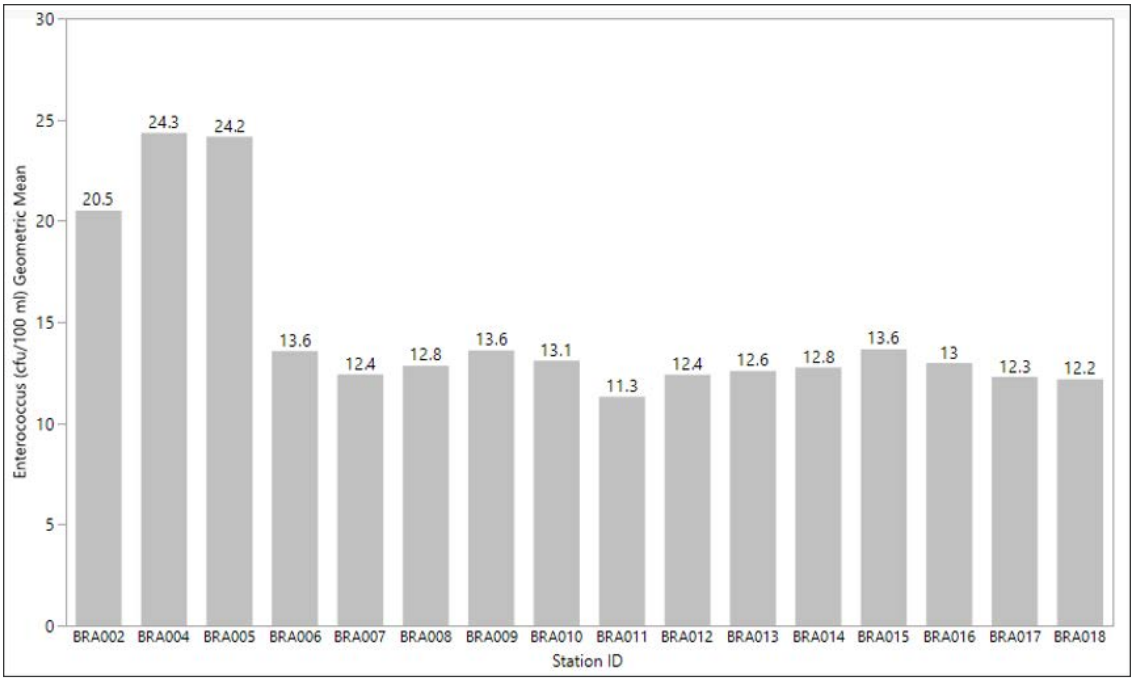

Figure 38. Geometric mean of enterococci concentrations by site in Brazoria County beaches (January 2009 - December 2019).

Table 28. One-way MANOVA with enterococci as the dependent variable in Brazoria County at the Quintana Beach gulf sites (BRA004-BRA005). Bold parameters denote significant p-value <0.05.

Parameters	Number of Samples	Correlation	Mean	Standard Deviation	P-value
Nitrite plus Nitrate-Nitrogen (mg/l)	**40**	**0.41**	**0.10**	**0.11**	**0.0083**
Tidal Amplitude (ft)	**130**	**0.19**	**2.90**	**0.54**	**0.0335**
Total Kjeldahl Nitrogen (TKN) (mg/l)	38	0.26	0.51	0.21	0.1140
Total Phosphorus (TP) (mg/l)	38	0.22	0.09	0.08	0.1837
pH (s.u.)	40	0.19	7.89	0.44	0.2416
Precipitation (in)	130	0.12	4.11	3.81	0.1730
Total Organic Carbon (TOC) (mg/l)	36	0.08	3.38	1.62	0.6444
Discharge (cfs)/Gauge height, feet, seaward	131	0.05	1.41	0.38	0.5376
Dissolved Oxygen (mg/l)	40	0.01	5.31	2.31	0.9681
Chlorophyll a (µg/l)	36	0.01	9.91	6.02	0.9643
Chloride (mg/l)	**37**	**-0.53**	**16,502.37**	**4,241.39**	**0.0007**
Sulfate (mg/l)	**40**	**-0.51**	**2,234.42**	**762.32**	**0.0007**
Alkalinity (mg/l)	**39**	**-0.40**	**117.30**	**7.87**	**0.0109**
Specific Conductance (µS/cm)	**40**	**-0.40**	**43,300**	**6,202.42**	**0.0100**
Salinity (ppt)	**40**	**-0.41**	**27.96**	**4.46**	**0.0091**
Temperature (°C)	40	-0.11	22.63	5.80	0.4806
Transparency (m)	39	-0.12	0.74	0.28	0.4534
Ammonia-Nitrogen (mg/l)	39	-0.14	0.07	0.04	0.3996
Total Dissolved Solids (mg/l)	9	-0.59	29,470.00	7,135.21	0.0946
Total Fluoride (mg/l)	40	-0.04	1.43	2.18	0.8005
Total Suspended Solids (mg/l)	40	-0.21	17.01	9.82	0.1960

Nueces County

Nueces County lies along the south-central Texas Gulf coast and encompasses some of the most heavily used beaches in Texas (GLO, 2018). Forty-six sites are monitored in Nueces County, 24 sites are located on gulf beaches, while the remaining 22 sites are on bay beaches (Figure 39, Table 29).

Summary statistics for all sites are presented in Table 30. The arithmetic means at 11 sites exceeded the BAV and all were bay beaches. The geometric means at 5 bay sites (NUE028, NUE029, NUE031, NUE032, and NUE033) exceeded the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters. One bay beach site exceeded the concern and fully supporting criterion (20-25% BAV exceedances) and seven bay beach sites did not support the recreational beach criterion (>25% BAV exceedances).

A Tukey-Kramer test was used to analyze the transformed means of enterococci concentrations among the 18 beaches (Table 31). Ropes, Cole, and Poenisch Parks, all bay beaches, were significantly different from all other beaches. Sites at these three beaches also did not support the criterion for the recreational beach use. The remaining beaches were connected at varying levels and therefore had some common characteristics.

Percent BAV exceedances were calculated by site using a rolling seven-year assessment period and for each year for the duration of the period of record. Most sites fully supported the recreational beach use for all assessment periods, but a few bay beach sites did not (Table 32). Six bay beach sites (NUE026, NUE028, NUE029, NUE031, NUE032 and NUE033) either met the criterion for concern and fully supporting (20-25% BAV exceedances) or did not support the recreational beach use (>25% BAV exceedances) for all the assessment periods. One bay beach site (NUE045) met the criterion for concern and fully supporting (20-25% BAV exceedances) the recreational beach use for two assessment periods, 2012-2018 and 2013-2019.

Annual percent BAV exceedances by site revealed most sites fully supported the recreational beach use (Table 33). However, 14 bay sites of the 46 sites assessed either met the criterion for concern and fully supporting (20-25% BAV exceedances) or did not support the recreational beach use (>25% BAV exceedances) during one or more of the assessment periods.

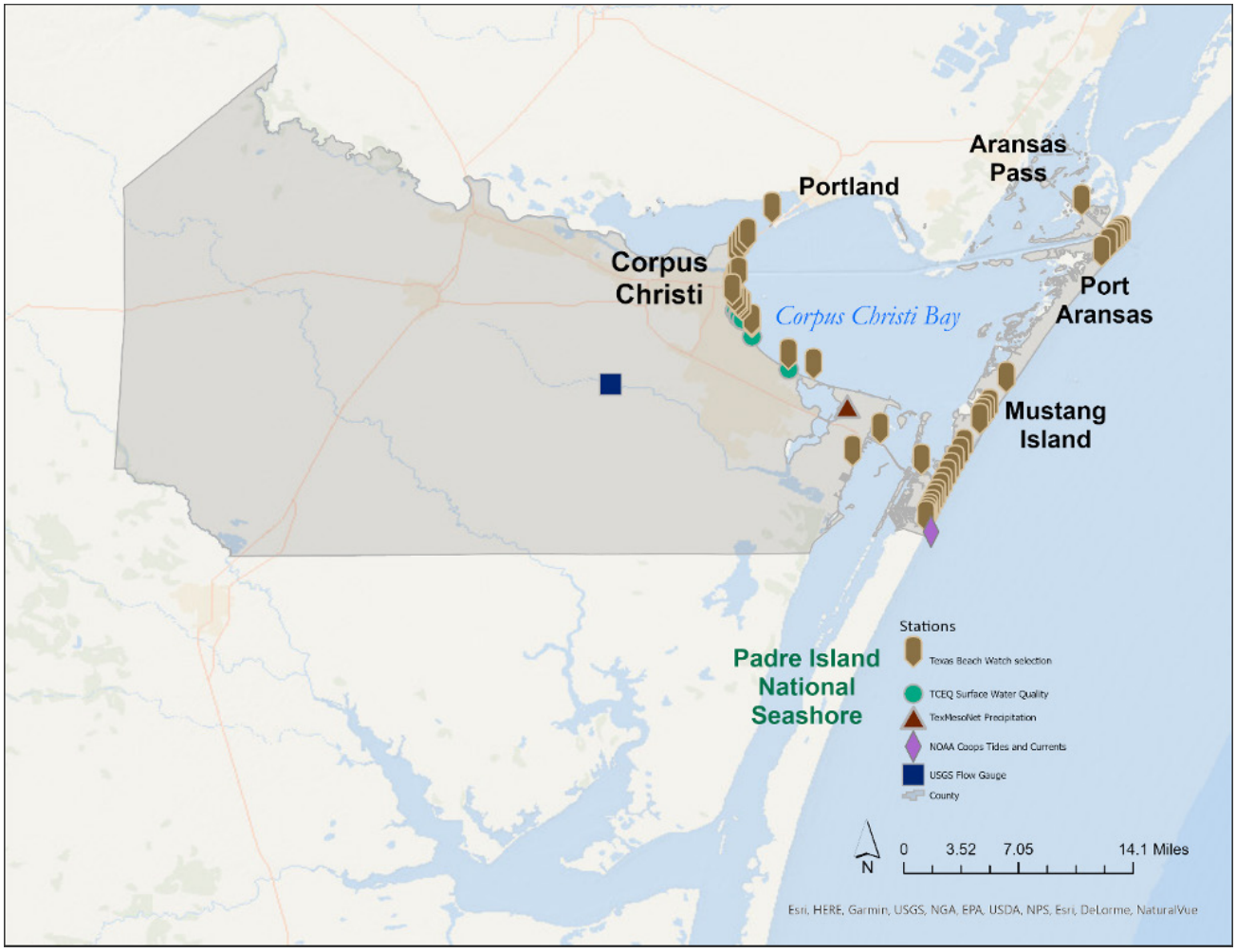

Figure 39. Environmental monitoring stations in Nueces County.

Monthly analysis of enterococci arithmetic means (Figure 40) resulted in exceedance of the BAV in all months except August for the bay beaches. None of the gulf beaches exceeded the BAV. Monthly geometric means for bay beaches in March and September exceeded the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters, while none of the gulf beaches exceeded that criterion (Figure 41).

Annual analysis of enterococci arithmetic means resulted in all bay beaches exceeding the BAV, while none of the gulf beaches did (Figure 42). For the annual geometric mean analysis, none of the Gulf beaches exceeded the geometric mean criterion, but in 2015 the bay beach sites did exceed the geometric mean criterion (Figure 43).

Site analysis of enterococci arithmetic means revealed none of the gulf sites exceeded the BAV, while most of the bay sites did exceed the BAV (Figure 44). For site analysis of geometric means, only Bay beach sites (NUE028, NUE029, NUE031, NUE032, and NUE033) exceeded the TCEQ primary contact recreation numeric criterion for enterococci bacteria in marine waters (Figure 45).

A one-way MANOVA with log transformed TBW enterococci data was performed to assess correlation with hydrodynamic alterations and other physical and chemical parameters at two bay Ropes Park sites (NUE028 and NUE029) in Nueces County. Three parameters at Ropes Park bay sites resulted in significant p-values (<0.05) and positive correlations. They included precipitation, discharge, and tidal amplitude (Table 34). One parameter, TDS, resulted in a significant p-value (<0.05) and negative correlation.

Table 29. Texas Beach Watch (TBW) beaches and sites in Nueces County.

County	Beach ID	Beach Name	Station ID
Nueces	TX149569	TAMUCC – University Beach	NUE025
	TX199413	Emerald Beach	NUE050
	TX227625	Packery Channel Park	NUE044
	TX259473	Cole Park	NUE031
			NUE032
			NUE033
			NUE035
	TX305317	Corpus Christi Marina	NUE045
			NUE046
			NUE047
	TX314643	Padre Balli Park	NUE017
			NUE018
			NUE019
			NUE020
			NUE021
			NUE022
			NUE023
			NUE024
	TX315916	Port Aransas – South	NUE005
			NUE006
	TX396020	Mustang Island	NUE048
	TX442541	JFK Causeway – SW	NUE042
	TX536781	McGee Beach	NUE036
			NUE037
	TX538780	Lighthouse Lake	NUE049
	TX546628	North Beach	NUE038
			NUE039
			NUE040
			NUE041

Table 29 cont. Texas Beach Watch (TBW) beaches and sites in Nueces County.

County	Beach ID	Beach Name	Station ID
Nueces	TX551380	Mustang Island State Park	NUE007
			NUE008
			NUE009
			NUE010
			NUE012
	TX607336	JP Luby Park	NUE013
			NUE014
			NUE015
			NUE016
	TX682648	Poenisch Park	NUE026
	TX722300	Port Aransas Park	NUE001
			NUE002
			NUE003
			NUE004
	TX821303	Ropes Park	NUE028
			NUE029
	TX937228	Laguna Shores	NUE043

Table 30. Summary statistics of enterococci (cfu/100 ml) data by site in Nueces County (January 2009 - December 2019).

Site	Statistic							
	N	Arithmetic Mean	Geometric Mean	Median	Min.	Max	Standard Deviation	# BAV Exceedances (%)
NUE001	426	27.8	8.8	5.0	5.0	1970.0	124.2	15 (3.5)
NUE002	422	19.8	9.0	5.0	5.0	712.0	58.4	12 (2.8)
NUE003	419	17.9	8.9	5.0	5.0	680.0	45.7	8 (1.9)
NUE004	428	21.5	8.7	5.0	5.0	725.0	62.4	17 (4.0)
NUE005	432	22.9	9.0	5.0	5.0	890.0	66.3	21 (4.9)
NUE006	426	23.6	8.5	5.0	5.0	2224.0	114.3	15 (3.5)
NUE007	410	7.8	6.0	5.0	5.0	108.0	10.5	1 (0.2)
NUE008	414	10.8	6.4	5.0	5.0	257.0	24.3	7 (1.7)
NUE009	412	10.3	6.6	5.0	5.0	201.0	19.9	5 (1.2)
NUE010	409	8.9	6.3	5.0	5.0	207.0	16.0	2 (0.5)
NUE012	414	12.4	7.1	5.0	5.0	341.0	27.2	3 (0.7)
NUE013	418	20.5	7.8	5.0	5.0	2392.0	121.1	8 (1.9)
NUE014	418	19.6	8.0	5.0	5.0	2014.0	103.2	7 (1.7)
NUE015	420	19.2	8.3	5.0	5.0	857.0	62.7	11 (2.6)
NUE016	425	26.6	8.9	5.0	5.0	2224.0	124.9	15 (3.5)
NUE017	428	29.5	9.7	5.0	5.0	3654.0	179.9	18 (4.2)
NUE018	421	20.9	9.2	5.0	5.0	1553.0	80.1	11 (2.6)
NUE019	426	22.0	9.6	5.0	5.0	875.0	59.0	14 (3.3)
NUE020	429	27.4	9.3	5.0	5.0	1595.0	114.1	19 (4.4)
NUE021	427	45.3	10.0	5.0	5.0	5475.0	313.4	17 (4.0)
NUE022	428	35.5	9.7	5.0	5.0	2851.0	188.3	18 (4.2)
NUE023	436	38.6	10.5	5.0	5.0	4884.0	242.2	26 (6.0)
NUE024	437	28.1	9.9	5.0	5.0	1160.0	81.1	27 (6.2)
NUE025	454	220.3	18.0	7.7	5.0	24196.0	1428.2	63 (13.9)
NUE026	517	392.1	31.2	20.0	5.0	24196.0	2037.4	130 (25.1)
NUE028	641	821.9	69.3	63.0	5.0	24196.0	3255.8	265 (41.3)
NUE029	548	915.8	70.0	61.0	5.0	24196.0	3346.9	225 (41.0)
NUE031	616	793.0	54.5	46.5	5.0	24196.0	3251.5	232 (37.7)
NUE032	608	945.3	57.7	47.3	5.0	24196.0	3602.8	224 (36.8)
NUE033	548	815.1	39.2	20.0	5.0	24196.0	3359.4	161 (29.4)
NUE035	515	445.6	30.5	20.0	5.0	24196.0	2101.7	128 (24.9)
NUE036	449	207.5	15.4	5.0	5.0	24196.0	1544.5	62 (13.8)

Table 30 cont. Summary statistics of enterococci (cfu/100 ml) data by site in Nueces County (January 2009 - December 2019).

Site	Statistic							
	N	Arithmetic Mean	Geometric Mean	Median	Min.	Max	Standard Deviation	# BAV Exceedances (%)
NUE037	440	95.9	12.9	5.0	5.0	9563.0	619.8	49 (11.1)
NUE038	422	119.4	12.4	5.0	5.0	24196.0	1264.7	28 (6.6)
NUE039	432	181.2	11.7	5.0	5.0	24196.0	1722.1	40 (9.3)
NUE040	413	84.6	9.0	5.0	5.0	24196.0	1192.4	20 (4.8)
NUE041	414	46.4	8.9	5.0	5.0	8664.0	433.1	20 (4.8)
NUE042	435	80.6	14.2	5.0	5.0	5400.0	387.9	45 (10.3)
NUE043	220	78.6	18.7	15.5	5.0	4106.0	321.4	27 (12.3)
NUE044	407	81.4	8.9	5.0	5.0	14136.0	871.0	18 (4.4)
NUE045	496	562.5	26.9	20.0	5.0	24196.0	2919.2	107 (21.6)
NUE046	442	288.0	12.6	5.0	5.0	24196.0	2302.9	50 (11.3)
NUE047	414	127.6	8.7	5.0	5.0	17329.0	1186.9	21 (5.1)
NUE048	416	10.3	6.5	5.0	5.0	340.0	23.3	5 (1.2)
NUE049	369	56.2	8.5	5.0	5.0	12033.0	631.3	17(4.6)
NUE050	475	205.7	21.9	15.0	5.0	17329.0	1150.7	90 (18.9)

Table 31. Texas Beach Watch (TBW) data for enterococci concentrations for Nueces County connecting numbers report from Tukey-Kramer analysis. Enterococci concentrations at sites with different levels are significantly different. (JMP Pro 15.1.0 2019).

Beach ID	Beach Name	Level									Mean *Enterococcus* (ln(y))
TX821303	Ropes Park	9									4.24
TX259473	Cole Park		8								3.80
TX682648	Poenisch Park			7							3.44
TX227625	Emerald Beach				6						3.09
TX937228	Laguna Shores				6	5					2.93
TX149569	TAMUCC – University Beach				6	5					2.89
TX305317	Corpus Christi Marina					5					2.70
TX442541	JFK Causeway - SW					5					2.66
TX536781	McGee Beach					5					2.65
TX546628	North Beach						4				2.34
TX314643	Padre Balli Park						4				2.27
TX227625	Packery Channel Park						4	3	2		2.19
TX22300	Port Aransas Park						4	3			2.18
TX315916	Port Aransas Park – South						4	3			2.17
TX538780	Lighthouse Lake						4	3	2	1	2.14
TX607336	JP Luby Park							3	2		2.11
TX551380	Mustang Island State Park									1	1.87
TX396020	Mustang Island								2	1	1.87

Table 32. Percent BAV (104 cfu/100 ml) exceedances in Nueces County for each seven-year assessment period from January 2009 to December 2019.

Site ID	Assessment Period				
	2009-2015	2010-2016	2011-2017	2012-2018	2013-2019
NUE001	4.0	4.0	3.3	4.1	3.0
NUE002	1.9	1.9	2.6	3.3	3.3
NUE003	1.5	1.5	1.5	2.6	2.6
NUE004	4.7	4.7	3.6	3.6	3.3
NUE005	3.6	3.6	3.3	5.1	5.1
NUE006	3.3	3.3	2.9	3.6	3.6
NUE007	0.0	0.0	0.0	0.0	0.4
NUE008	1.9	2.3	2.3	1.5	1.5
NUE009	1.1	1.5	1.5	1.5	1.5
NUE010	0.4	0.7	0.7	0.4	0.4
NUE012	1.1	1.1	1.1	1.1	0.8
NUE013	2.5	2.5	2.5	1.5	1.5
NUE014	2.2	2.6	2.2	1.9	1.1
NUE015	3.3	3.6	3.6	3.0	2.6
NUE016	3.7	4.0	4.4	3.3	2.9
NUE017	3.3	3.6	3.0	3.3	3.9
NUE018	2.2	2.6	2.9	2.9	2.6
NUE019	4.4	4.4	3.7	2.6	2.6
NUE020	5.4	6.1	5.0	4.3	3.6
NUE021	3.7	4.7	4.7	4.0	4.2
NUE022	5.3	5.0	3.9	2.6	2.2
NUE023	5.3	6.4	6.0	5.7	7.0
NUE024	5.0	5.6	6.0	5.0	6.6
NUE025	14.4	15.0	13.1	15.6	12.4
NUE026	26.0	25.9	23.9	25.2	21.1
NUE028	38.6	39.8	40.9	44.0	44.1
NUE029	36.8	39.0	38.0	39.8	38.6
NUE031	34.9	35.8	35.4	38.7	38.8
NUE032	23.1	22.5	24.1	27.9	30.8
NUE033	23.0	22.7	22.5	24.5	25.4
NUE035	13.7	13.7	13.7	15.2	16.0
NUE036	13.7	13.7	13.7	15.2	16.0

Table 32 cont. Percent BAV (104 cfu/100 ml) exceedances in Nueces County for each seven-year assessment period from January 2009 to December 2019.

Site ID	Assessment Period				
	2009-2015	2010-2016	2011-2017	2012-2018	2013-2019
NUE037	10.3	10.6	9.2	11.2	11.8
NUE038	6.0	8.4	7.0	7.4	5.9
NUE039	7.5	11.3	9.3	9.7	8.6
NUE040	4.4	5.7	4.3	5.0	4.3
NUE041	4.4	5.4	3.4	4.4	4.0
NUE042	13.4	10.7	8.0	5.6	4.5
NUE043	11.2	11.4	12.1	12.6	9.8
NUE044	2.4	2.8	2.4	3.2	5.5
NUE045	18.7	19.7	19.5	21.3	22.8
NUE046	12.2	12.2	10.4	12.3	11.6
NUE047	5.9	5.5	4.1	5.2	4.1
NUE048	5.9	5.5	4.1	5.2	4.1
NUE049	1.1	1.1	1.5	1.5	1.5
NUE050	2.5	3.8	4.3	4.6	5.2

Table 33. Annual percent BAV (104 cfu/100 ml) exceedances in Nueces County by site for January 2009 to December 2019.

Site	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
NUE001	2.6	7.3	0.0	7.7	2.7	5.1	2.7	2.5	2.6	5.0	0.0
NUE002	2.6	0.0	2.6	2.7	0.0	2.6	2.7	2.5	5.1	7.3	2.6
NUE003	2.6	0.0	0.0	0.0	2.7	2.6	2.7	2.5	0.0	7.3	0.0
NUE004	7.3	7.3	2.6	2.7	5.3	5.1	2.7	7.1	0.0	2.6	0.0
NUE005	7.3	2.6	2.6	2.7	5.3	5.1	0.0	7.1	0.0	15.6	2.6
NUE006	2.6	2.6	5.0	2.7	2.7	0.0	7.7	2.5	0.0	9.5	2.6
NUE007	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6
NUE008	0.0	0.0	5.0	2.7	0.0	0.0	5.6	2.5	0.0	0.0	2.6
NUE009	0.0	0.0	0.0	2.7	5.3	0.0	0.0	2.5	0.0	0.0	2.6
NUE010	0.0	0.0	2.6	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0
NUE012	0.0	0.0	0.0	2.7	5.3	0.0	0.0	0.0	0.0	0.0	0.0
NUE013	2.6	0.0	7.3	0.0	2.7	5.1	0.0	2.5	0.0	0.0	0.0
NUE014	0.0	2.6	2.6	5.3	5.3	0.0	0.0	2.4	0.0	0.0	0.0
NUE015	0.0	0.0	7.3	2.7	2.7	2.6	7.7	2.5	0.0	2.6	0.0
NUE016	2.6	2.6	7.3	5.3	5.3	2.6	0.0	4.9	5.1	0.0	2.6
NUE017	0.0	9.8	5.0	2.7	2.7	2.6	0.0	2.5	5.1	7.3	7.3
NUE018	0.0	5.1	2.6	2.7	2.7	2.6	0.0	2.5	7.5	2.6	0.0
NUE019	0.0	5.1	7.1	5.3	5.3	2.6	5.3	0.0	0.0	0.0	5.0
NUE020	0.0	7.5	5.0	10.0	7.7	7.5	0.0	4.9	0.0	0.0	5.0
NUE021	0.0	0.0	5.0	7.7	2.7	7.5	2.7	7.1	0.0	0.0	9.5
NUE022	5.0	7.5	11.6	2.6	5.3	5.1	0.0	2.5	0.0	2.6	0.0
NUE023	0.0	5.1	7.3	2.7	2.7	11.9	7.7	7.1	2.6	5.0	11.6
NUE024	2.6	2.6	11.6	2.7	2.7	9.8	2.7	7.1	5.1	5.0	13.6
NUE025	7.7	16.3	5.3	27.1	15.0	2.8	26.5	12.2	2.8	22.7	5.0
NUE026	29.4	23.9	32.1	31.4	25.0	16.7	23.4	28.6	10.3	41.1	2.6
NUE028	36.4	36.4	23.4	39.3	52.4	28.6	54.2	44.4	43.9	45.0	40.6
NUE029	26.5	34.5	29.4	44.4	38.9	31.4	52.1	42.4	27.1	42.1	36.2
NUE031	28.0	26.5	28.0	34.0	36.5	35.2	56.4	34.0	23.9	50.8	34.5
NUE032	27.5	26.5	14.3	22.2	17.1	12.5	41.7	23.4	37.7	40.7	42.4
NUE033	20.5	23.4	14.3	18.6	24.4	7.9	52.2	18.2	22.2	27.7	25.5
NUE035	10.0	12.5	5.3	7.9	25.0	7.9	27.7	9.8	12.5	15.4	13.6
NUE036	10.0	12.5	5.3	7.9	25.0	7.9	27.7	9.8	12.5	15.4	13.6

Table 33 cont. Annual percent BAV (104 cfu/100 ml) exceedances in Nueces County by site for January 2009 to December 2019.

Site	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
NUE037	7.7	14.6	7.5	7.9	10.5	5.4	18.2	9.8	5.4	21.4	11.6
NUE038	2.6	10.0	2.7	10.3	0.0	0.0	16.3	19.6	0.0	5.4	0.0
NUE039	2.6	14.3	5.3	10.3	2.9	2.9	14.3	29.4	0.0	7.9	2.6
NUE040	2.7	10.0	2.7	5.4	0.0	0.0	10.0	11.9	0.0	7.9	0.0
NUE041	0.0	14.3	2.7	5.4	2.9	0.0	5.3	7.3	0.0	10.3	2.6
NUE042	19.6	18.6	21.7	12.8	8.1	2.8	10.5	0.0	0.0	5.3	5.0
NUE043	10.0	7.9	10.0	20.9	17.1	0.0	ND	ND	ND	ND	ND
NUE044	0.0	2.8	0.0	2.9	5.6	2.8	2.9	2.6	0.0	5.4	19.1
NUE045	5.3	16.3	25.5	18.6	19.5	14.6	31.4	11.9	14.6	38.2	29.6
NUE046	5.3	20.0	5.3	7.9	15.0	7.9	23.9	5.1	7.9	18.6	2.6
NUE047	2.7	12.2	2.7	7.9	5.6	0.0	10.0	0.0	2.8	10.3	0.0
NUE048	2.7	12.2	2.7	7.9	5.6	0.0	10.0	0.0	2.8	10.3	0.0
NUE049	2.6	0.0	0.0	0.0	2.7	2.6	0.0	2.5	2.6	0.0	0.0
NUE050	2.7	0.0	3.4	2.9	5.6	0.0	2.9	11.9	3.6	5.3	7.3

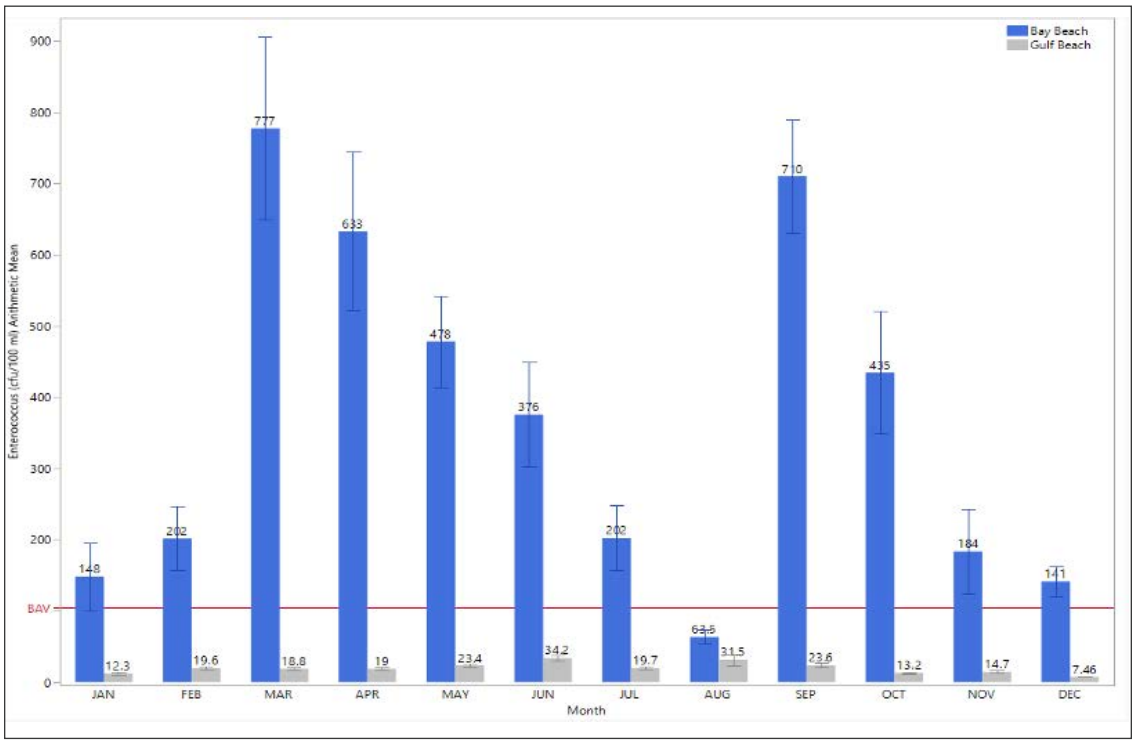

Figure 40. Mean monthly enterococci values for Nueces County bay and gulf beaches (January 2009 - December 2019). Error bars represent 95% confidence interval of the mean

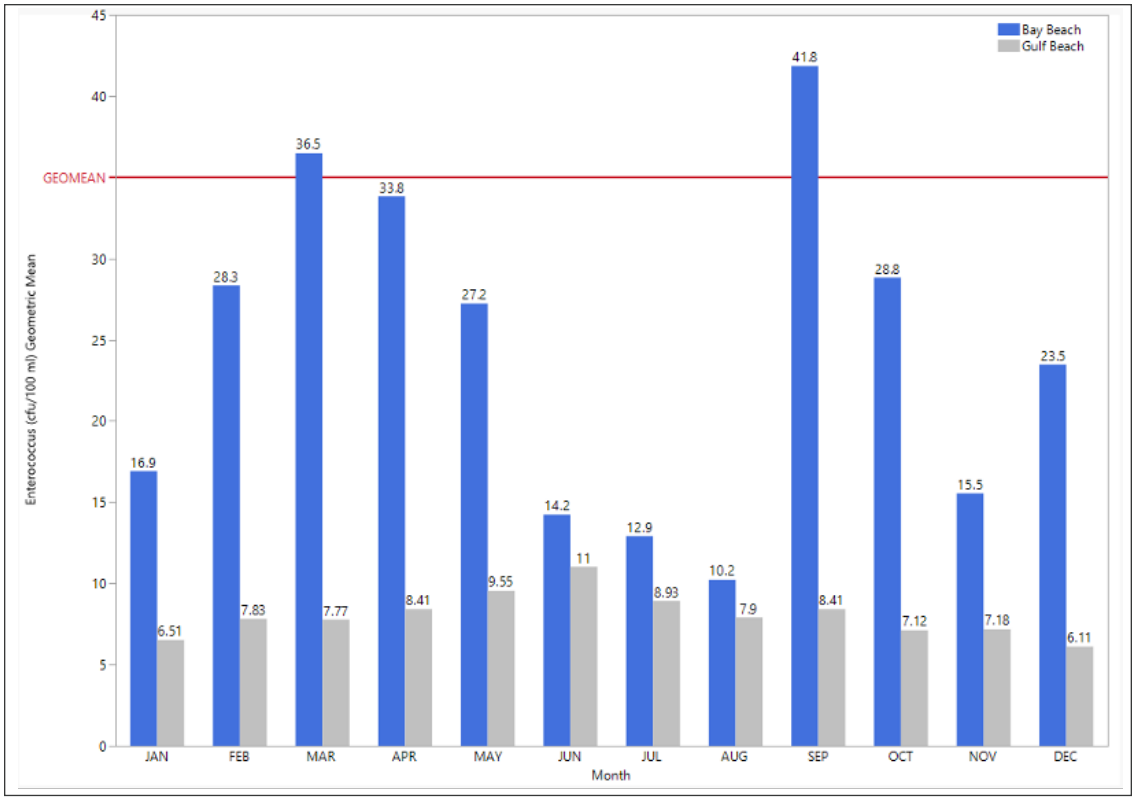

Figure 41. Monthly geometric mean enterococci (cfu/100 ml) for Nueces County bay and gulf beaches (January 2009 - December 2019).

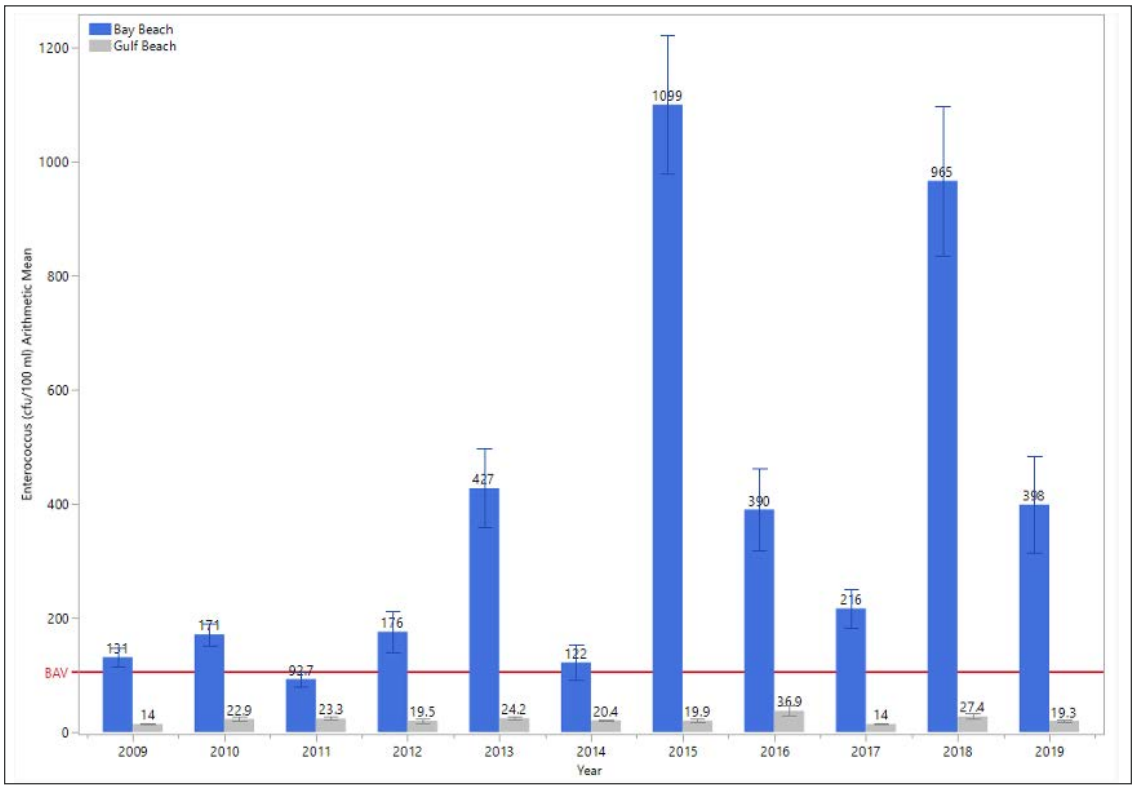

Figure 42. Annual arithmetic mean annual enterococci (cfu/100 ml) for Nueces County bay and gulf beaches (January 2009 - December 2019).

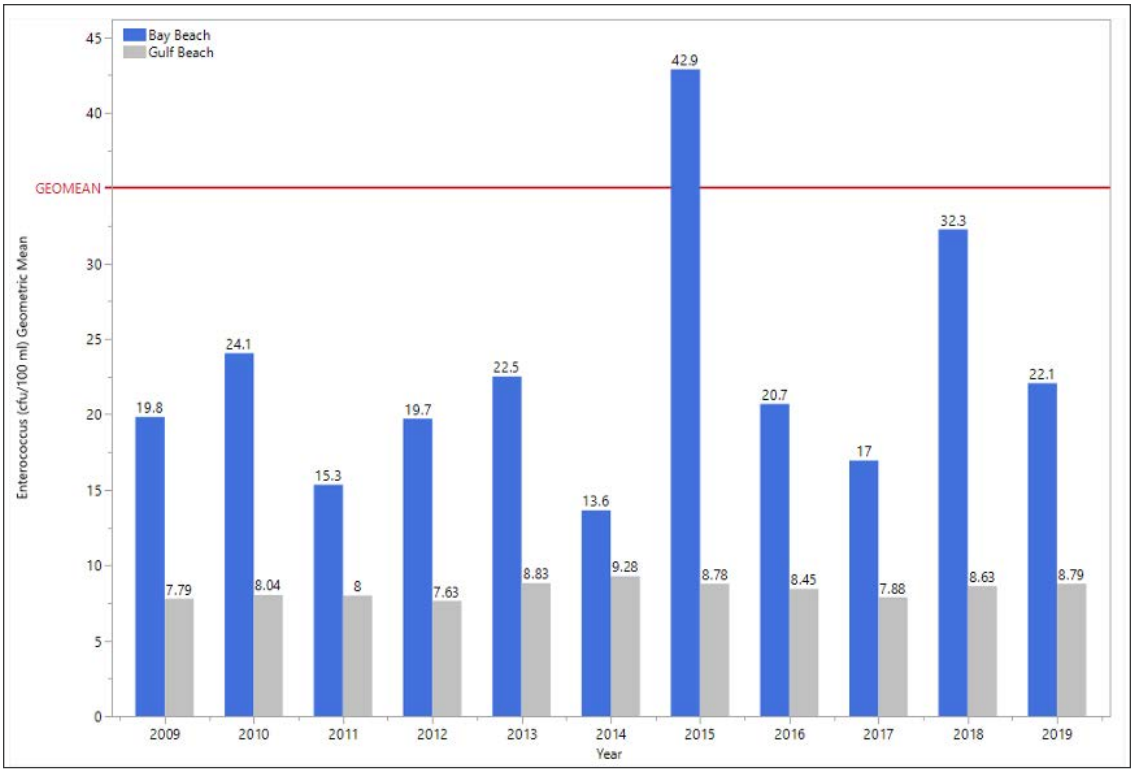

Figure 43. Annual geometric mean enterococci (cfu/100 ml) for Nueces County bay and gulf beaches (January 2009 - December 2019).

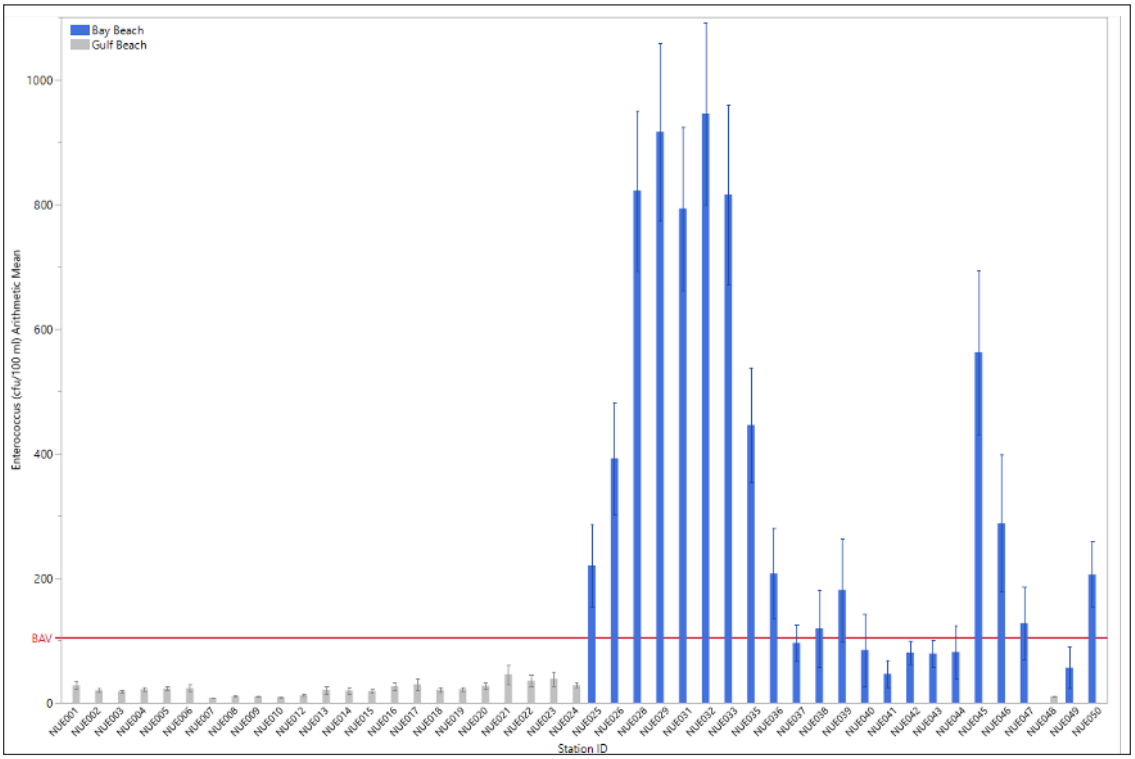

Figure 44. Station arithmetic mean of enterococci concentrations (cfu/100 ml) for Nueces County bay and gulf beaches (January 2009 - December 2019).

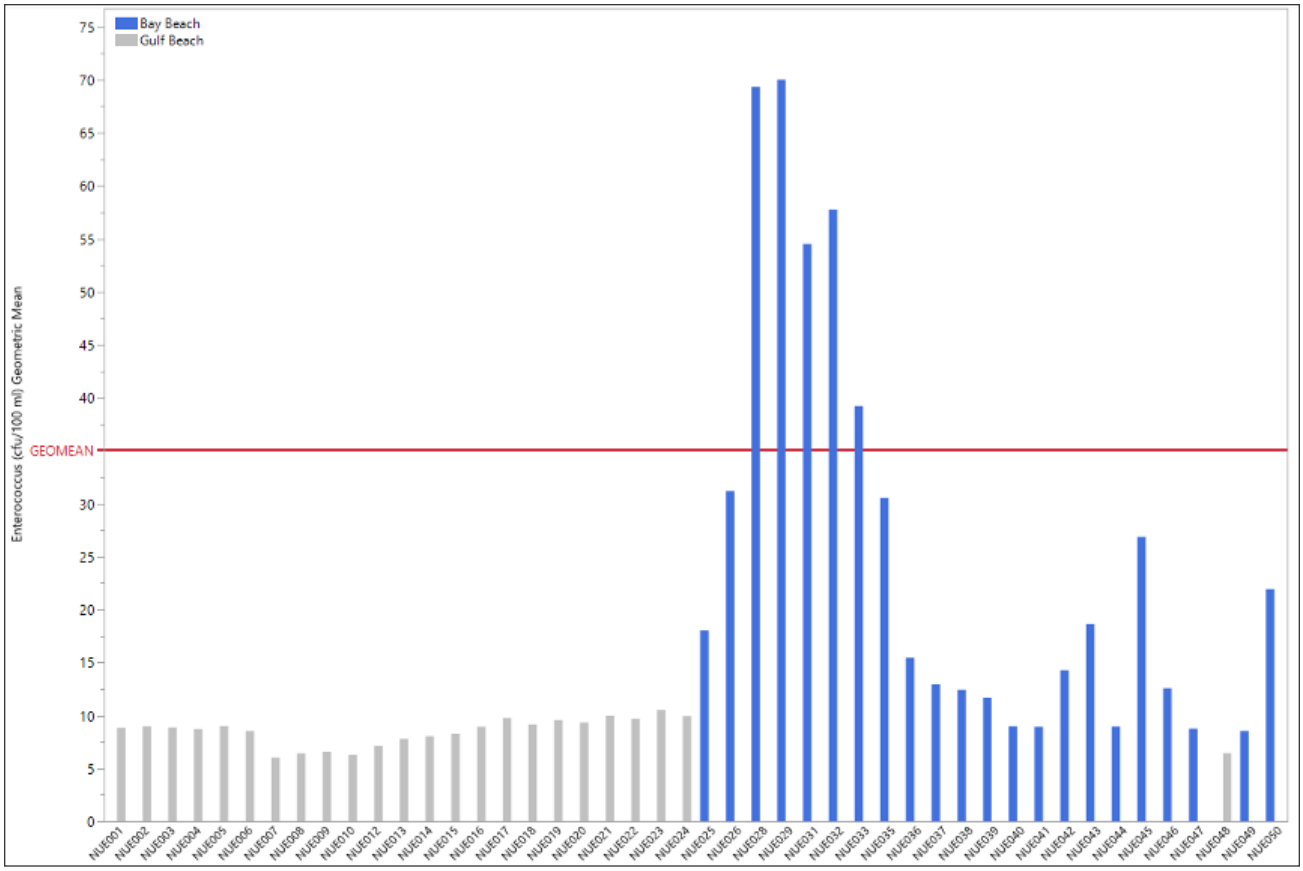

Figure 45. Station geometric mean of enterococci concentrations (cfu/100 ml) for Nueces County bay and gulf beaches (Jan 2009 - Dec 2019). Error bars represents one standard error from the mean.

Table 34. One-way MANOVA with enterococci as the dependent variable in Nueces County at the Ropes Park bay sites (NUE028-NUE029). Bold parameters denote significant p-value <0.05.

Parameters	Number of Samples	Correlation	Mean	Standard Deviation	P-value
Precipitation (in)	**132**	**0.56**	**1.34**	**2.88**	**<0.0001**
Discharge (cfs)	**132**	**0.43**	**28.23**	**73.37**	**<0.0001**
Tidal Amplitude (ft)	**132**	**0.25**	**2.72**	**0.55**	**0.0042**
Salinity (ppt)	47	0.06	33.82	5.05	0.7004
Temperature (°C)	47	0.05	23.95	5.97	0.7633
Transparency (m)	36	0.05	0.88	0.32	0.7940
Specific Conductance (µS/cm)	47	0.05	51,753.17	6,501.01	0.7380
Dissolved Oxygen (mg/l)	47	0.02	7.39	1.24	0.8953
Total Organic Carbon (TOC) (mg/l)	35	0.01	3.80	1.37	0.9514
Ammonia-Nitrogen (mg/l)	37	0.00	0.06	0.04	0.9926
Total Dissolved Solids (mg/l)	**7**	**-0.83**	**32,728.57**	**4,123.80**	**0.0204**
Nitrite plus Nitrate-Nitrogen (mg/l)	38	-0.14	0.04	0.01	0.4113
Alkalinity (mg/l)	39	-0.11	126.85	9.75	0.5154
Total Kjeldahl Nitrogen (TKN) (mg/l)	34	-0.10	0.54	0.20	0.5746
Total Fluoride (mg/l)	39	-0.10	1.13	1.63	0.5595
Total Suspended Solids (mg/l)	38	-0.09	20.32	10.89	0.5885
Chloride (mg/l)	38	-0.08	20,239.47	4,067.37	0.6360
Chlorophyll a (µg/l)	37	-0.08	6.24	5.44	0.6284
Total Phosphorus (TP) (mg/l)	35	-0.06	0.06	0.04	0.7145
Sulfate (mg/l)	38	-0.06	2,770.53	693.76	0.7081
pH (s.u.)	47	-0.05	8.10	0.16	0.7581

SUPPLEMENTARY HOT SPOT SPATIAL ANALYSIS

A supplementary hot spot spatial analysis was conducted during the latter stages of this project and in response to limited environmental data availability in the nearshore Gulf of Mexico associated with gulf beach sites. Interpretation of results associated with this analysis were not completed, therefore preliminary results are provided in Appendix A as supplementary information.

TPW monitors hydrological field parameters at randomly-selected sites in Texas bays and estuaries and along the nearshore Gulf as part of their Coastal Fisheries Division's Resource Monitoring Program. TPW hydrological monitoring data were acquired and spatially interpolated for concurrent analysis with TBW enterococci data.

Results of the supplementary hot spot analysis are presented by year and hydrological parameter (dissolved oxygen, temperature and salinity) (Appendix A). The symbology of each output raster was adjusted to reflect minimum and maximum values for the three parameters included in the analysis (i.e., 5-39°C for temperature, 0-92.5 ppt for salinity, and 0.1-24 mg/l for dissolved oxygen). Red represents high values and blue represents low values for temperature and salinity, while blue represents high values and red represents low values for dissolved oxygen. The map legend represents hot and cold spot analyses with higher and lower confidence intervals (i.e., p-values 0.01, 0.05, and 0.10) for station values higher/lower than the mean percent BAV exceedance per site.

A boosted tree regression (BTR) model was applied using the TPW and TBW data but was not successful. Future analyses using this approach are recommended with additional data sources with higher temporal and spatial resolution and continuity that corresponds with the TBW data.

DISCUSSION

The Texas Gulf coast exhibits an environmental gradient from Jefferson County along the northeast Texas coast to Cameron County along the southwest Texas coast. Salinity is typically inversely proportional to precipitation and freshwater inflow along the gradient, whereby the northeast exhibits lower salinities in response to higher precipitation and freshwater inflows, while the southwest exhibits higher salinities in response to lower precipitation and freshwater inflows. An environmental gradient is also well documented within Texas estuaries from west to east as freshwater from rivers mixes with saltwater from the Gulf of Mexico. Most Texas estuaries are semi-enclosed embayments with increasing residence times from north to south and bordered by a series of barrier islands along the Gulf coast. The recreational beaches included in the current study are situated along these shorelines and reflect similarities with these environmental gradients.

Latitudinal geographic analysis revealed significantly higher concentrations and percent BAV exceedances in the upper and middle Texas coastal areas as compared to the lower Texas coast. Fecal indicator bacteria were significantly higher in bay beaches than gulf beaches along the east to west gradient, likely a result of lack of flushing in the semi-enclosed embayments, as compared to the gulf beach sites that experience direct wave and tidal action and water exchange with the Gulf of Mexico.

The site analysis resulted in ten stations that did not support the recreational beach criterion between >25% and 41% of the time for the entire period of record. All ten stations were located within recreational bay beaches in semi-enclosed embayments in Nueces, Matagorda and Harris Counties, three of the four counties with the highest overall percent BAV exceedances in the county analysis. These ten stations also exhibited significant positive correlations with precipitation in the multivariate analysis, reflecting the effect of nonpoint source runoff from adjacent, highly populated, urbanized areas during rainfall events. The physical location of these ten stations and ease of access by recreational beach goers should be a great concern to local and state managers of recreational water resources, eco-tourism, and public health.

Gulf beach sites in Matagorda and Brazoria Counties exceeded the BAV criterion for the concern and fully supporting TCEQ IR listing category. The multivariate analysis revealed enterococci values at gulf beach sites in Matagorda and Brazoria Counties were significantly and positively correlated with tidal amplitude and nitrite+nitrate-nitrogen. These findings imply potential nonpoint source seepage of on-site septic systems during high tides from nearby residential neighborhoods. Concurrent water quality monitoring of surface water, ground water, and interstitial sediment pore water is recommended to track water movement dynamics as they relate to tides, precipitation and other parameters.

The peak and non-peak seasonal analysis for bay and gulf beaches resulted in statistically significant differences for gulf beaches, but not for bay beaches. Bay beaches had higher overall means than gulf beaches and were not statistically significantly different by season. These results imply the lack of flushing and high residence times within bay environments, as compared to gulf beaches, may be affecting enterococci concentrations seasonally.


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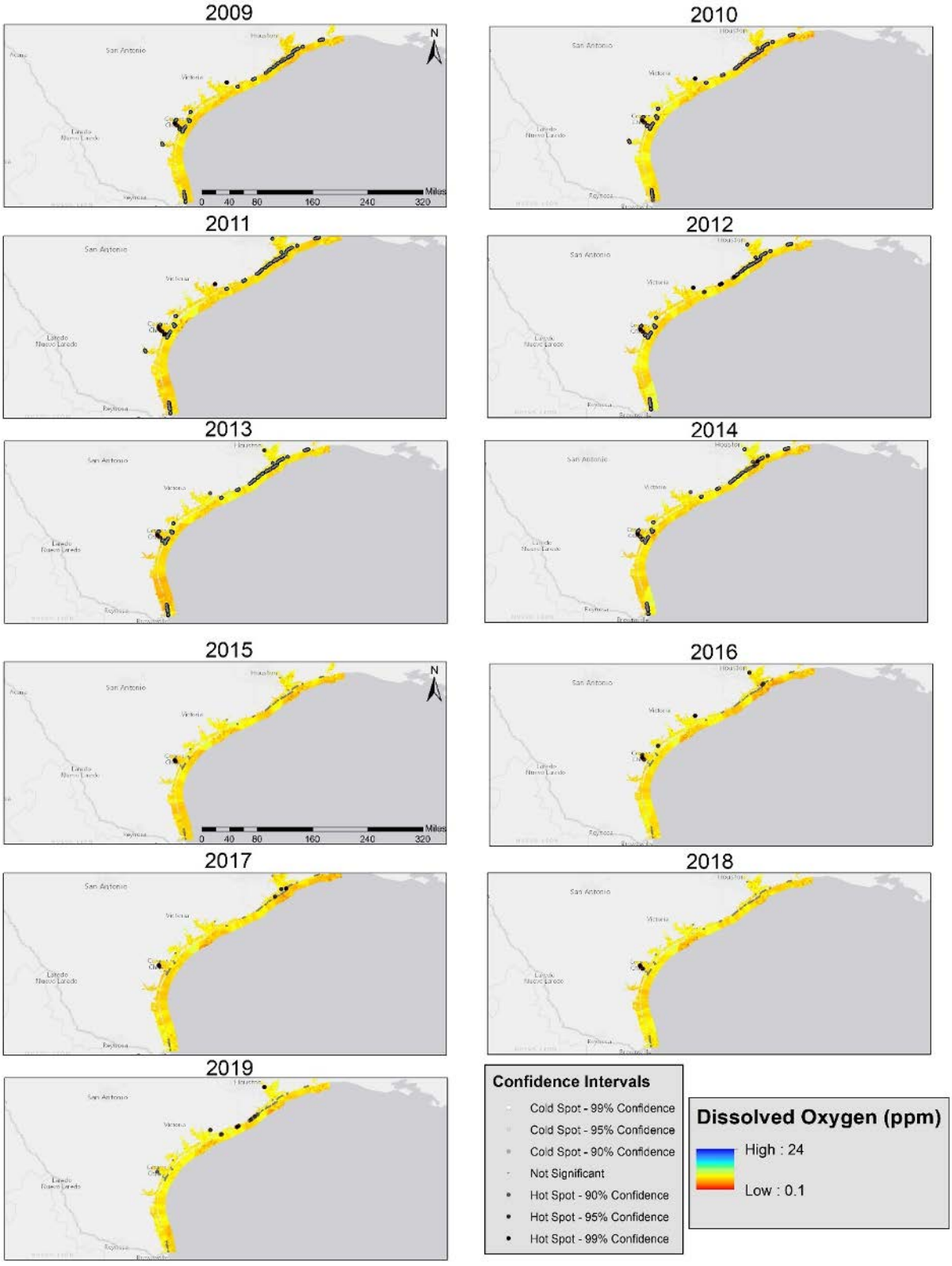
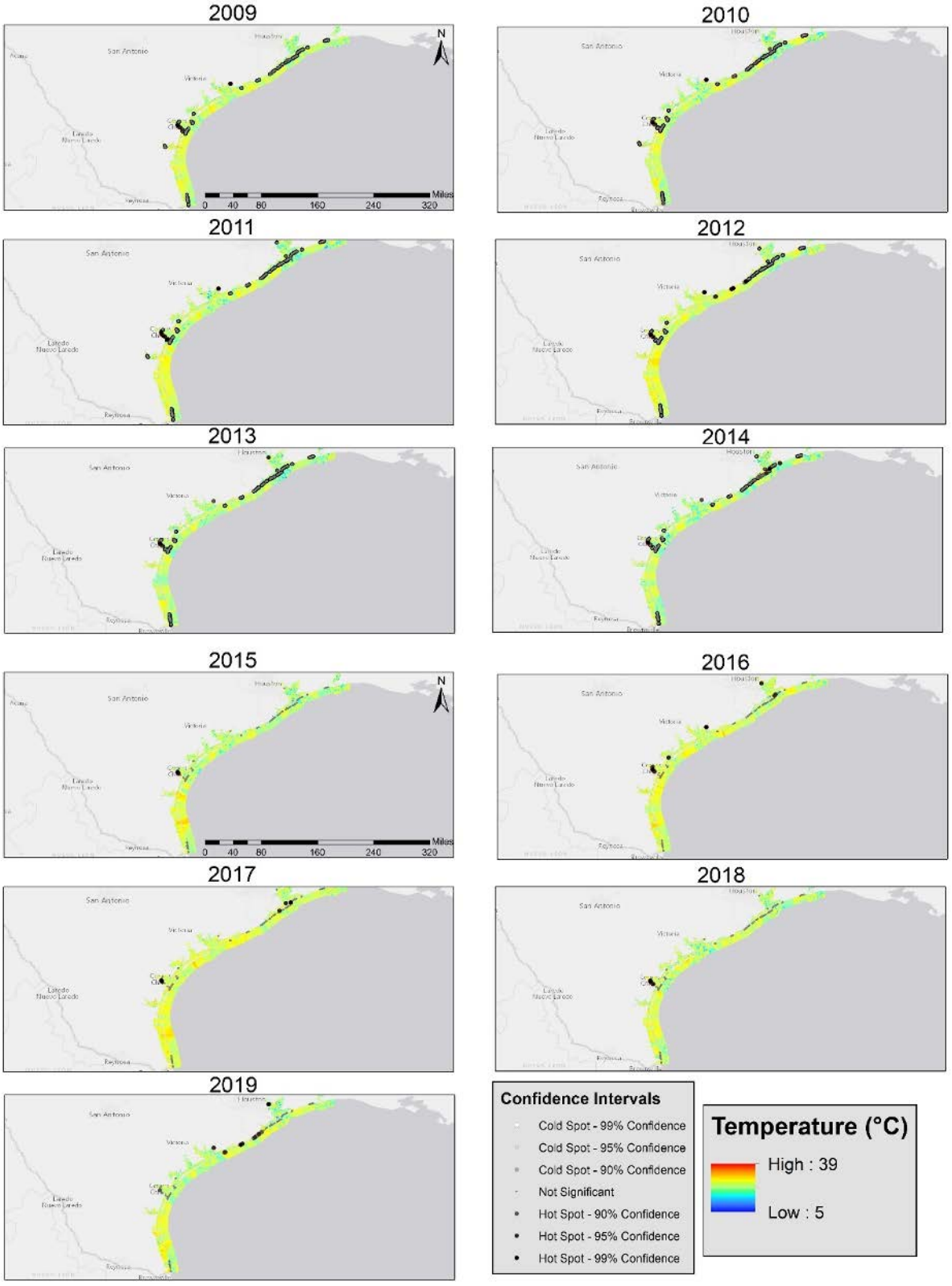
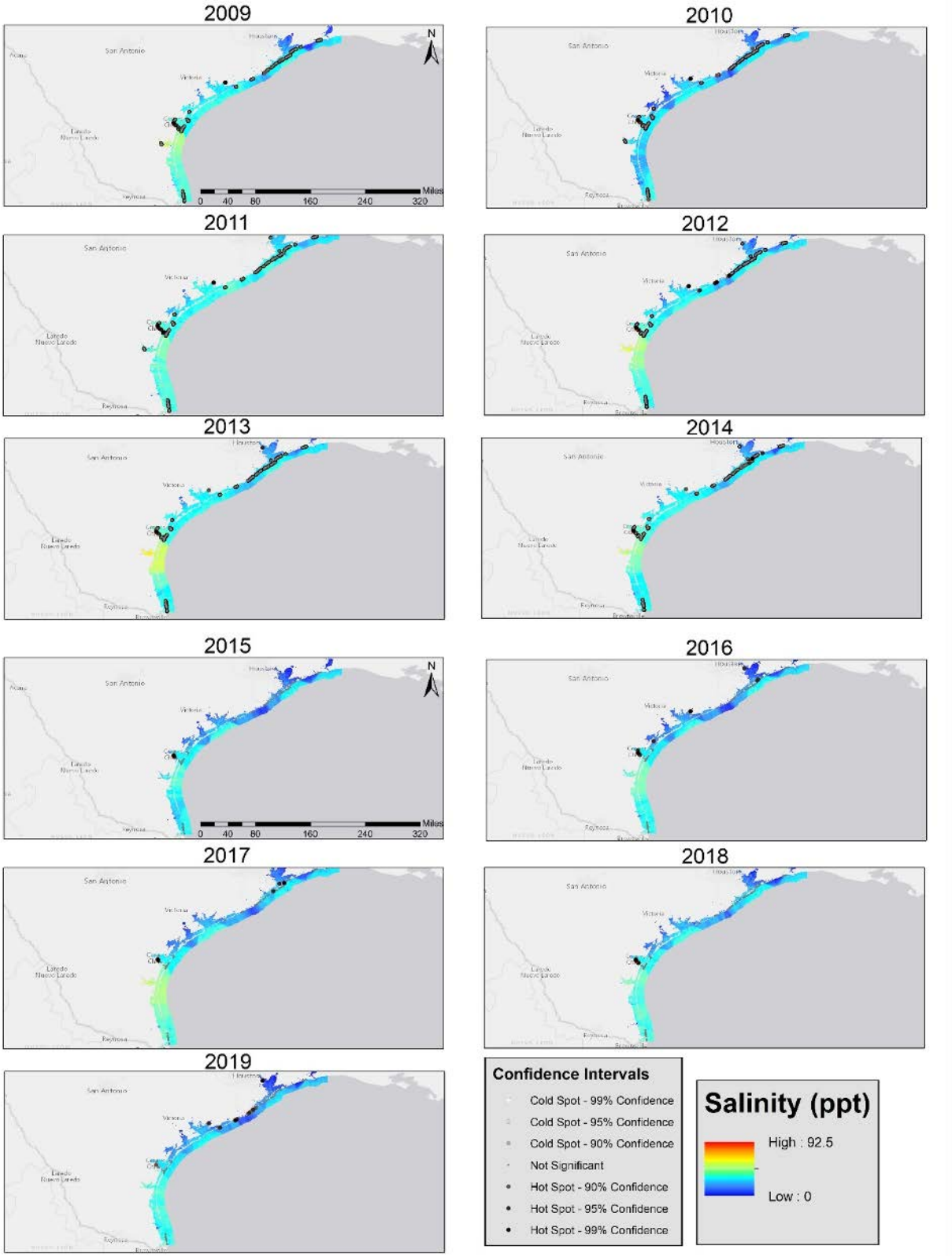
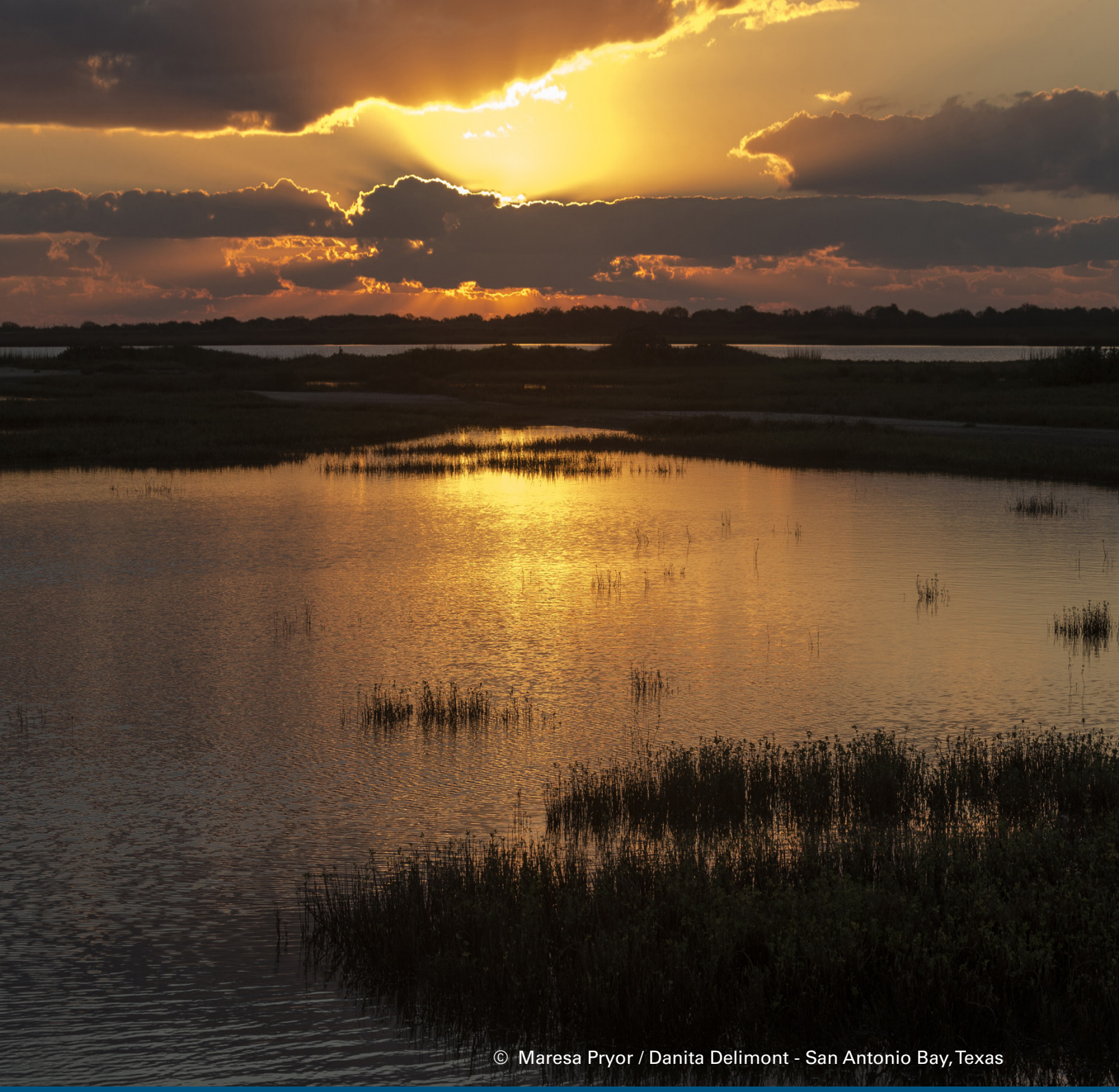
APPENDIX A.
SPATIAL HOT SPOT ANALYSIS OF PERCENT BAV EXCEEDANCES AND TPW HYDROLOGICAL DATA




2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
N
0 40 80 160 240 320
Miles
Confidence Intervals
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
Temperature (°C)
High : 39
Low : 5


2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
San Antonio
Victoria
Laredo
Nuevo Laredo
Reynosa
N
0 40 80 160 240 320
Miles
Confidence Intervals
Cold Spot - 99% Confidence
Cold Spot - 95% Confidence
Cold Spot - 90% Confidence
Not Significant
Hot Spot - 90% Confidence
Hot Spot - 95% Confidence
Hot Spot - 99% Confidence
Salinity (ppt)
High : 92.5
Low : 0



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