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Analysis of Fecal Loadings Into Bayous Grande, Chico, and Texar Pensacola Bay System, FL

12 September 2006

Prepared for:
Florida Department of Health
Escambia County Health Department

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Abstract

Chronic fecal contamination of waterways within the Pensacola Bay, FL system represents both a public health and environmental problem. This report summarizes the findings of a multi-year study to identify sources of loadings of fecal contamination within the urban bayous of Pensacola, FL: Bayou Grande, Bayou Chico, and Bayou Texar. Thirty-one stations were established along the shoreline of Bayou Grande, forty-two in Bayou Chico, and thirty-three in Bayou Texar. Stations were selected to coincide with storm water drainages, perennial streams, and areas of likely groundwater discharge indicated by topography and freshwater wetland plants in salt water areas. Spatially explicit loading to all three systems was apparent. The intensity of this geographic variability (as variance in system-wide data) increased with moderate rainfall (up to 1.6" within the past 48 hours), but higher levels of rainfall, and presumably associated wind-mixing of the systems, resulted homogenization of the system and loss of both lower and higher count records. Analysis of station-specific data for rainfall effects on contamination indicated some stations with high concentrations at zero rainfall, presumably from groundwater loadings or feral waterfowl, and others with more dependence on rain, presumably as storm water inputs and enhanced groundwater discharge. In Bayou Grande, the residential areas of the northern and western drainages, and not the Naval Air Station along the southern shore, appear to be the major source areas of chronic fecal contamination to the system. GIS plots indicate older residential development using septic tanks in low-lying areas are source areas. In Bayou Chico, concentrations of nitrogen and fecal bacteria decreased along the salinity gradient of the system as a general trend, indicating the three freshwater and residential areas of the bayou as sources to the system. GIS plots of the data clearly indicate the residential areas, as opposed to the industrial and commercial marina areas along the main part of the bayou, as the sources of contamination. Older residential development using septic tanks in low-lying areas are likely sources. In Bayou Texar, nitrogen and fecal bacteria also decreased along the salinity gradient of the system as a general trend, indicating the Carpenters Creek drainage area as the primary groundwater sources to the system, with the main bayou area served by residential sewer being affected mainly by rainfall. Older residential development using septic tanks and older sewer lines in the Carpenters Creek drainage area are likely sources.

Introduction

Fecal contamination of surface and ground waters is a nationwide environmental and human health problem. As point sources of this contamination are increasingly restricted and improved, attention is beginning to focus on non-point source loadings from storm water runoff and septic tank (onsite sewage treatment and disposal system; OSTDS) effluents. This focus is being driven by a need to address chronic impairment of water resources that have not responded to increased control of point source discharges. This study was undertaken to attempt to localize and define sources of fecal loading into Bayous Grande, Chico and Texar, the urbanized bayous of the Pensacola Bay system. These bayous have a history of fecal contamination and public health closures for recreational use.

Bayou Grande presents a natural experiment insofar as the northern shoreline and drainage area are largely covered by older residential development using septic tanks systems for wastewater disposal, whereas the southern shoreline and drainage are occupied by the Pensacola Naval Air Station (NAS). This provides for a comparison of residential to undeveloped and lightly developed landscape. NAS is serviced by its own wastewater treatment plant with a surface water effluent discharge near the mouth of the bayou. Much of the shoreline of the NAS is occupied by the base golf course and wooded areas. A northern branch of the bayou extends into a residential area serviced by septic tanks south of Gulf Beach Highway.

Bayou Chico has historically supported more industrial activity than the other urban bayous of the Pensacola Bay system. The upper reaches of the drainage area are bifurcated into a western extension and a northern extension. The latter is further bifurcated into east and west branches. The northern extension passes through two constrictions formed by a former railroad trestle and its earth-filled approaches (south constriction) and a bridge carrying Rt. 98, Navy Boulevard (north constriction). Land use within the Bayou Chico drainage basin is a mix of industrial/commercial and residential development. The north and west reaches of the system are mostly covered by older residential development using septic tanks systems for wastewater disposal. The lower and main part of the bayou is dominated by heavy industry (shipbuilding, scrap metal, chemical manufacturing and distribution, petroleum storage and distribution) and commercial and recreational marinas.

Bayou Texar is surrounded by residential development on a sewer system in contrast to the residential areas around bayous Chico and Grande, and thus provides for a comparison of residential sewer service and septic tank use. Past industrial activity in the Palafox corridor has contributed toxic materials via groundwater flow and storm water runoff to the upper reaches of the bayou. Carpenter’s Creek feeding in the northern end of the bayou drains areas using septic tanks. Despite the predominance of sewer service, the bayou has chronic fecal contamination problems.

This report presents the results of multiyear sampling to define spatially explicit sources of fecal contamination into these water bodies.

Materials and Methods

Stations for sampling were identified by visual survey of the shoreline for storm and groundwater drainage pipes, surface water inputs (intermittent and continuous), and likely areas of ground water discharge, as indicated by freshwater wetland vegetation in salt water areas and land contours. Stations were also established in the open waters of the Bayous.

The distribution of the 31 Bayou Grande stations is displayed in Figure 1. Bayou Grande station names associated station coordinates are listed in Table 1. The distribution of the 42 Bayou Chico stations (37 regularly sampled; 5 added late in the study) is displayed in Figure 2. Bayou Chico station names and coordinates are listed in Table 2. The distribution of the 33 Bayou Texar stations is displayed in Figure 3. Station names and coordinates are listed in Table 3. Bayou Grande samples were taken at monthly intervals from 13 December 1999 to 17 October 2001. Bayou Chico samples were taken at monthly intervals from 11 November 2001 to 30 December 2003. Bayou Texar samples were taken from December 1999 to June 2003.

At each station, time of sampling, water temperature, pH, salinity, and dissolved oxygen were recorded by calibrated water quality meter. Water samples were obtained using State of Florida Department of Environmental Protection (DEP) Standard Operating Procedures (SOP), by Escambia County Health Department (ECHD) personnel. Samples were analyzed by standard methods in either the laboratory of Severn Trent Laboratories, Pensacola, FL (some nutrient analyses) or the Wetlands Research Laboratory at the University of West Florida for Biochemical oxygen demand (BOD; EPA Method 405.1, U.S. EPA, 1983), Enterococci (E; EPA Method 1600, U.S. EPA, 1997), Fecal Coliforms (FC; SM9221E, Eaton, et al., 1995), Total nitrate/nitrite (TNO3/NO2 as N; U.S. EPA, 1993), and Total phosphate (TP as P; U.S. EPA 1983). The UWF Wetlands Lab facility is State of Florida certified for environmental analysis (Lab ID: E71176), conforming to the standards of the National Environmental Laboratory Accreditation Conference (NELAC). The laboratory complies with full chain of custody sample storage and handling practices.

Data were reported to the ECHD as analyses of sample lots (by sampling date) were completed. The final dataset is the subject of this report. Microsoft Excel was used for data reduction and analysis. Limits of detection were reported in lieu of zero values. For each station over the time period of sampling, normality of the data was assessed and arithmetic and geomeans were determined for use as a summary dataset, as appropriate. Standard deviations for arithmetic means and coefficients of variation (standard deviation/mean) for geomeans are reported. Correlation analysis was performed to assess any interrelationships between measured parameters.

Regression analysis was used to determine conservative mixing of measured constituents with seawater. Regression was also used for Log *Enterococcus* counts as a function of rainfall in the 48 hours prior to each sampling event for entire bayous and for each station. Station specific regression models of log *Enterococcus* counts as a function of rainfall were used to estimate geomeans of *Entercoccus* contamination at zero rainfall (y-intercept values) and dependence of contamination on rainfall (slope estimates).

Kaleidagraph (Synergy Software, Inc.) was used to generate graphs. Arcview GIS was used to compile geospatial distribution maps for analytical parameters. Statistical models, graphs, and GIS plots are presented for data visualization purposes. No statistical significance is implied unless clearly stated.

Additional sampling was conducted in Bayous Grande and Chico to isolate ground water concentrations of fecal contamination. Sampling in Bayou Grande visually targeted streams and seepage areas in the intertidal zone at low tides. Sampling in Bayou Chico used a similar approach but with the assistance of an infrared imaging to identify groundwater drainages into the bayou by their thermal signatures. A Flir infrared/visible digital video camera was used to image thermal plumes and record visible images of the same fields. The sampling time was coincident with low surface water temperatures in the bayou and extreme low tides to expose the intertidal zone. Point locations displaying warm groundwater signatures as either general seepage areas or defined rivulets crossing the intertidal zone were sampled for *Enterococcus* analysis. These samples were also analyzed by a molecular source tracking method using the *Bacteroides* assay developed by Bernhard and Field (2000), which has proved to be highly specific for human fecal bacteria (Martin *et al*., in prep). In many cases, "hotspots" were sampled by digging small holes and allowing the ground water to accumulate and overflow prior to sampling. Data on septic tank and drain field placement were obtained from the public records of septic tank inspections at the Escambia County Health Department and from local residents.

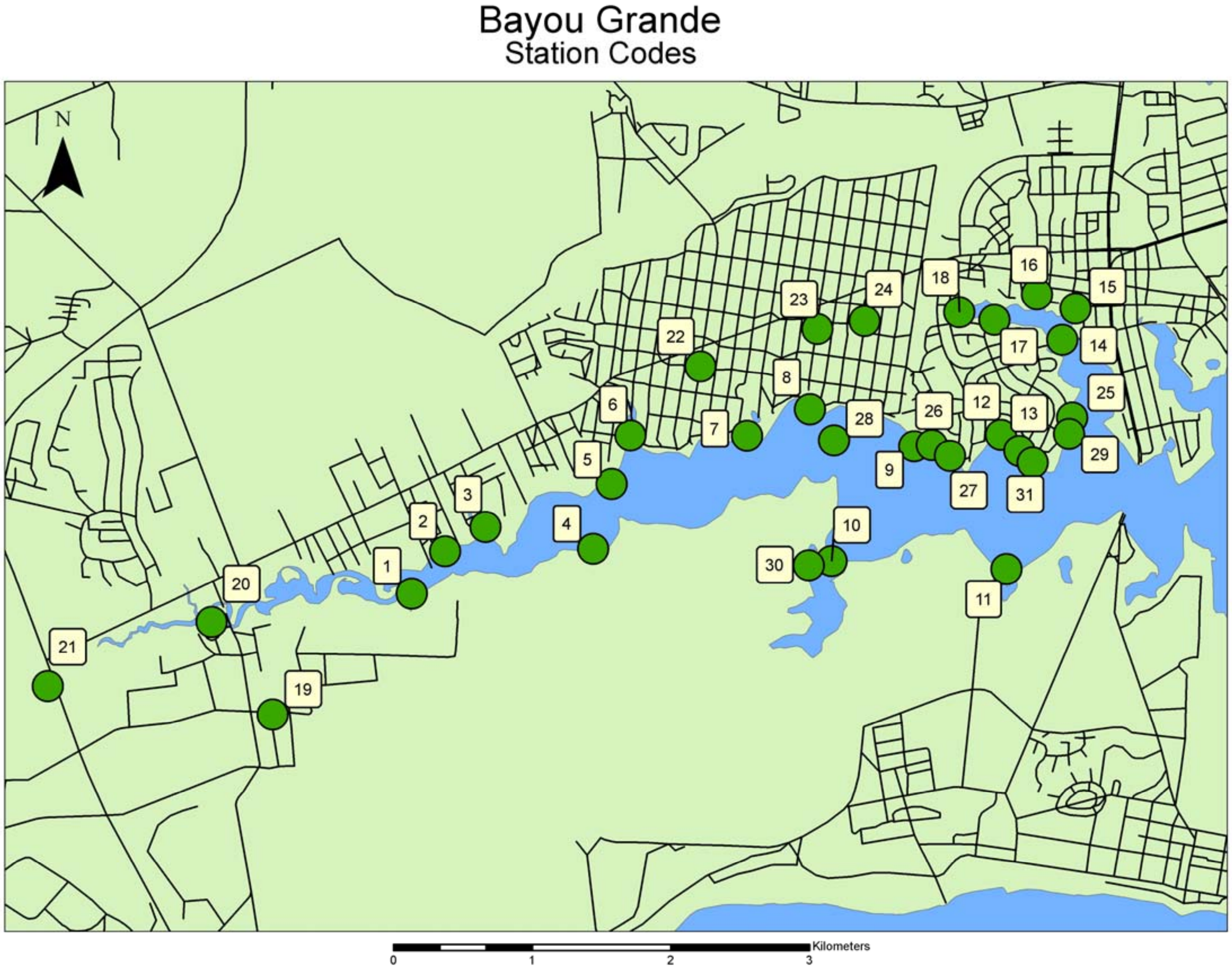

Figure 1. Sampling Station locations in Bayou Grande, FL. See Table 1 for latitude and longitude coordinates, and station descriptors.

Table 1. Station codes and coordinates for Bayou Grande sampling

Station Code	Station Name	Longitude	Latitude
1	Sherman Grove	-87.32987	30.36418
2	Kingsport Ave.	-87.32744	30.36700
3	Acapulco Camino	-87.32447	30.36866
4	Southside tributary	-87.31635	30.36742
5	Athens Ave	-87.31509	30.37168
6	Inlet at Athens	-87.31378	30.37486
7	Bremen Ave. tributary	-87.30502	30.37504
8	Bartow Ave. tributary	-87.30037	30.37686
9	Cousineau Rd. storm drain	-87.29246	30.37464
10	Southside site 2	-87.29843	30.36704
11	Golf Course drain 1	-87.28503	30.36683
12	Greve Rd. tributary	-87.28598	30.37553
13	Kalash Dr. storm drain	-87.28457	30.37454
14	Navy Point bridge (PC15)	-87.28157	30.38184
15	Oak Ave.	-87.28064	30.38389
16	Jamaica Avenue	-87.28355	30.38475
17	Syrcle sandbar	-87.28669	30.38302
18	Syrcle Dr.	-87.28936	30.38345
19	Loop Road	-87.34004	30.35609
20	Barrios Circle	-87.34481	30.36199
21	End of bayou	-87.35697	30.35754
22	Fairfield/Rentz creek	-87.30867	30.37946
23	Bartow Ave. creek	-87.29996	30.38210
24	Paulding Ave. creek	-87.29645	30.38272
25	Baublits Rd. SE storm drain	-87.28067	30.37678
26	Baublits Rd. storm drain	-87.29115	30.37475
27	Labree Rd. storm drain	-87.28975	30.37409
28	Midbayou	-87.29849	30.37490
29	Navy Point park storm drain	-87.28088	30.37571
30	Palmettos	-87.30014	30.36671
31	Payne Rd. storm drain	-87.28355	30.37380

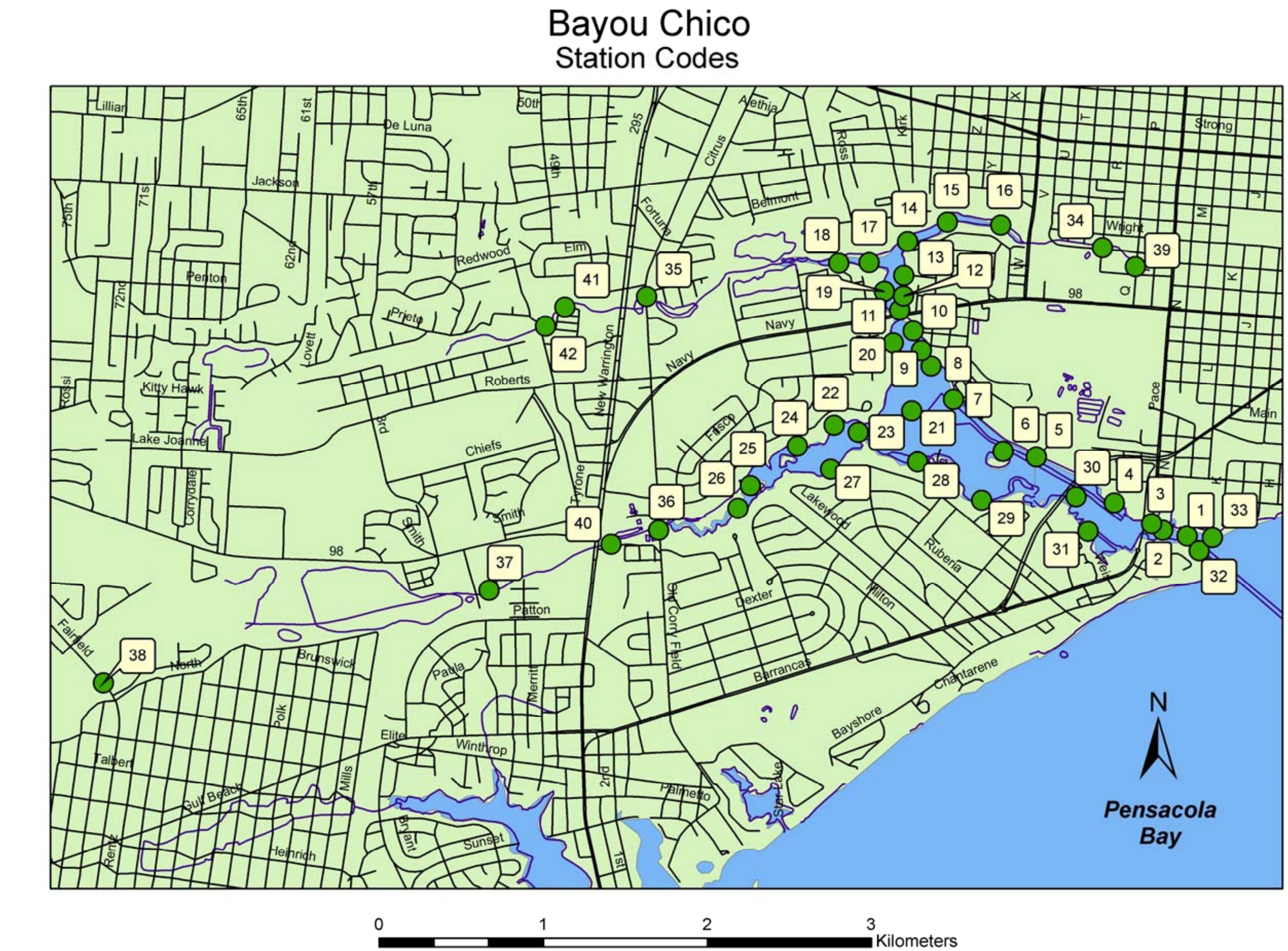

Figure 2. Sampling Station locations in Bayou Chico, FL. See Table 2 for latitude and longitude coordinates, and station descriptors.

Table 2. Stations for the analysis of fecal and nutrient loading in Bayou Chico, FL.

Station Code	Station Name	Longitude	Latitude
1	PYC Boat Ramp	-87.24021	30.39940
2	Bahia Mar Fuel Dock	-87.24176	30.39968
3	Pace Storm Drain	-87.24248	30.40003
4	Runyan's Seawall	-87.24489	30.40112
5	Scrapyard Phragmites	-87.24990	30.40353
6	Midbayou (Scrapyard/Island)	-87.25202	30.40380
7	Pensacola Shipyard A-10	-87.25526	30.40657
8	Pensacola Shipyard end	-87.25674	30.40838
9	Tressle Apartments	-87.25738	30.40922
10	Vince Whibbs GMC Storm Drain	-87.25793	30.41029
11	Navy Boulevard Bridge	-87.25882	30.41142
12	Church Fragmites	-87.25861	30.41219
13	Sawgrass at Tin Boat House	-87.25862	30.41333
14	NE Branch Mouth	-87.25843	30.41520
15	NE Branch Midway	-87.25594	30.41633
16	NE Branch East End	-87.25255	30.41624
17	NW Branch Gazebo	-87.26085	30.41398
18	NW end	-87.26277	30.41391
19	Rip Rap	-87.25983	30.41243
20	Juncus at Apartments	-87.25918	30.40960
21	Channel Marker 17	-87.25788	30.40589
22	Rope Fence	-87.26279	30.40498
23	Lakewood Park	-87.26125	30.40463
24	West Branch Cattails	-87.26509	30.40379
25	West Branch Marsh Point	-87.26801	30.40154
26	West end Last Dock	-87.26875	30.40028
27	Swamplillies at Green Roof	-87.26294	30.40256
28	Tire Pole	-87.25742	30.40308
29	Bell Marine Phragmites	-87.25329	30.40107
30	Pelican Pole	-87.24731	30.40139
31	Mahogany Landing	-87.24649	30.39951
32	Marker 10/ Pilings	-87.23941	30.39861
33	Ditch	-87.23859	30.39936
34	S-Street	-87.24606	30.41514
35	Corry Field Road North	-87.27490	30.41179
36	Corry Field Road South	-87.27374	30.39895
37	Brigadier	-87.28441	30.39540
38	Fairfield	-87.30871	30.38973
39	Q-Street	-87.24393	30.41415
40	New Warrington	-87.27674	30.39811
41	Twin Oaks Apartment	-87.28008	30.41110
42	Twin Oaks/Prieto	-87.28128	30.41002

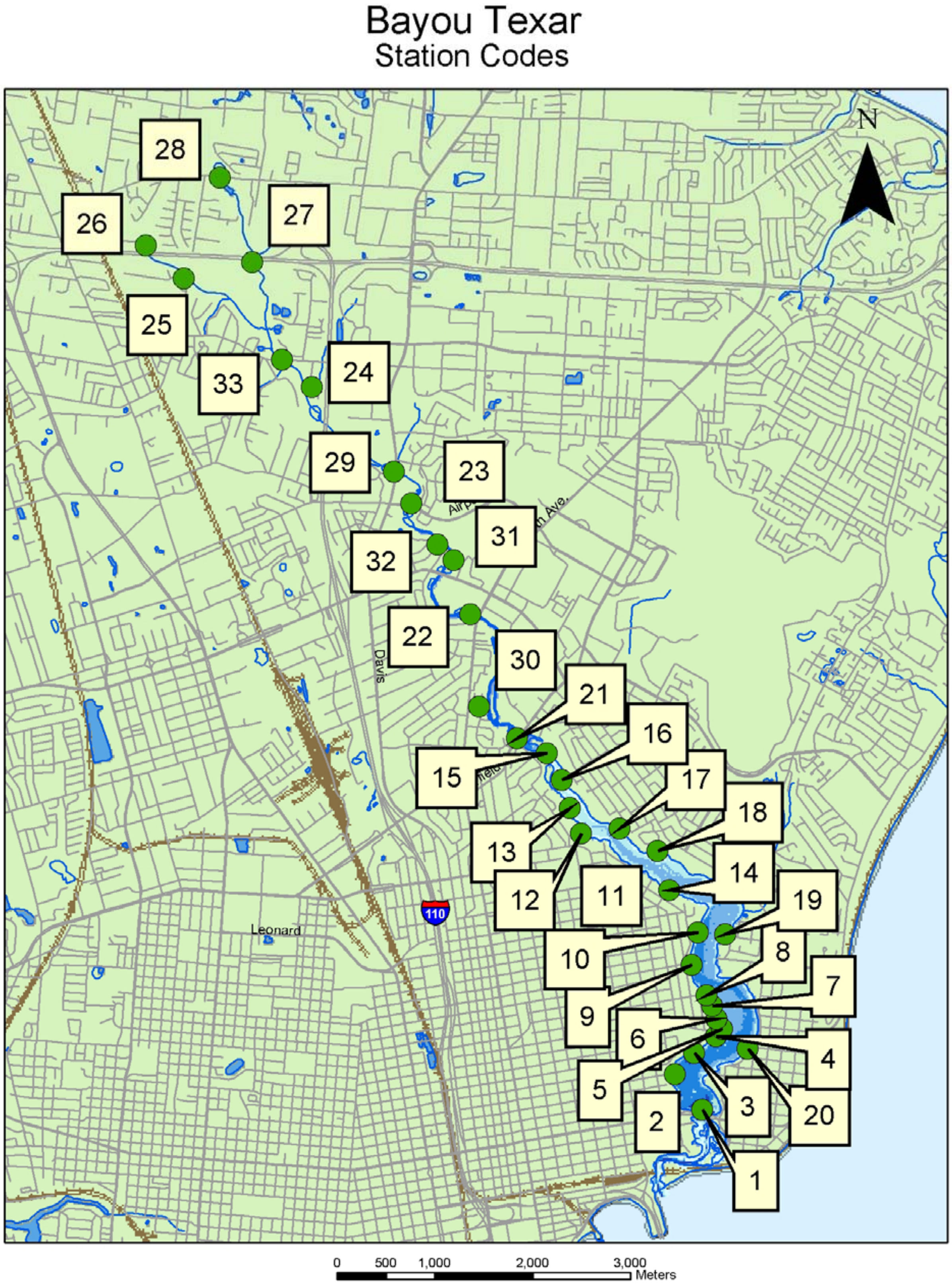

Figure 3. Sampling Station locations in Bayou Texar, FL. See Table 3 for latitude and longitude coordinates, and station descriptors.

Table 3. Stations for the analysis of fecal and nutrient loading in Bayou Texar, FL.

Station Code	Station Name	Longitude	Latitude
1	Cervantes Bridge	-87.18822	30.42641
2	Brainerd St. pond	-87.19123	30.42959
3	Bayview Park pvc/storm drain	-87.18920	30.43157
4	Tree Roots	-87.18696	30.43316
5	Boathouse (point)	-87.18630	30.43386
6	Rocks/Gazebo	-87.18692	30.43480
7	Oriental Garden	-87.18740	30.43598
8	South Whaley fragmites	-87.18806	30.43691
9	Whaley Ditch storm drain	-87.18974	30.43970
10	Birnam Woods green SD	-87.18915	30.44268
11	Blackshear Ave. SD	-87.19229	30.44652
12	Blanford place FW seep	-87.20189	30.45151
13	34th St. storm drain	-87.20311	30.45383
14	Six Cement poles-tan house	-87.19229	30.44652
15	Carpenter Creek center	-87.20573	30.45882
16	Driftwood 4 SD	-87.20410	30.45639
17	Texar Woods SD	-87.19778	30.45204
18	Seville Dr. (2) SD	-87.19367	30.45011
19	Banquos Court SD	-87.18625	30.44256
20	Bayou Blvd./Perry SD	-87.18355	30.43212
21	12th Ave. bridge	-87.20894	30.46014
22	9th Ave.	-87.21429	30.47148
23	Airport Blvd.	-87.22087	30.48151
24	Born Court	-87.23176	30.49196
25	Boiling Brook	-87.24572	30.50169
26	Sears Warehouse	-87.24985	30.50461
27	Interstate 10-Historical Dist.	-87.23848	30.50333
28	Olive Road	-87.24214	30.51103
29	Walton/Davis	-87.22278	30.48440
30	Brookside Place	-87.21309	30.46293
31	Creekside Office	-87.21623	30.47637
32	Springhill	-87.21799	30.47776
33	Burgess Road	-87.23502	30.49439

Results

Bayou Grande

For Bayou Grande, a total of 757 samples were taken over a time period from 13 December 1999 to 17 October 2001. The summary data are presented in Tables 4 and 5. Samples for Nitrate + Nitrite were processed at two separate facilities, with one reporting a higher detection limit (100 μg/L), which was reported if the samples were not above that level.

None of the physico-chemical parameters could be associated specifically with freshwater inflow to the bayou. Conservative mixing diagrams are often used to identify the behavior of substances along the mixing gradient of freshwater and marine water. In a conservative mixing event, there will be a linear decrease or increase of a substance along the gradient from a freshwater or marine source, respectively. Non-conservative behavior, i.e., non-linearities in this type of plot, indicates either sources (data points above a diagonal dilution line) or sinks (data points below a diagonal dilution line) for a substance along the salinity gradient. In this study, none of the parameters measured behaved absolutely conservatively, especially for Bayou Grande. Figure 4 shows this type of plot for Phosphate. The slope of this line is not significantly different from zero, resulting from samples being below the detection limit for analysis, diffuse sources along the salinity gradient, and/or sediment buffering, as is common for estuaries. Figure 5 shows the analysis for Enterococci. This fecal contamination indicator does not show conservative behavior, indicating that their origin is from diffuse sources along the salinity gradient and not specifically from the freshwater origins of the bayou. Using correlation analysis with the entire dataset (with appropriate transformations for normality), none of the parameters measured were predictive of fecal bacteria concentrations within the system. The only factors showing correlation greater than 70% were variations on the fecal indicators themselves and not between fecal indicators and environmental parameters.

The inability of standard statistical methods applied to the entire dataset to determine fecal contamination concentration patterns within the bayou leads to different ways of viewing the data. Geospatial plotting is a powerful tool in visually determining geographic correlations and loading points that are obscured in traditional statistical approaches. Figures 6-9 show the dataset represented in this fashion using Arcview GIS. Figure 6 displays the distribution of mean Phosphate values, and Figure 7 displays the mean Biological Oxygen Demand (BOD) values for all stations in Bayou Grande. Figure 8 shows the geomean data for *Enterococcus* at each station in the bayou. The high geomean areas for this fecal contamination indicator are found in the wetlands and ditch that parallels Gulf Beach Highway, the upper part of the branch north of Navy Point, and the west end of the Bayou. It is instructive to recognize that the high concentration samples were recovered from developed areas along the northern half of the Bayou drainage basin, whereas relatively low counts were recovered from the open Bayou shoreline and along the undeveloped southern shore. The contrast accounts for mobile sources of fecal contamination that would occur throughout the bayou such as wildlife (raccoons, waterfowl, gulls, etc.). Indeed, wildlife densities would be conceivably higher along the NAS shoreline where less disturbance from human activity would occur. Some non-human mobile sources, however, such as domestic/feral waterfowl fed by waterfront homeowners, gulls attracted to anthropogenic food sources, and dog feces in yards may counter if not overwhelm any contributions by wildlife in undeveloped areas.

Table 4. Physico-chemical water quality measures from Bayou Grande sampling.

Station Name	Sta. code	Temp	std	pH	std	Salinity ppt	std	DO mg/L	std	BOD mg/L	CV	$NO_{3/2}$ µg/L	CV	TP mg/L	CV
Sherman Grove	1	22.89	6.85	7.24	0.43	19.51	7.43	6.91	1.36	2.33	1.67	57.44	0.16	0.103	0.07
Kingsport Ave.	2	23.55	6.63	7.52	0.33	21.03	6.96	7.35	1.52	2.50		100		0.070	
Acapulco Camino	3	23.15	7.06	7.47	0.38	21.84	6.59	6.97	2.05	1.51	0.30	40.32	0.17	0.098	0.04
Southside tributary	4	22.38	7.2	7.56	0.46	20.04	8.92	7.95	1.52						
Athens Ave	5	23.14	6.74	7.67	0.32	22.91	6.17	7.81	1.34	2.32		100		0.070	
Inlet at Athens	6	23.35	6.52	7.53	0.39	22.32	6.86	7.41	1.6	1.92		100		0.090	
Bremen Ave. tributary	7	23.58	6.59	7.76	0.27	23.55	5.71	7.69	1.41	1.51		100		0.070	
Bartow Ave. tributary	8	23.33	6.71	7.71	0.37	22.96	6.24	7.78	1.42	1.96		100		0.070	
Cousineau Rd. SD	9	23.55	6.76	7.91	0.24	23.73	5.89	8.02	1.39	2.05		100		0.080	
Southside site 2	10	23.02	6.71	7.8	0.26	22.96	5.85	7.87	1.42						
Golf Course drain 1	11	22.67	7.11	7.77	0.28	22.15	6.22	8.13	1.24	1.75		100		0.060	
Greve Rd. tributary	12	24.08	6.62	7.84	0.28	22.62	6.49	7.95	1.48						
Kalash Dr. storm drain	13	23.83	6.51	7.9	0.24	23.01	6.48	8.12	1.49						
Navy Pt bridge (PC15)	14	23.63	7.2	7.89	0.28	22.88	6.32	8.29	1.3	1.94		100		0.080	
Oak Ave.	15	24.03	6.77	7.79	0.24	22.71	6.28	8.07	1.43	2.20	0.63	45.52	0.19	0.105	0.05
Jamaica Avenue	16	24.1	6.58	7.78	0.25	22.52	7.25	7.92	1.45	2.24		100		0.070	
Syrcle sandbar	17	24.03	7	7.88	0.17	23.43	6.63	8.08	1.42	2.05		100		0.070	
Syrcle Dr.	18	24.22	7.14	7.57	0.4	20.01	8.87	8.07	1.5	1.54		100		0.070	
Loop Road	19	22.54	5.49	6.24	0.92	0.02	0.05	7.94	1.06	2.95	0.42	65.45	0.18	0.142	0.05
Barrios Circle	20	26.21	7.53	6.79	0.52	11.08	7.53	7.06	2.14						
End of bayou	21	20.45	6.07	5.85	0.98	0.11	0.31	6.67	2.47	3.20		100		0.070	
Fairfield/Rentz creek	22	20.23	6.18	5.66	1.2	0.09	0.23	3.03	1.7	3.42	0.84	63.72	0.21	0.123	0.15
Bartow Ave. creek	23	19.83	5.34	6.04	0.91	0.04	0.05	4.97	1.51	2.64		100		0.090	
Paulding Ave. creek	24	20	5.17	5.72	1.17	0.03	0.05	4.07	1.5	1.78		100		0.090	
Baublits Rd. SE SD	25	24.11	6.88	7.88	0.28	22.52	6.63	8.34	1.25						
Baublits Rd. storm drain	26	23.77	6.64	7.85	0.31	23.37	6.06	7.95	1.51						
Labree Rd. storm drain	27	23.88	6.69	7.86	0.27	23.35	5.95	8	1.36						
Midbayou	28	23.22	6.52	7.85	0.76	23.66	12.6	7.99	2.17	1.72		100		0.070	
Navy Pt park SD	29	24.08	7	7.9	0.31	22.57	6.73	13.1	17.7						
Palmettos	30	23.4	6.73	7.81	0.24	22.2	6.32	7.73	1.58						
Payne Rd. storm drain	31	23.75	6.76	7.89	0.33	23	6.44	8.32	1.41						

Table 5. Summary fecal indicator data from Bayou Grande sampling.

station name	station code	Entero GeoMean	Entero CV	Entero Max	Entero Min	Fecal Geomean	Fecal CV	Fecal Max	Fecal Min
Sherman Grove	1	42.11	0.44	2830	2	68.32	0.33	4400	20
Kingsport Ave.	2	45.96	0.41	230	4	836.52	0.29	9000	20
Acapulco Camino	3	78	0.39	6560	4	471.67	0.35	9000	20
Southside tributary	4	15.49	0.5	300	1	149.36	0.33	1700	20
Athens Ave	5	12.53	0.67	170	1	139.55	0.37	1700	20
Inlet at Athens	6	26.82	0.52	1700	1	265.45	0.36	3000	20
Bremen Ave. tributary	7	9.35	0.71	130	1	47.27	0.23	170	20
Bartow Ave. tributary	8	22.2	0.57	490	1	187.27	0.36	1300	20
Cousineau Rd. storm drain	9	6.09	0.7	56	1	10.5		1	1
Southside site 2	10	7	0.66	52	1	1.45	0.26	589	20
Golf Course drain 1	11	19.88	0.61	500	1	58.57	0.24	500	20
Greve Rd. tributary	12	20.64	0.47	240	1				
Kalash Dr. storm drain	13	7.5	0.94	2000	1				
Navy Point bridge (PC15)	14	10.57	0.57	230	1	91.9	0.27	800	20
Oak Ave.	15	75.59	0.42	9000	11	1198.95	0.29	16000	20
Jamaica Avenue	16	39.54	0.41	2210	3	681.82	0.35	9000	20
Syrcle sandbar	17	16.6	0.57	600	1	811.36	0.38	16000	20
Syrcle Dr.	18	67.39	0.38	3000	4	482.73	0.31	3000	20
Loop Road	19	50.62	0.37	1300	1	235.24	0.32	2400	20
Barrios Circle	20	43.15	0.33	230	4	868.64	0.29	9000	20
End of bayou	21	45.07	0.35	500	4	301.5	0.36	1700	20
Fairfield/Rentz creek	22	115.76	0.26	600	13	1984	0.39	16000	20
Bartow Ave. creek	23	111.86	0.31	1210	19	879.41	0.36	9000	20
Paulding Ave. creek	24	257.09	0.21	1520	20	2758.18	0.31	16000	20
Baublits Rd. SE storm drain	25	4.24	1.22	200	1				
Baublits Rd. storm drain	26	7.7	0.87	880	1				
Labree Rd. storm drain	27	9.04	0.86	280	1				
Midbayou	28	4.3	0.97	28	1	28.23	0.28	130	1
Navy Point park storm drain	29	3.8	1.14	102	1				
Palmettos	30	5.29	0.83	44	1	56.67	0.26	500	20
Payne Rd. storm drain	31	6.2	1.07	2000	1				

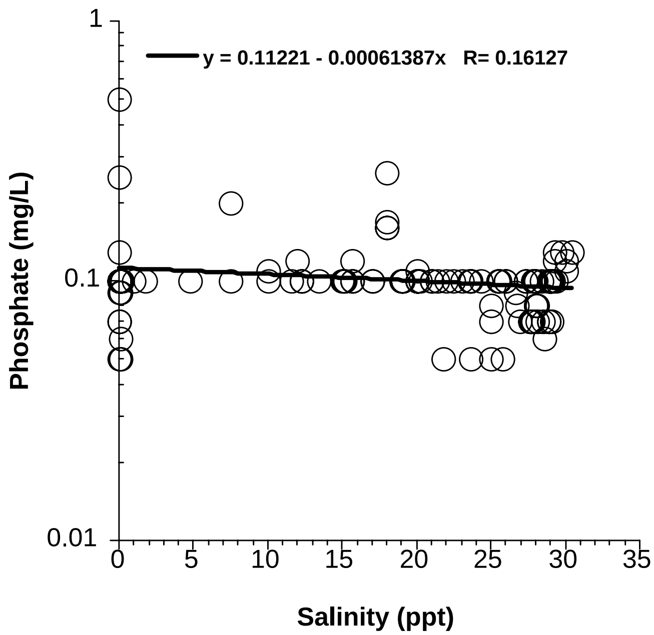

Figure 4. Conservative mixing diagram for Total Phosphate in Bayou Grande.

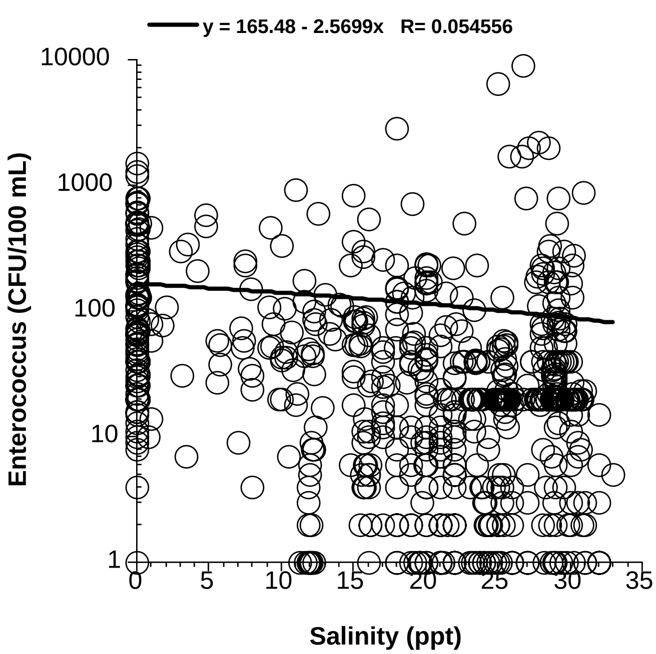

Figure 5. Conservative mixing diagram for *Enterococcus* in Bayou Grande.

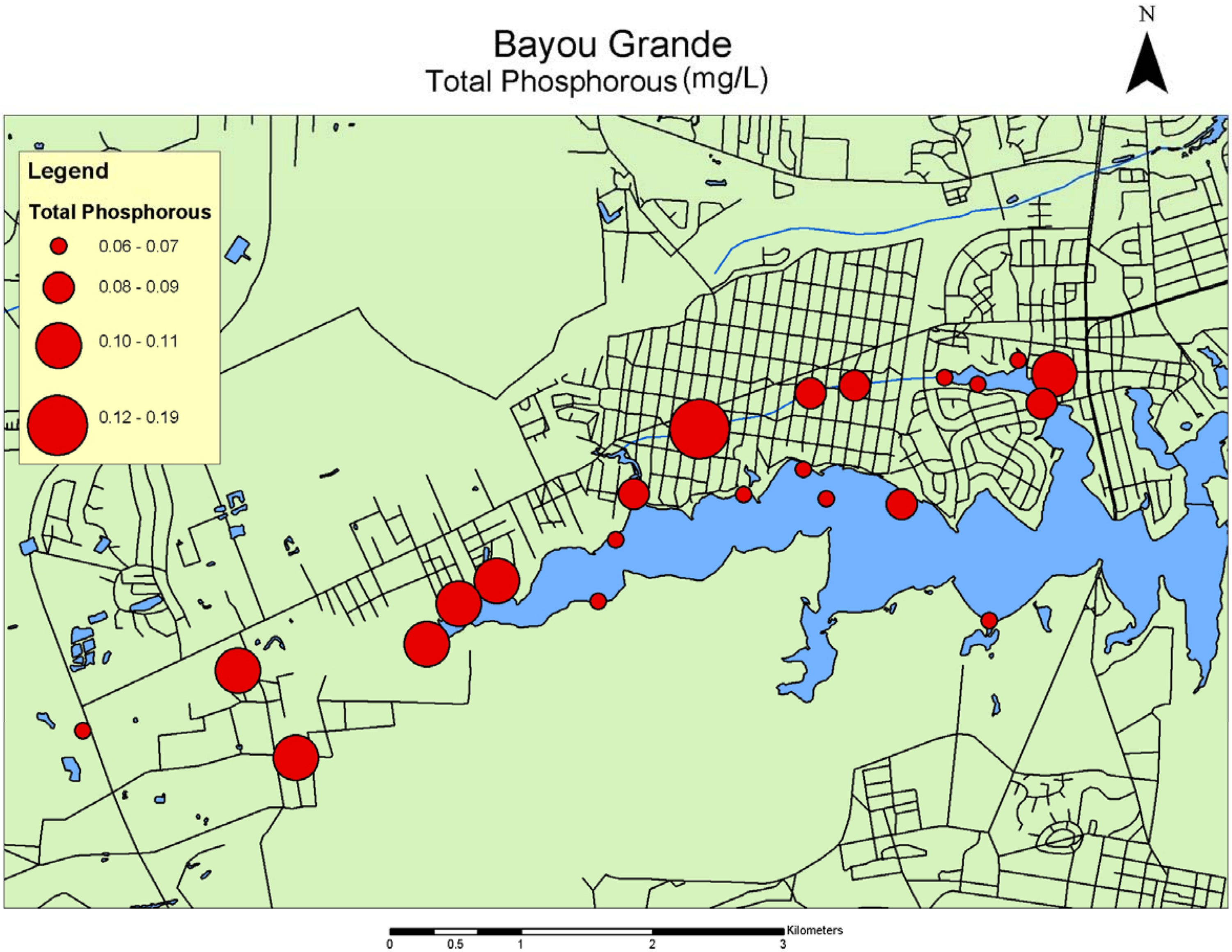

Figure 6. Distribution of mean Phosphate values from Bayou Grande Stations.

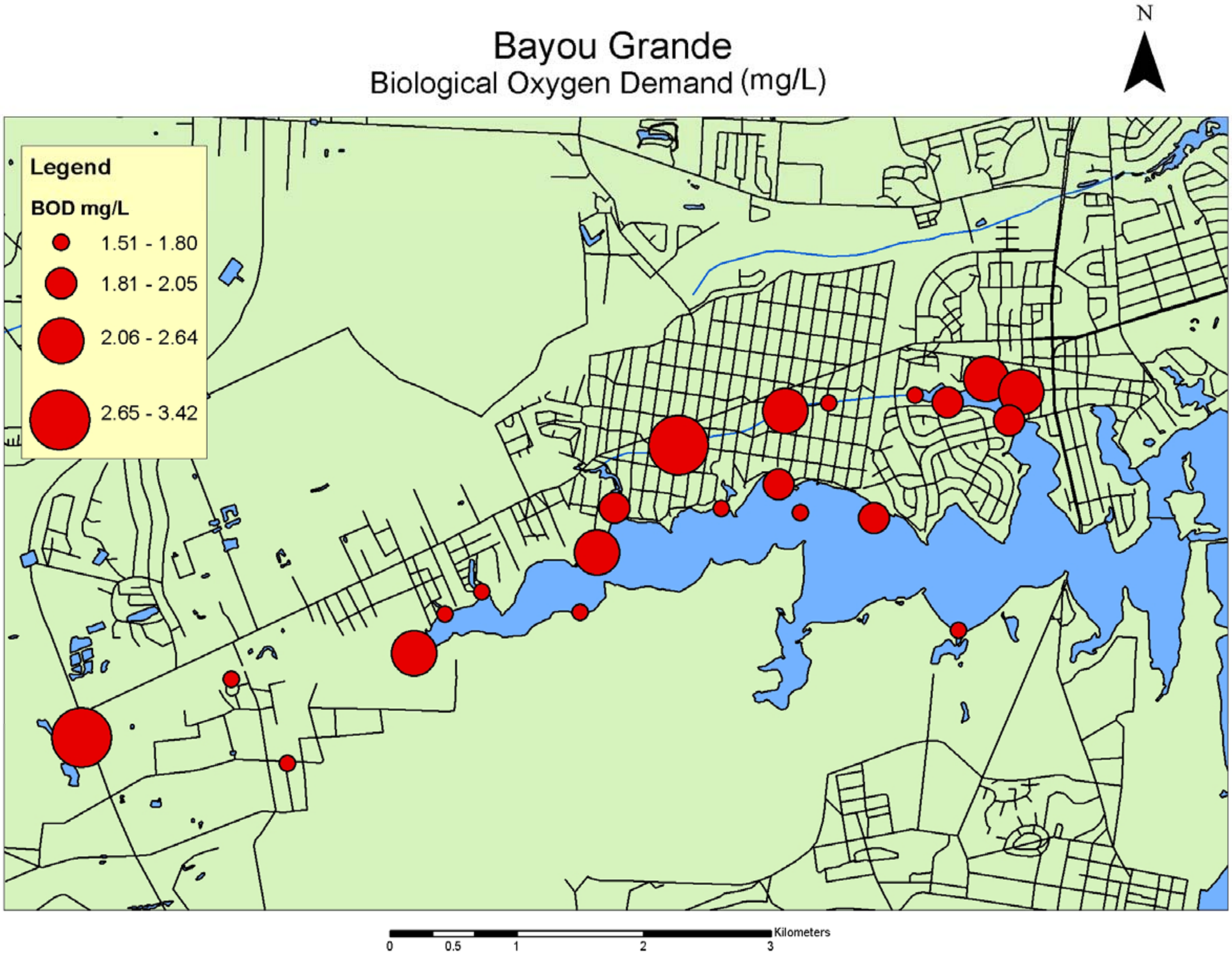

Figure 7. Distribution of mean BOD values from Bayou Grande Stations.

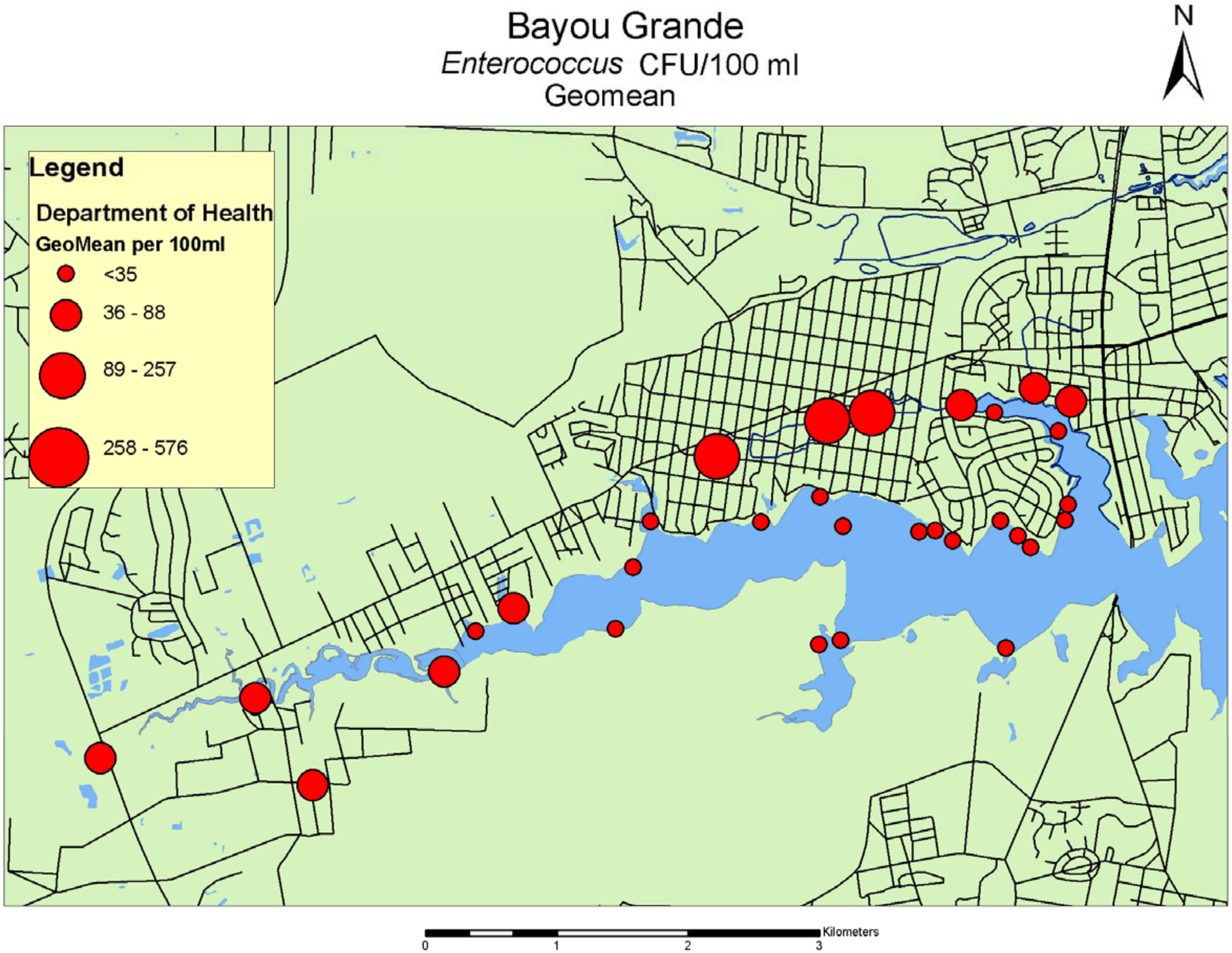

Figure 8. Distribution of the geomean of *Enterococcus* counts from Bayou Grande Stations.

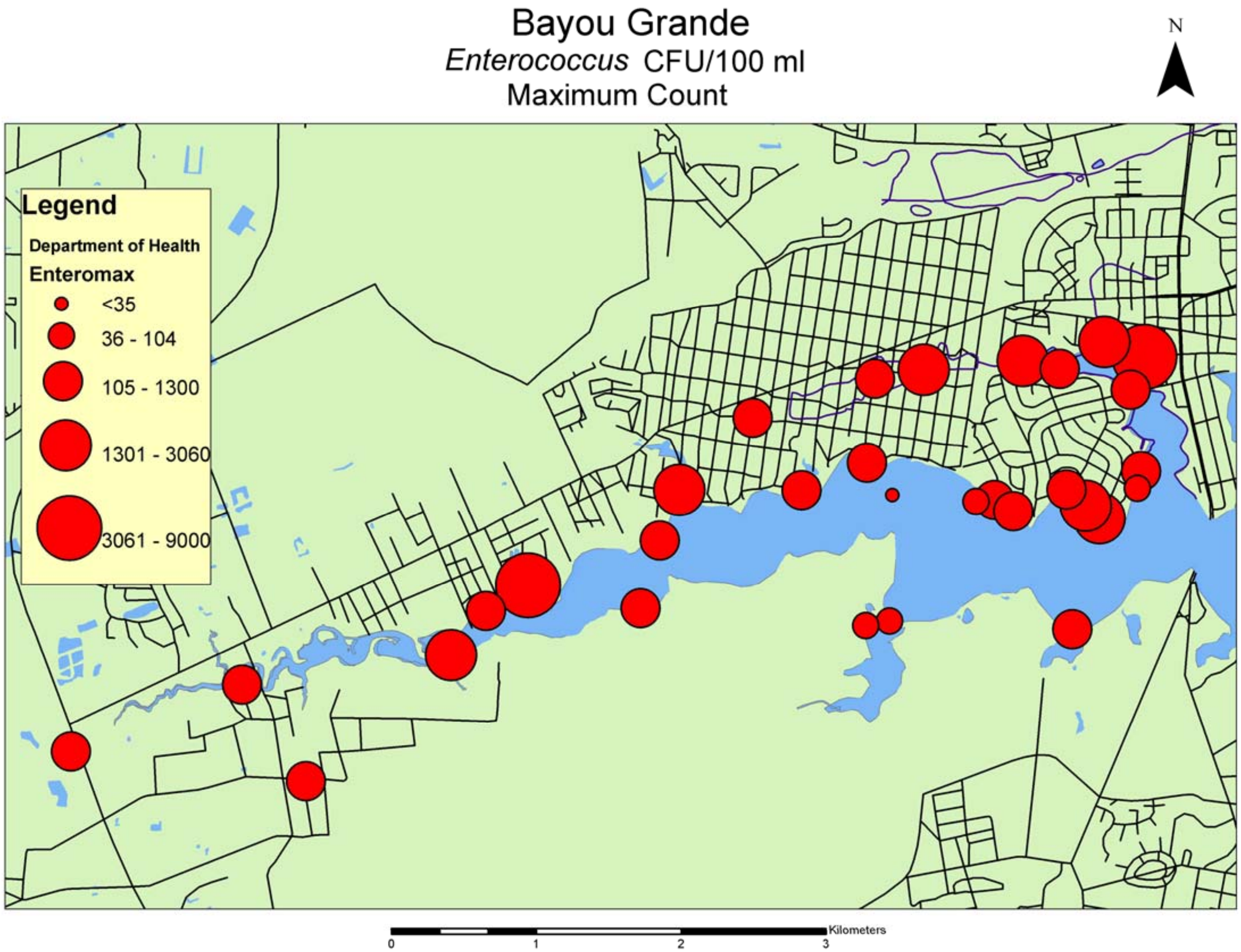

Figure 9. Distribution of the maximum of *Enterococcus* counts from Bayou Grande Stations.

Chronic impact areas would be displayed on a plot of minimum *Enterococcus* numbers recorded. For Bayou Grande, none of the minimum recorded values were above the regulatory threshold of a 30 day geomean greater than 35 CFU/100 ml or the 104 CFU/100 ml single sample maximum. The maximum *Enterococcus* numbers (Figure 9) would reflect rain effects on groundwater flow and episodic loading perhaps more relatable to waterfowl or storm water runoff, especially where high maximum values do not correspond to high Geomeans or minimum values. Included in this category would be stations Kalash Dr. storm drain and Payne Rd. storm drain. Highest values of Phosphate and BOD were associated spatially with the high *Enterococcus* geomeans. While variance in the overall dataset prevents these patterns from emerging with traditional statistics, they are apparent visually in the GIS plots.

Analysis of the observed fecal contamination dependence on rainfall provides some additional insights. Analysis of the entire data set (Figure 10), while not providing any statistically significant models, shows high levels of fecal contamination occurring in times of no rainfall. It also indicates that the highest levels of fecal bacteria and the highest variance in system-wide fecal loadings are found following moderate rainfall events (<1"), while a large rainstorm results lower fecal bacteria counts and lower system-wide variance, presumably due to dilution and mixing with storm events.

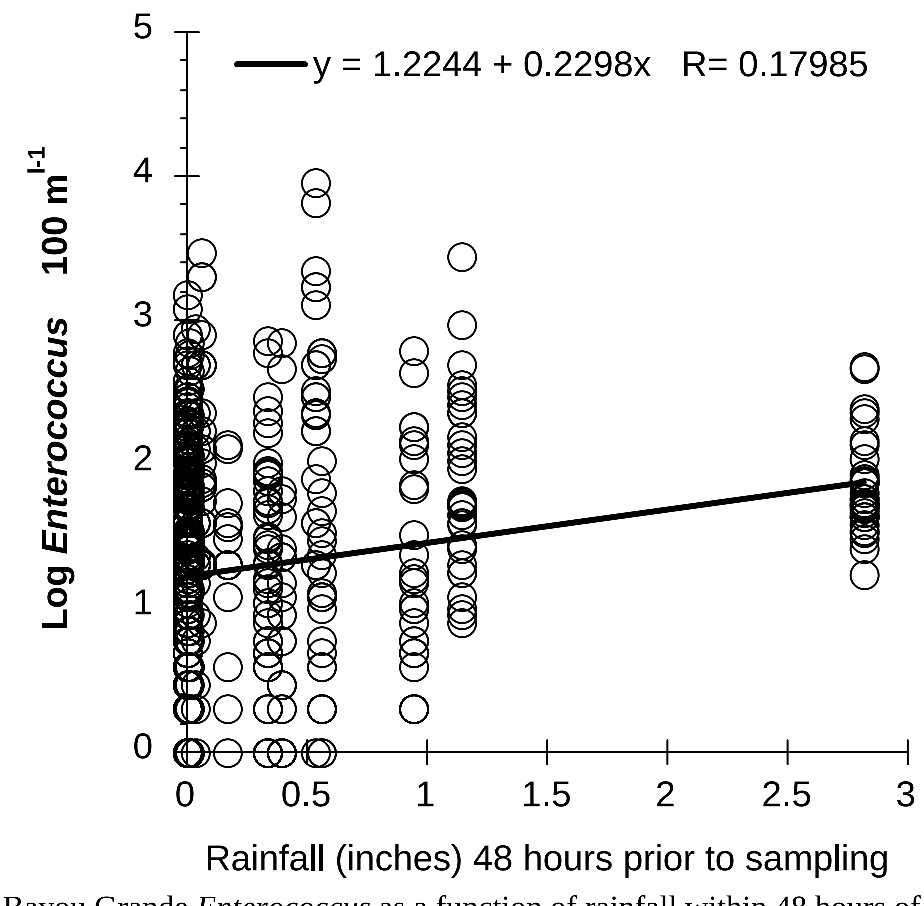

Figure 10. Bayou Grande *Enterococcus* as a function of rainfall within 48 hours of sampling.

Given the spatially explicit loading patterns found with the GIS analysis and the variance response seen in Figure 10, the dependence of fecal contamination as a function of rainfall was tested for each station. Data associated with rainfall greater than 1.6 " 48 hours prior to sampling was excluded, as this level of disturbance appears to homogenize the spatial specificity of loadings throughout the system (Figure 10). Two parameters are important outcomes of this analysis. The y-intercept estimate of linear regressions of Log *Enterococcus* as a function of rainfall provides a geomean of *Enterococcus* values for all sampling times with zero rain within the previous 48 hours. This value is indicative of groundwater loading or diffuse, non-storm water sources such as waterfowl. The slope estimates of these functions indicate rainfall influence on *Enterococcus* numbers. Positive slope values indicate increased fecal loading with rainfall as storm water runoff or rain infiltration and enhanced ground water flow. Negative slopes indicate dilution of fecal contamination by rainfall. Because of the high variability in fecal numbers, and the use of these data as relative indicators, a p value of 0.06 was chosen as a threshold of significance for this analysis. Even so, non-significant relationships are still valid as visualization tools in defining trends at the various stations, as outlined below. Some of the variability in counts may be ascribed to tidal mixing and displacement of contamination from its source.

The regression parameters are listed in Table 6. All of the y-intercept estimates are significant, while only two stations' data yielded significant (different from zero) rain effect slope estimates. One of these, station 4, Southside Tributary, had a decline in contamination with increasing rain (negative slope). The other, Station 16 Jamaica Avenue, had contamination significantly increased by moderate rainfall. The lack of other significant effects is due to some combination of high variance, the preponderance of data at zero rainfall, and a real result that rain had little or no impact on contamination levels at these stations.

Despite the low R^2 values, the resulting graphs are valuable as visualization tools, and are included in this report (Figure 11). A high y-intercept and flat (horizontal) or negative slope would be indicative of ground water loading and either a lack of storm water contribution, a storm water contribution that is of the same magnitude (flat) or less (negative by dilution) than the groundwater. A low y-intercept and steep slope would indicate little if any ground water contribution and loading mainly from storm water sources or storm water redistribution of contamination.

The slope values are presented spatially in Figure 12. Geomeans of *Enterococcus* counts for zero rainfall sampling events (y-intercept estimates) are plotted spatially in Figure 13. This GIS analysis clearly shows the impact of contaminated groundwater in the heavily developed area surrounding the creek/ditch stations Fairfield/Rentz Creek, Bartow Avenue, and Paulding Avenue Creek, and the lack of such loading in other areas of the bayou. This analysis provides a better indication of chronically impacted sites than the minimum recorded values from all samples that would be impacted more by mixing and dilution.

Table 6. Regression analysis of Bayou Grande station data as a function of rainfall < 2 inches 48 hours prior to sampling. . Significant parameter estimates ($p < 0.06$) are indicated in bold

Station Code	Station name	R^2	Slope	p-value	Intercept	p-value	geomean @zero rain
1	Sherman Grove	0.072	0.592	0.239	**1.485**	**2.25E-07**	**30.559**
2	Kingsport Ave.	0.073	-0.446	0.264	**1.483**	**1.99E-08**	**30.426**
3	Acapulco Camino	0.110	0.695	0.142	**1.646**	**1.60E-08**	**44.239**
4	Southside tributary	0.139	-0.681	0.096	**1.322**	**4.36E-08**	**20.971**
5	Athens Ave	0.000	0.045	0.926	**1.037**	**2.75E-05**	**10.886**
6	Inlet at Athens	0.022	0.315	0.523	**1.302**	**1.36E-06**	**20.039**
7	Bremen Ave. tributary	0.000	-0.010	0.982	**0.922**	**5.08E-05**	**8.358**
8	Bartow Ave. tributary	0.031	0.410	0.448	**1.232**	**9.24E-06**	**17.073**
9	Cousineau Rd. storm drain	0.011	0.167	0.649	**0.708**	**7.03E-05**	**5.106**
10	Southside site 2	0.007	0.141	0.726	**0.824**	**3.87E-05**	**6.672**
11	Golf Course drain 1	0.020	0.337	0.549	**1.208**	**2.69E-05**	**16.127**
12	Greve Rd. tributary	0.074	0.511	0.246	**1.205**	**6.99E-07**	**16.036**
13	Kalash Dr. storm drain	0.001	0.067	0.910	**0.828**	**1.55E-03**	**6.731**
14	Navy Point bridge (PC15)	0.001	-0.041	0.918	**0.991**	**6.66E-06**	**9.798**
15	Oak Ave.	0.099	0.656	0.165	**1.766**	**5.33E-09**	**58.349**
16	**Jamaica Avenue**	**0.276**	**1.059**	**0.014**	**1.362**	**3.34E-08**	**23.027**
17	Syrcle sandbar	0.007	-0.177	0.719	**1.234**	**2.93E-06**	**17.147**
18	Syrcle Dr.	0.101	0.673	0.159	**1.689**	**1.32E-08**	**48.858**
19	Loop Road	0.026	0.311	0.483	**1.628**	**9.96E-09**	**42.501**
20	Barrios Circle	0.003	0.087	0.821	**1.602**	**1.53E-09**	**39.990**
21	End of bayou	0.082	0.505	0.209	**1.535**	**4.07E-09**	**34.310**
22	Fairfield/Rentz creek	0.000	-0.029	0.942	**2.066**	**3.14E-10**	**116.416**
23	Bartow Ave. creek	0.013	0.199	0.679	**2.034**	**1.35E-07**	**108.047**
24	Paulding Ave. creek	0.000	0.032	0.929	**2.404**	**4.33E-13**	**253.451**
25	Baublits Rd. SE storm drain	0.104	0.711	0.166	**0.429**	**3.43E-02**	**2.687**
26	Baublits Rd. storm drain	0.026	-0.377	0.495	**0.929**	**2.75E-04**	**8.493**
27	Labree Rd. storm drain	0.011	0.255	0.667	**0.870**	**1.03E-03**	**7.410**
28	Midbayou	0.002	-0.079	0.853	**0.622**	**1.24E-03**	**4.191**
29	Navy Point park storm drain	0.029	0.326	0.469	**0.465**	**1.27E-02**	**2.914**
30	Palmettos	0.014	-0.204	0.619	**0.718**	**1.88E-04**	**5.229**
31	Payne Rd. storm drain	0.056	0.596	0.316	**0.628**	**1.05E-02**	**4.249**

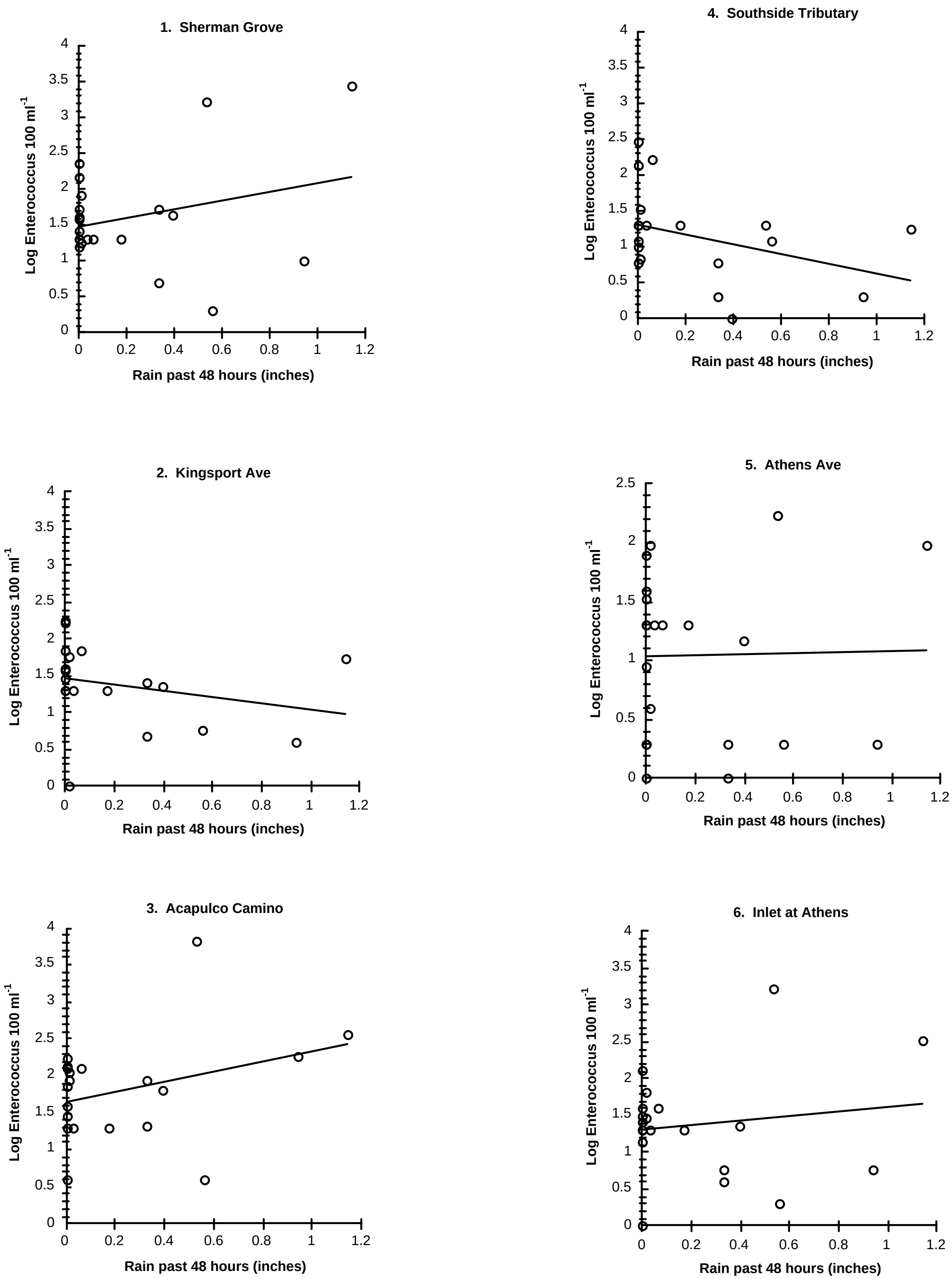

Figure 11. Station-specific analysis of rainfall dependence in Bayou Grande.

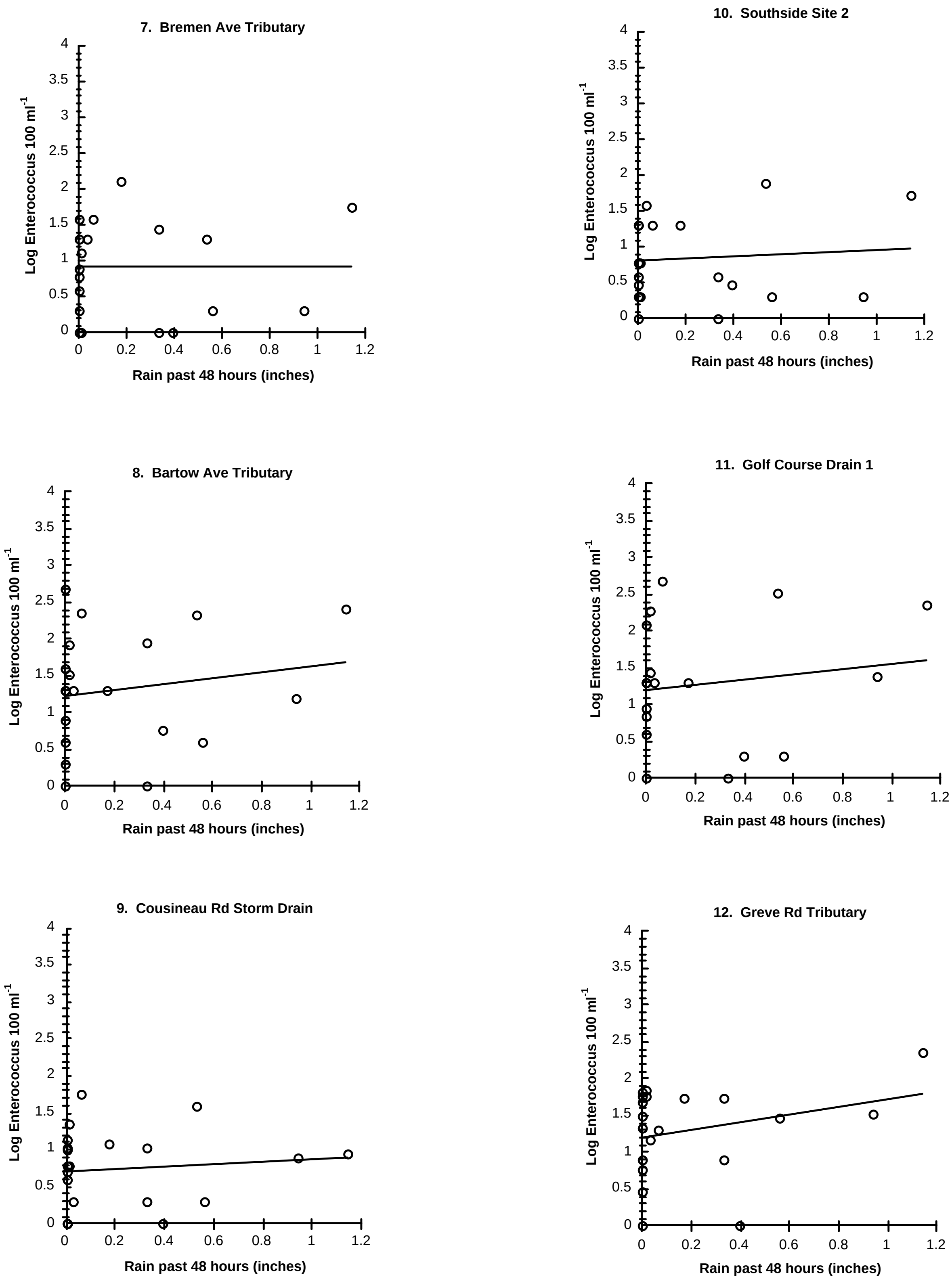

Figure 11. Station-specific analysis of rainfall dependence in Bayou Grande, continued.

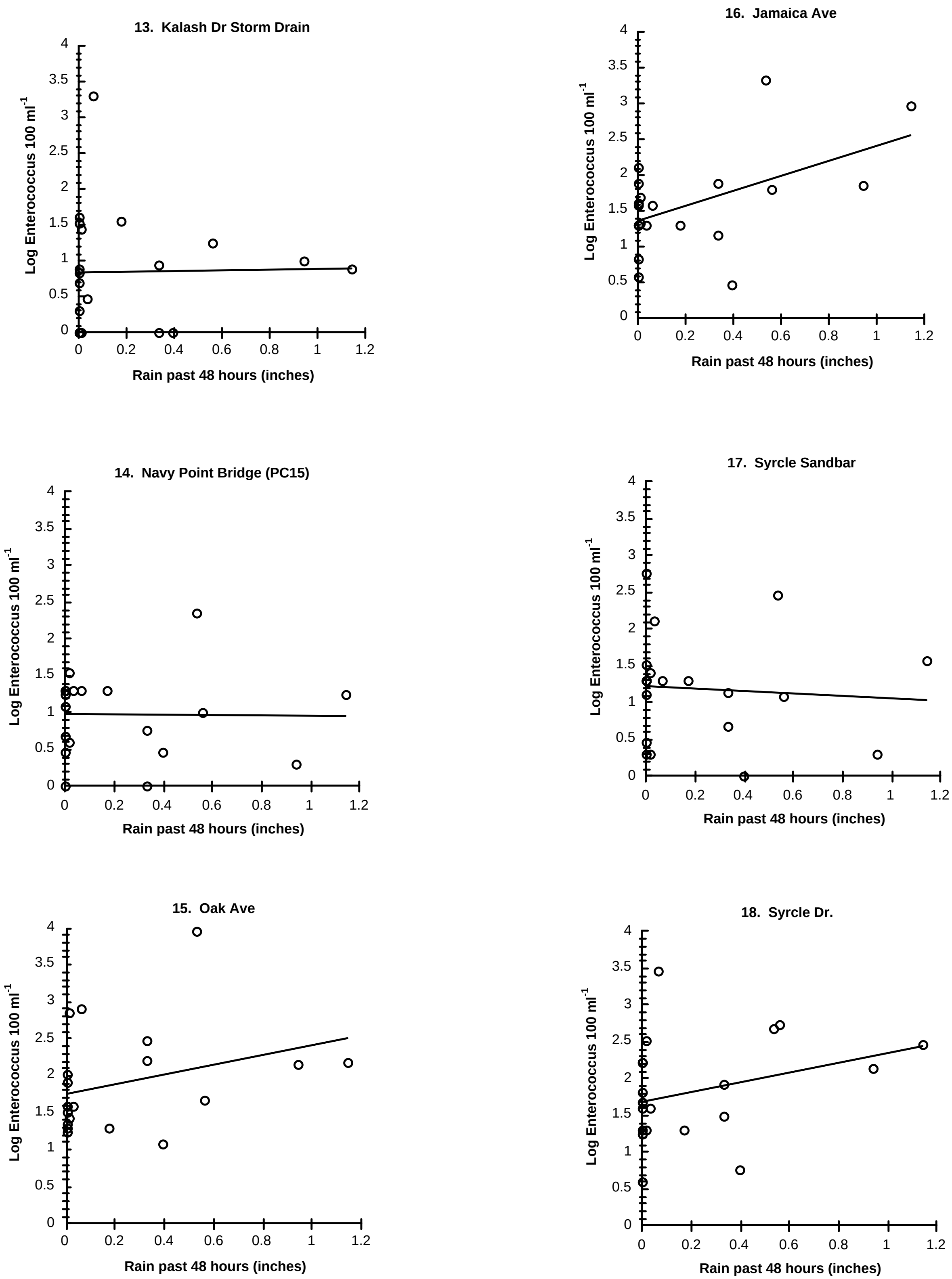

Figure 11. Station-specific analysis of rainfall dependence in Bayou Grande, continued.

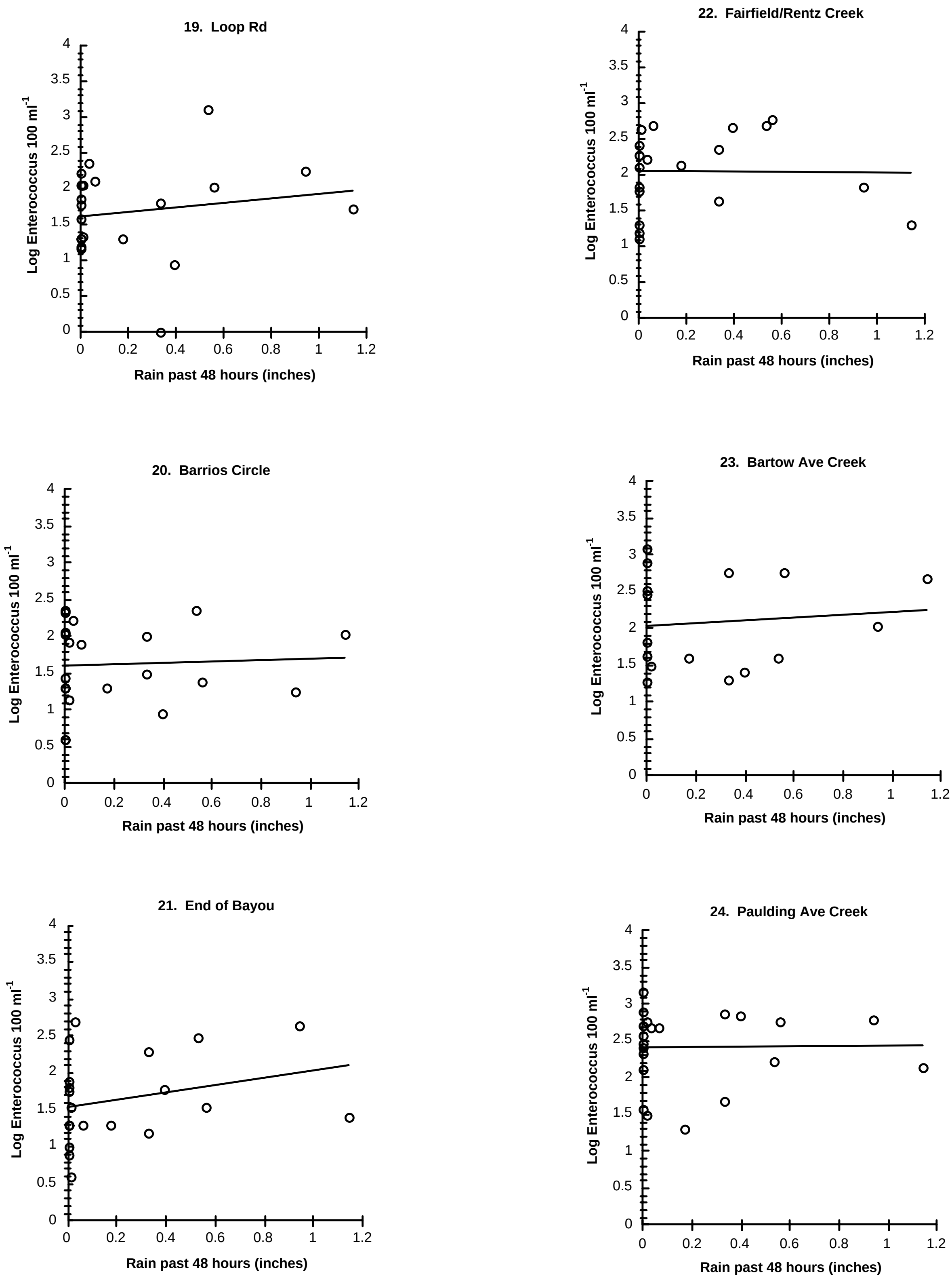

Figure 11. Station-specific analysis of rainfall dependence in Bayou Grande, continued.

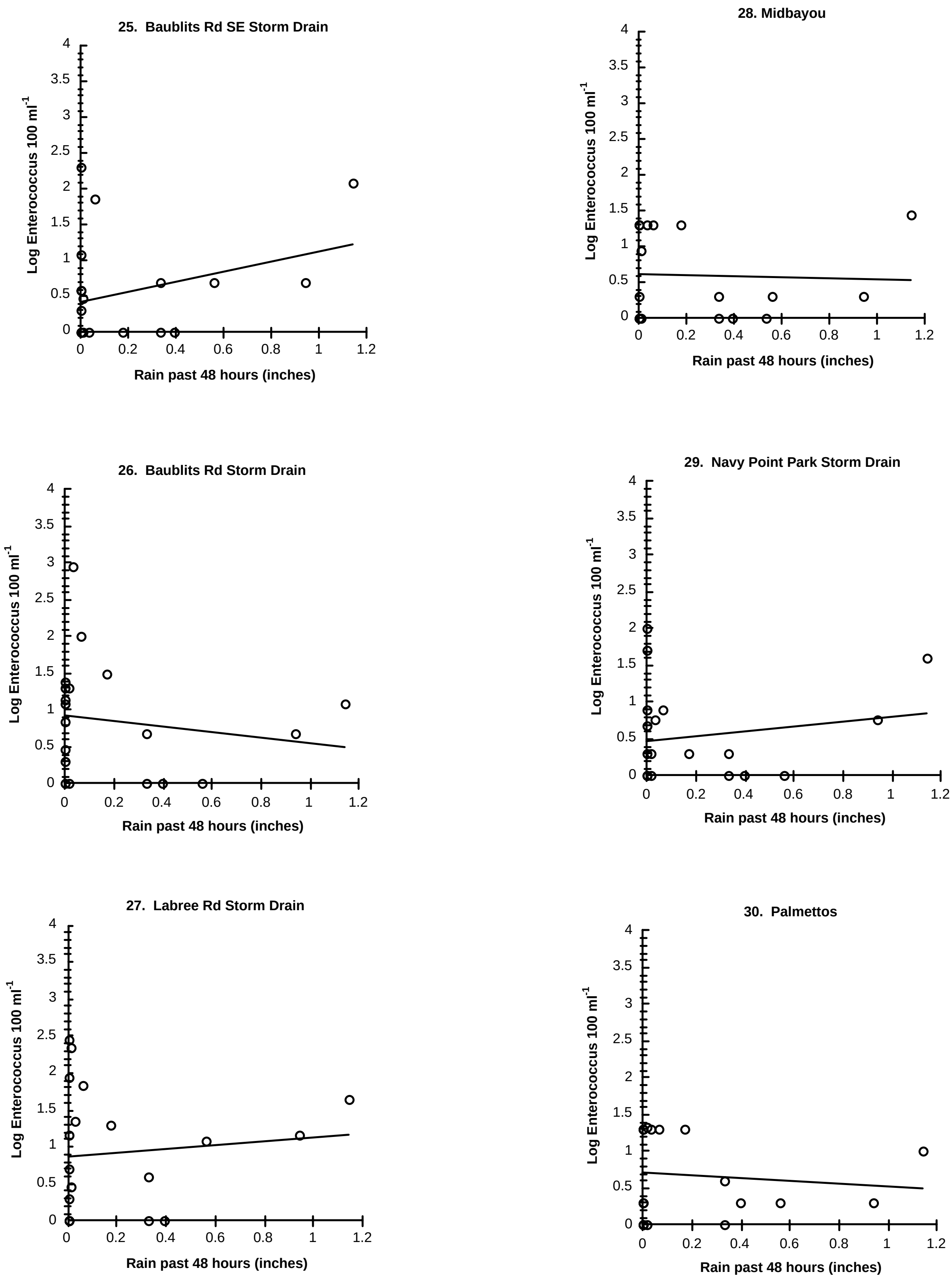

Figure 11. Station-specific analysis of rainfall dependence in Bayou Grande, continued.

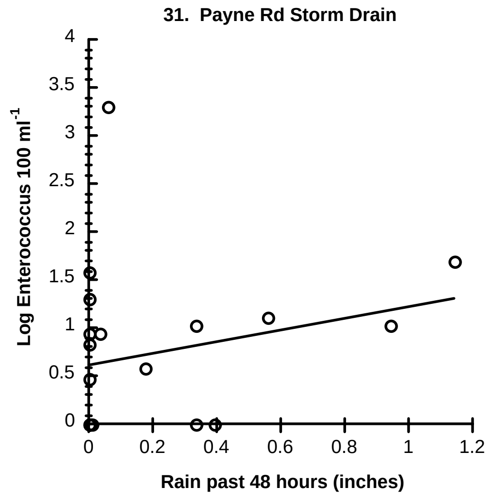

Figure 11. Station-specific analysis of rainfall dependence in Bayou Grande, concluded.

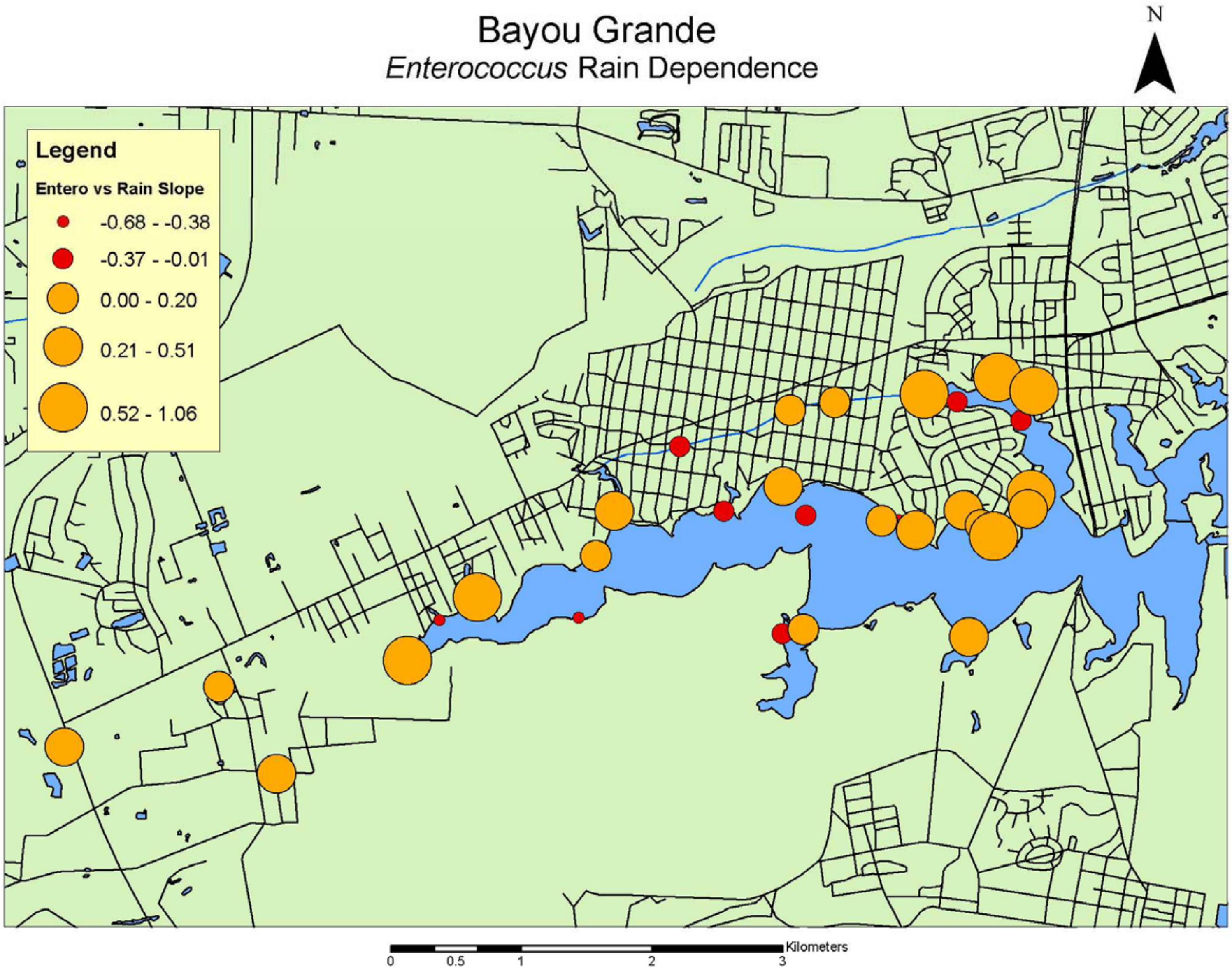

Figure 12. Slope values from station-specific regression analysis for Bayou Grande

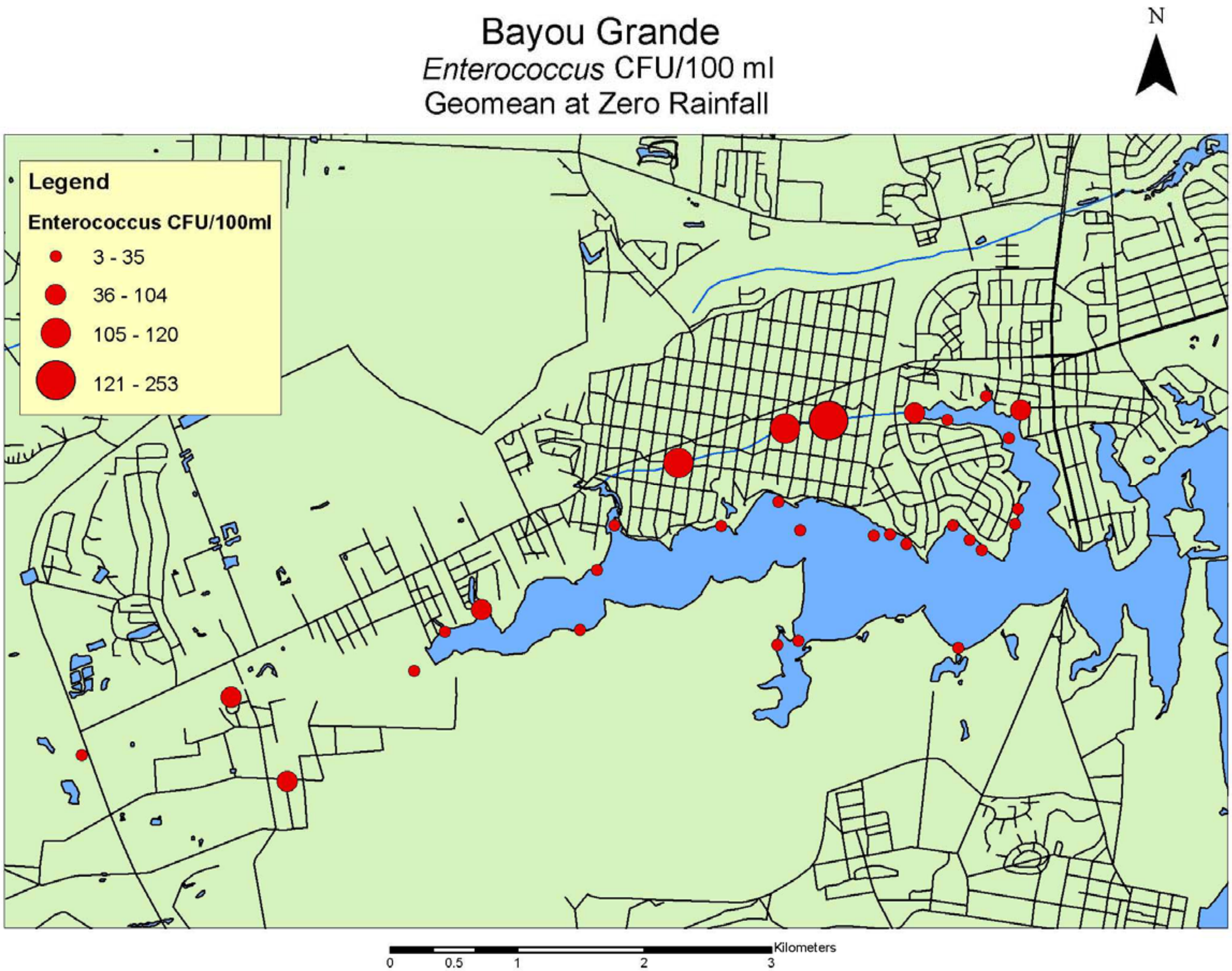

Figure 13. Geomeans of *Enterococcus* at zero rainfall for Bayou Grande estimated as y-intercepts from Regression analysis..

Bayou Chico

A total of 893 samples were taken over a time period from 14 November 2001 to 30 December 2003. The summary data are presented in Tables 7 & 8.

None of the parameters measured behaved absolutely conservatively, i.e., were diluted from a freshwater source along the salinity gradient in the bayou, although trends are apparent in the data. Figure 14 shows these plots for Nitrate + Nitrite and Phosphate. The nitrogen species appear to be loaded to the system from freshwaters, with a decline towards the bayou mouth and higher salinity. Phosphate, however, shows the opposite trend, suggesting the system may be phosphate limited, and phosphate is drawn into the system from the open bay. Geographic patterns of these data are shown in Figure 15 (Nitrate+Nitrite), Figure 16 (Phosphate), and Figure 17 (biological oxygen demand; BOD).

A conservative mixing analysis of *Enterococcus* counts indicates a stronger freshwater origin for fecal contamination in this system (Figure 18), unlike Bayou Grande, where no relationship of fecal concentrations to salinity was observed.

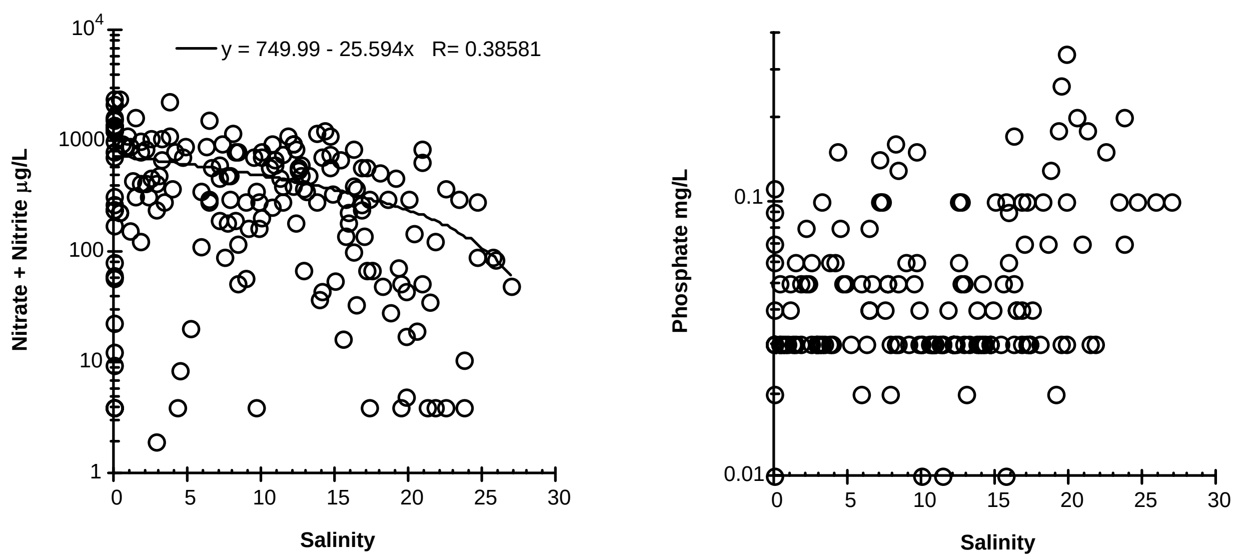

Figure 14. Conservative mixing diagrams for nitrogen and phosphorous in Bayou Chico.

Table 7. Physico-chemical water quality measures from Bayou Chico sampling.

site_ID	Site_Description	Temp	std	pH	std	Salinity ppt	std	DO mg/L	std	BOD mg/L	CV	$NO_{3/2}$ µg/L	CV	TP mg/L	CV
1	PYC Boat Ramp	21.77	6.28	7.67	0.35	17.06	7.12	7.24	1.27						
2	Bahia Mar Fuel Dock	21.74	6.37	7.67	0.34	16.58	7.16	7.20	1.12						
3	Pace Storm Drain	21.89	6.45	7.67	0.34	16.36	7.02	7.31	1.13						
4	Runyan's Seawall	21.86	6.58	7.66	0.34	16.57	7.17	7.11	1.07						
5	Scrapyard Fragmites	22.12	6.43	7.61	0.42	16.12	7.21	7.29	1.05						
6	Midbayou (Scrapyard/Island)	22.23	6.37	7.65	0.44	15.90	7.19	7.58	0.97						
7	Pensacola Shipyard A-10	22.62	6.31	7.60	0.44	16.28	7.14	7.08	1.19						
8	Pensacola Shipyard end	22.80	6.40	7.57	0.44	16.51	7.05	6.81	1.33						
9	Tressle Apartments	22.56	6.37	7.47	0.41	12.82	5.97	7.96	2.03	5.14		111.22		0.027	
10	Vince Whibbs GMC Storm Drain	22.66	6.21	7.43	0.42	13.12	5.97	7.70	1.79						
11	Navy Boulevard Bridge	22.92	5.88	7.28	0.38	11.86	6.41	7.67	2.18	1.63	1.139	301.05	0.218	0.051	0.287
12	Church Fragmites	23.18	5.94	7.24	0.41	12.11	6.42	7.86	2.18						
13	Sawgrass at Tin Boat House	23.50	5.74	7.24	0.44	12.03	6.38	7.44	1.76	1.41	1.662	421.17	0.162	0.028	0.269
14	NE Branch Mouth	23.63	5.46	7.17	0.41	12.50	6.66	7.34	2.15						
15	NE Branch Midway	23.41	5.82	7.00	0.37	11.25	7.35	6.27	2.09	2.39	1.024	484.15	0.154	0.050	0.252
16	NE Branch East End	23.38	5.70	6.76	0.32	9.89	7.07	4.96	1.71						
17	NW Branch Gazebo	23.68	5.70	7.09	0.45	10.91	5.88	7.37	2.20	2.33	0.540	614.26	0.154	0.040	0.192
18	NW end	23.54	5.42	6.99	0.41	9.48	6.23	6.36	1.66	2.33	0.615	315.29	0.276	0.054	0.280
19	Rip Rap	23.61	6.03	7.27	0.47	12.06	6.11	8.03	1.85	2.37	0.568	362.71	0.137	0.032	0.150
20	Juncus at Apartments	23.21	6.17	7.38	0.45	12.29	6.09	8.10	2.08	1.77	0.957	244.46	0.232	0.047	0.257
21	Channel Marker 17	23.13	6.58	7.68	0.49	16.25	6.93	7.96	1.05	1.23	3.889	73.91	0.125	0.067	0.302
22	Rope Fence	23.08	6.16	7.52	0.56	14.60	7.76	7.50	1.65						
23	Lakewood Park	22.93	6.41	7.55	0.58	14.65	7.43	7.74	1.31						
24	West Branch Cattails	23.42	6.15	7.42	0.55	14.37	8.07	7.20	1.48						
25	West Branch Marsh Point	23.28	5.80	7.24	0.61	10.94	7.24	6.54	1.83			426.40	0.028	0.032	0.281
26	West end Last Dock	25.19	4.35	7.13	0.65	10.52	6.33	6.07	1.81	2.32	0.373	72.04	0.409	0.055	0.355
27	Swamplillies at Green Roof	23.35	6.52	7.46	0.68	14.05	7.76	7.67	1.54						
28	Tire Pole	23.45	6.65	7.55	0.51	15.40	7.41	7.61	1.18						
29	Bell Marine Fragmites	22.52	6.83	7.62	0.46	15.42	7.24	7.83	1.09						
30	Pelican Pole	22.56	6.79	7.67	0.42	16.06	7.17	7.60	1.02						
31	Mahogany Landing	22.24	6.96	7.66	0.38	16.00	7.00	7.47	1.13	1.29	2.009	53.02	0.418	0.051	0.295
32	Marker 10/ Pilings	22.26	6.59	7.78	0.34	17.40	7.29	7.54	1.41						
33	Ditch	22.13	4.07	7.33	0.55	7.59	9.81	6.86	1.57	2.28	0.500	1760.21	0.061	0.030	0.000
34	S-Street	24.21	4.06	6.64	0.31	0.00	0.00	5.22	2.30	3.66	0.462	549.71	0.100	0.037	0.244
35	Corry Field Road North	22.17	4.03	6.93	0.40	0.05	0.05	5.49	1.67	1.81		1314.40		0.030	
36	Corry Field Road South	21.97	5.07	6.42	0.45	2.32	4.78	4.84	1.56	1.88	0.113	202.62	0.095	0.026	0.102
37	Brigadier	21.66	4.97	5.71	0.56	0.00	0.00	4.50	1.57	1.20	5.326	39.05	0.272	0.032	0.426

Table 7, continued. Physico-chemical water quality measures from Bayou Chico sampling.

site_ID	Site_Description	Temp	std	pH	std	Salinity ppt	std	DO mg/L	std	BOD mg/L	CV	$NO_{3/2}$ µg/L	CV	TP mg/L	CV
38	Fairfield	20.91	5.79	5.11	1.15	0.00	0.00	2.88	2.03	1.79	0.145	6.77	0.409	0.024	0.213
39	Q-Street	24.62	2.47	6.71	0.07	0.00	0.00	3.63	1.06	0.85	6.610	1331.82	0.012	0.030	0.000
40	New Warrington	23.15	3.30	6.51	0.56	0.05	0.10	5.01	1.13	3.35	0.615	224.42	0.044	0.036	0.128
41	Twin Oaks Apartment	21.66	5.05	6.92	0.28	0.00	0.00	6.41	2.83	2.17	0.405	1441.27	0.016	0.041	0.185
42	Twin Oaks/Prieto	20.46	4.71	6.99	0.11	0.00	0.00	8.15	2.02	1.81		2252.10		0.030	

Table 8. Summary fecal indicator data from Bayou Chico sampling.

site_ID	Site_Description	Geomean Entero	CV	entero min	entero max
1	PYC Boat Ramp	23.58	0.427	2	510
2	Bahia Mar Fuel Dock	26.30	0.426	4	640
3	Pace Storm Drain	34.68	0.411	2	400
4	Runyan's Seawall	12.59	0.544	2	270
5	Scrapyard Fragmites	21.79	0.444	2	450
6	Midbayou (Scrapyard/Island)	14.56	0.478	2	310
7	Pensacola Shipyard A-10	14.54	0.561	2	950
8	Pensacola Shipyard end	16.27	0.402	2	132
9	Tressle Apartments	64.90	0.302	14	940
10	Vince Whibbs GMC Storm Drain	66.18	0.329	6	1440
11	Navy Boulevard Bridge	93.05	0.379	10	4080
12	Church Fragmites	88.64	0.340	20	4260
13	Sawgrass at Tin Boat House	102.46	0.363	8	2600
14	NE Branch Mouth	96.29	0.333	6	5220
15	NE Branch Midway	144.02	0.322	10	6790
16	NE Branch East End	146.76	0.288	22	4370
17	NW Branch Gazebo	116.81	0.289	8	6380
18	NW end	146.47	0.292	16	5460
19	Rip Rap	45.69	0.442	2	2310
20	Juncus at Apartments	24.50	0.505	2	1020
21	Channel Marker 17	11.28	0.611	2	1080
22	Rope Fence	18.25	0.492	2	320
23	Lakewood Park	14.65	0.439	2	202
24	West Branch Cattails	20.16	0.396	2	126
25	West Branch Marsh Point	58.19	0.366	2	1130
26	West end Last Dock	59.32	0.325	4	790
27	Swamplillies at Green Roof	27.49	0.419	2	600
28	Tire Pole	28.44	0.381	2	329
29	Bell Marine Fragmites	24.35	0.436	2	280
30	Pelican Pole	22.38	0.473	2	271
31	Mahogany Landing	20.62	0.453	2	220
32	Marker 10/ Pilings	11.59	0.625	2	580
33	Ditch	201.53	0.305	2	3990
34	S-Street	429.14	0.136	74	1260
35	Corry Field Road North	407.54	0.203	0	2950
36	Corry Field Road South	179.92	0.211	8	2400
37	Brigadier	159.39	0.225	10	1380
38	Fairfield	45.72	0.310	4	600
39	Q-Street	329.76	0.162	80	1010
40	New Warrington	156.73	0.209	58	450
41	Twin Oaks Apartment	445.82	0.094	240	960
42	Twin Oaks/Prieto	376.29	0.110	132	600

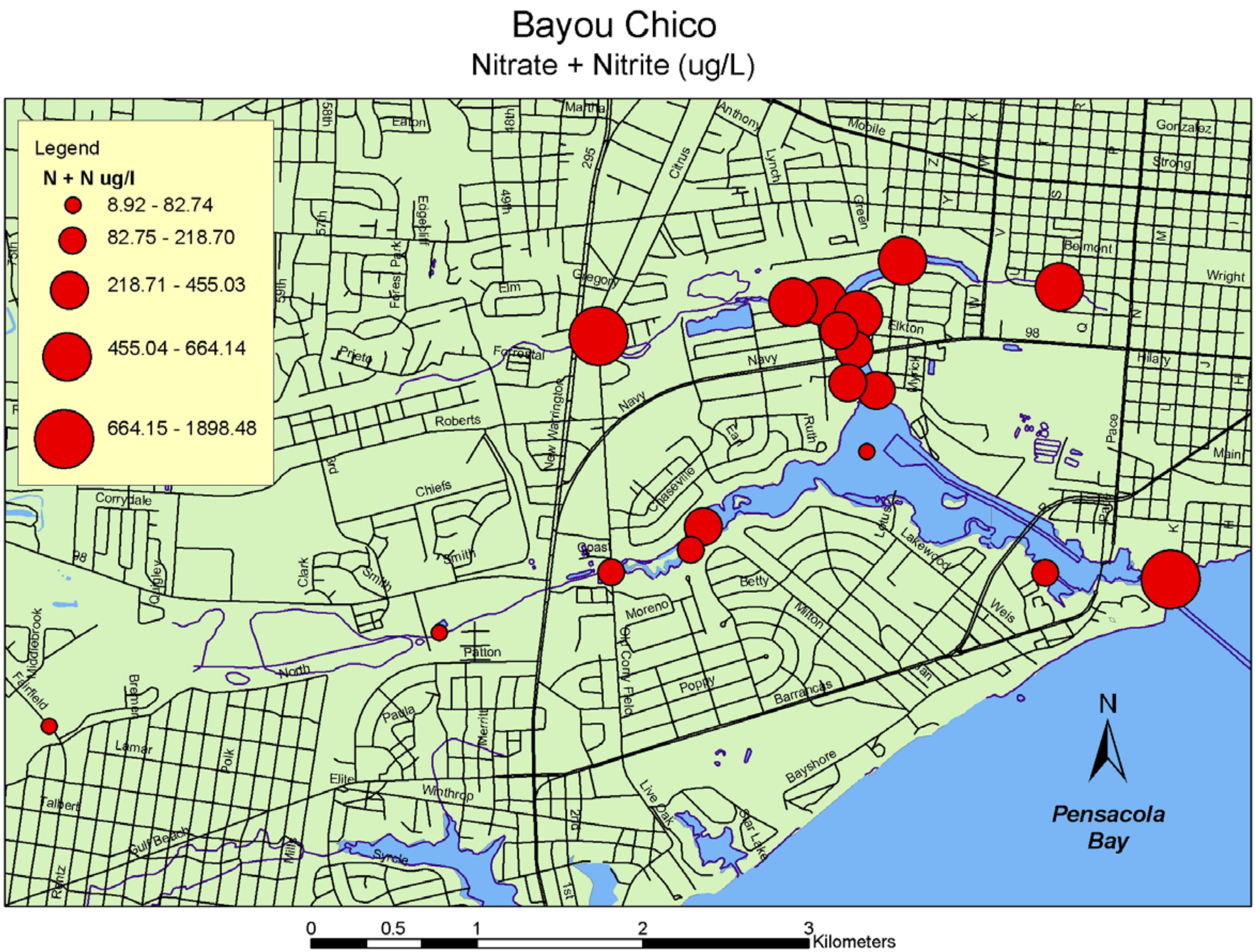

Figure 15. Mean Nitrate+Nitrite values for Bayou Chico station data.

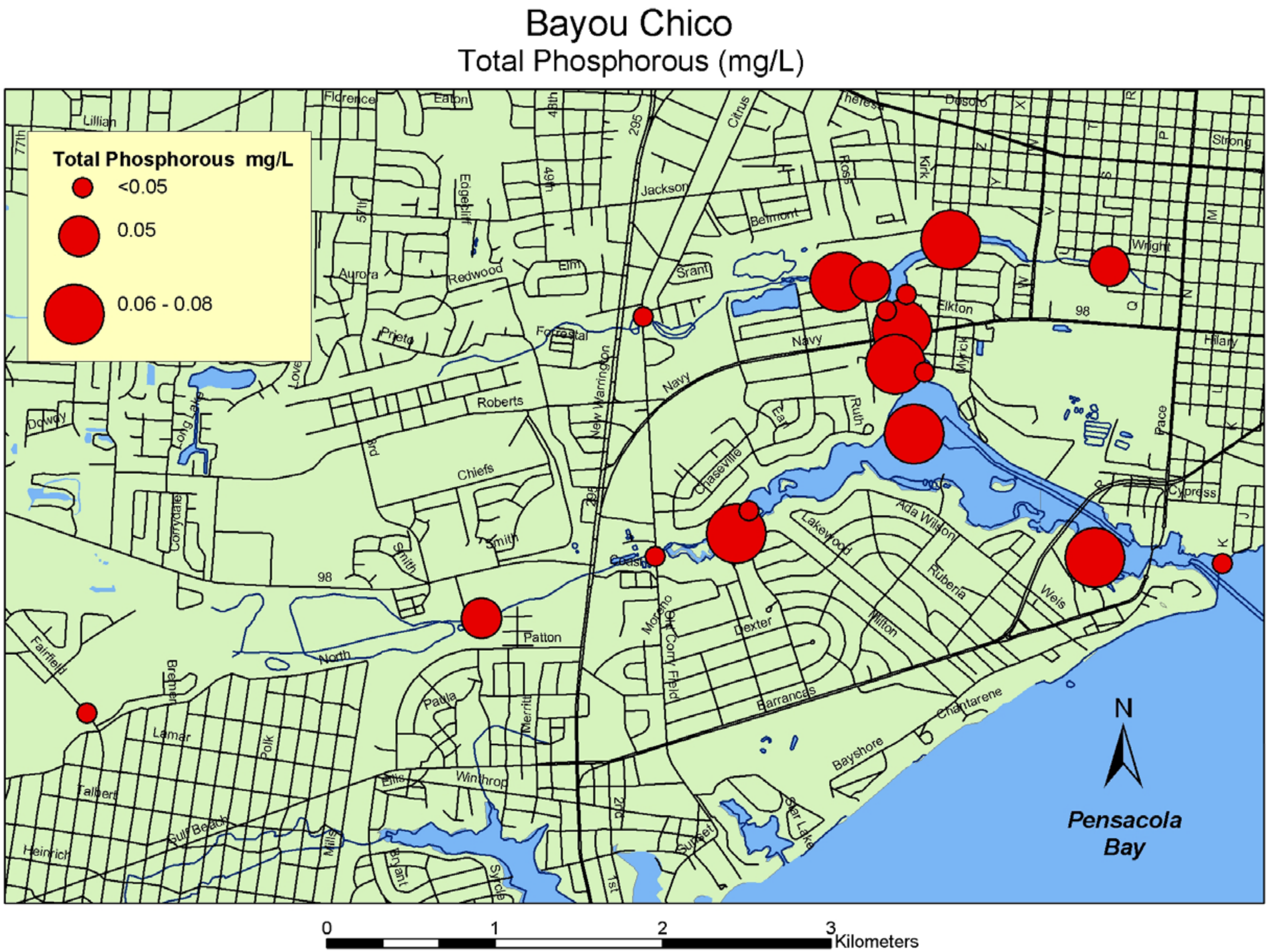

Figure 16. Mean Phosphate values for Bayou Chico station data.

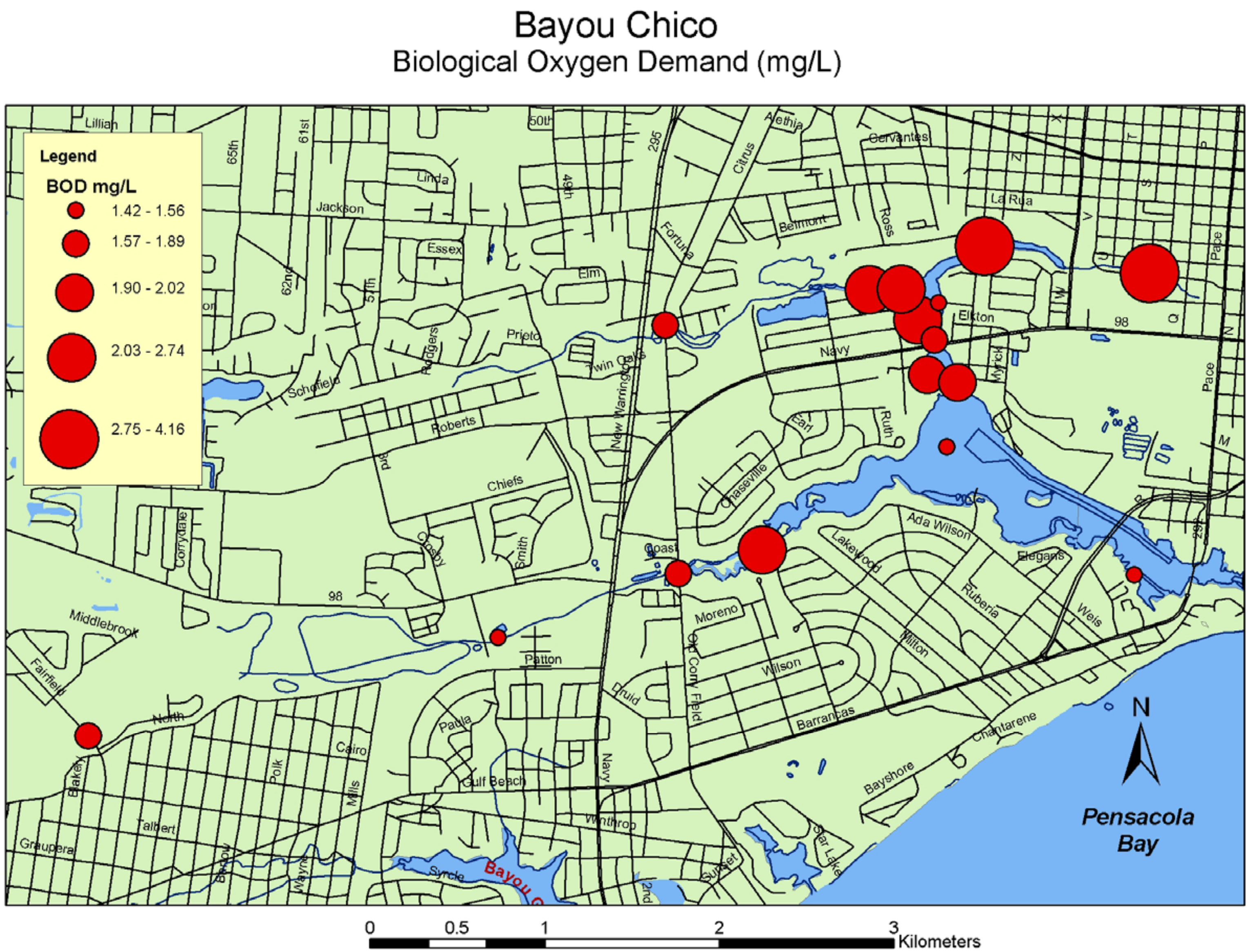

Figure 17. Mean BOD values for Bayou Chico station data.

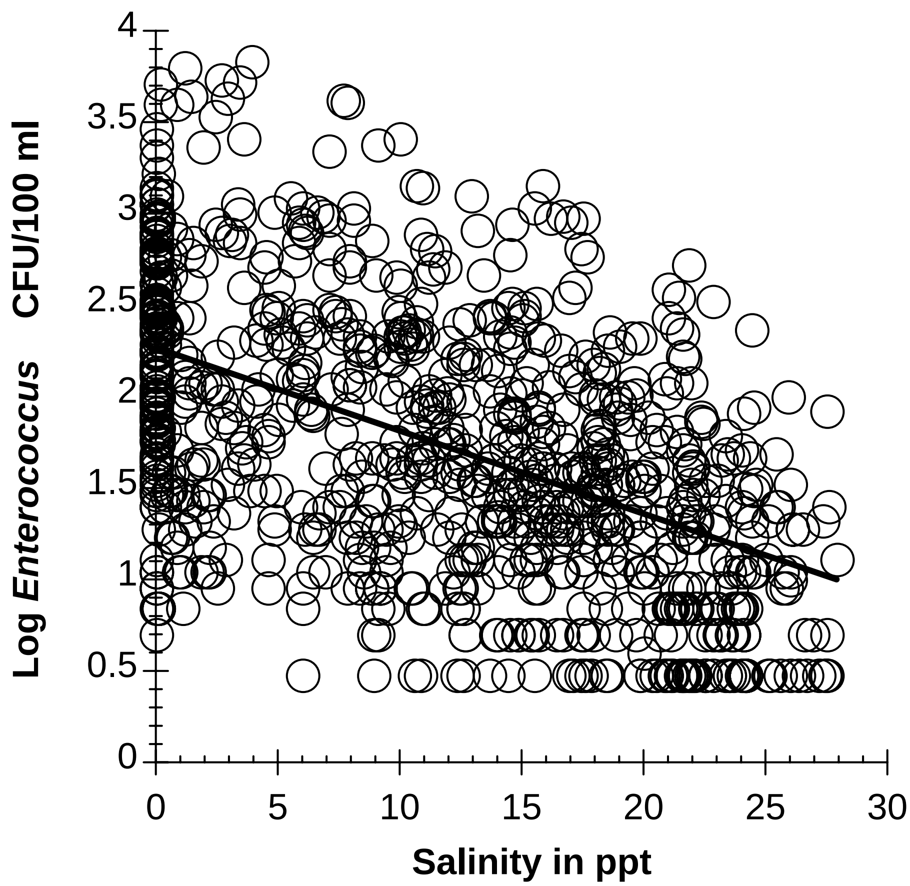

Figure 18. Conservative mixing analysis of *Enterococcus* in Bayou Chico.

Geospatial analysis of these data by station add resolution to the pattern of higher contamination levels at lower salinities. Figure 19 displays the distribution of contamination as the geomean of each station's data. With the exception of the drainage stream at the mouth of the bayou, the only stations with geomeans exceeding the 30 day geomean regulatory limit of 35 CFU/100 ml sample were located in the upper freshwater reaches of the bayou. This distribution is reinforced by the plot of minimum *Enterococcus* counts recorded at each station (Figure 20), which would be indicative of chronically impaired stations. Maximum recorded counts by station (Figure 21) should reflect storm water effects as well as chronic effects, and a few stations in the main part of the bayou reflect these episodic loadings. However the predominant pattern for the maximum recorded counts follows the patterns for geomeans and minimum counts.

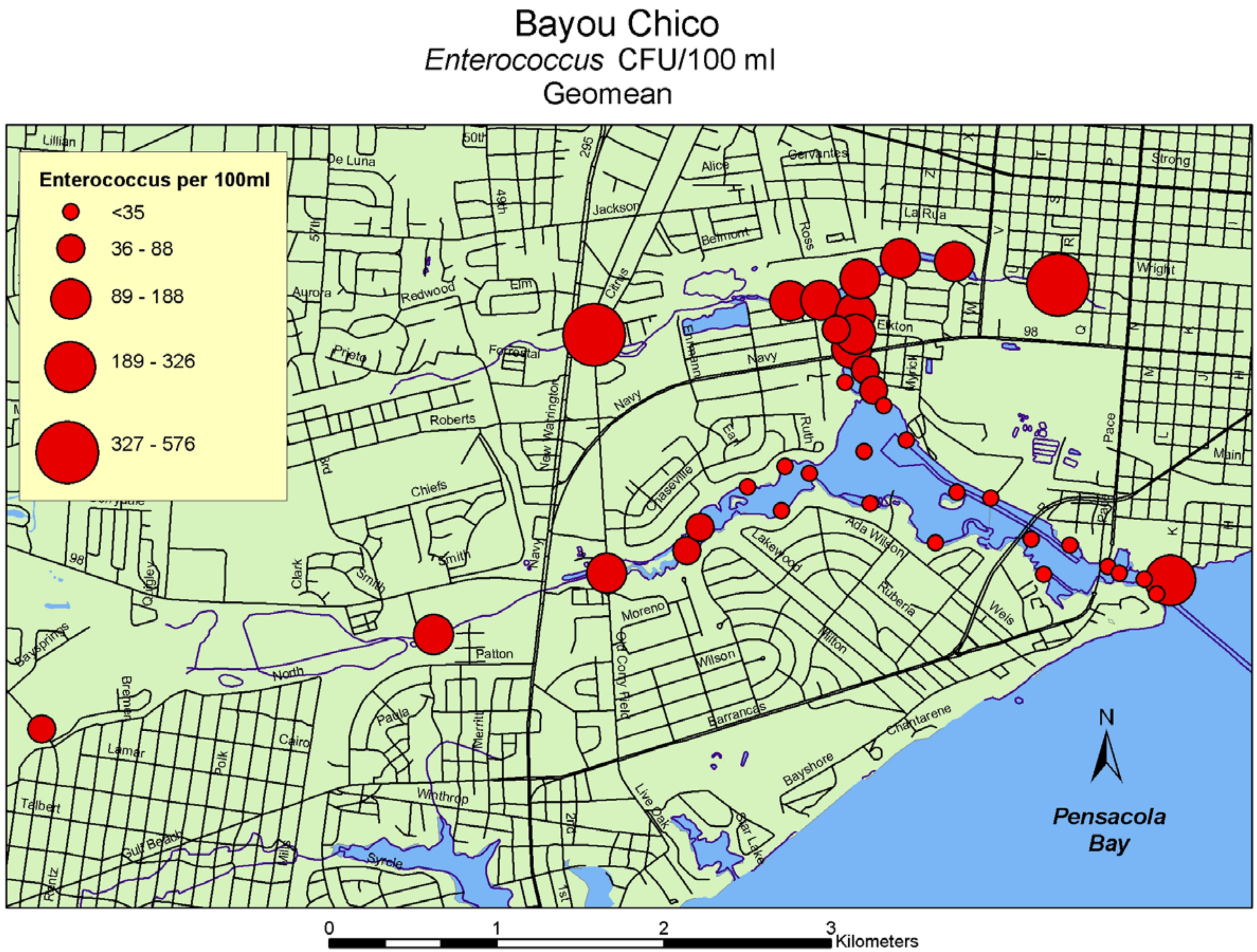

Figure 19. Geomeans of Bayou Chico station data for *Enterococcus* counts.

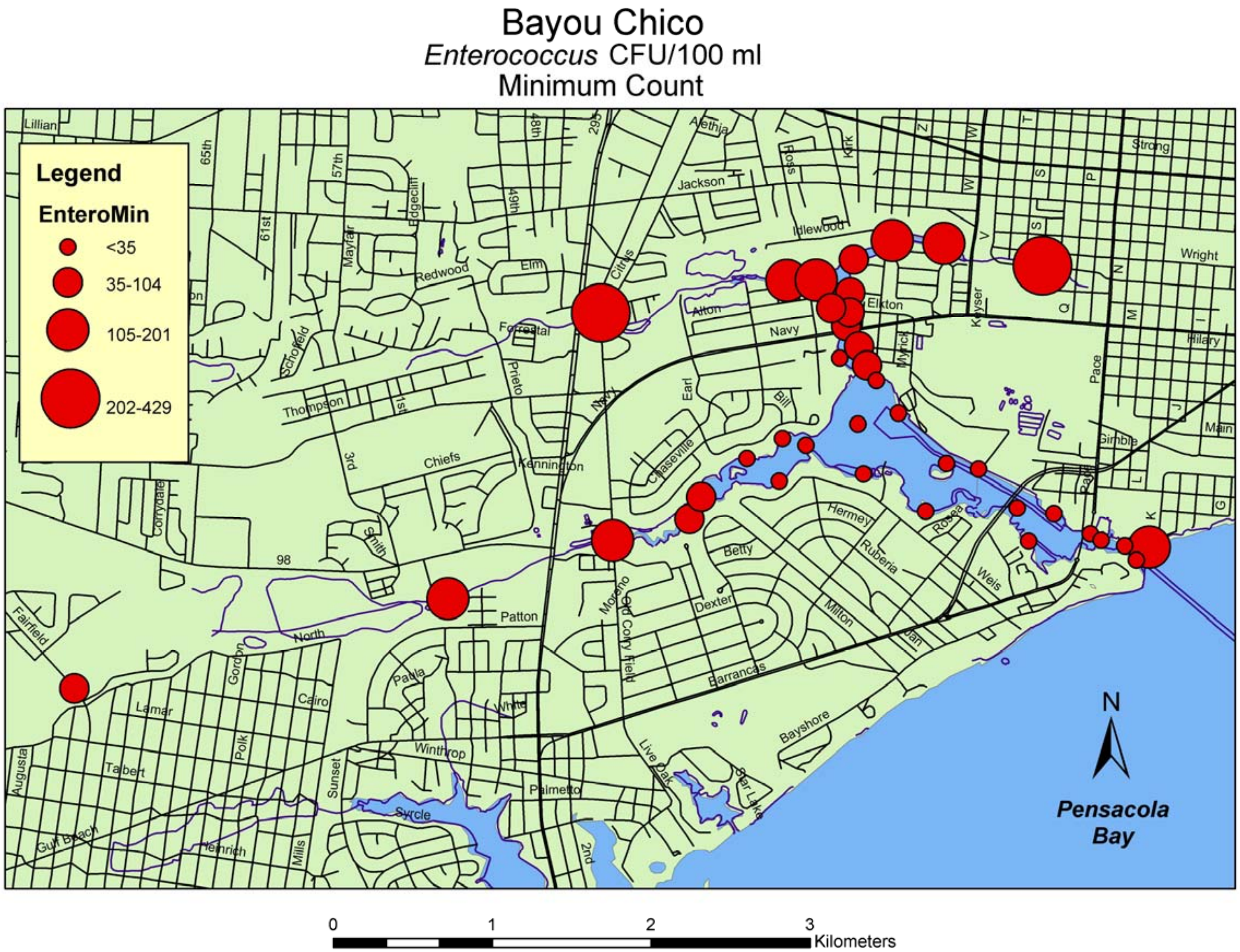

Figure 20. Bayou Chico station data for *Enterococcus* minimum counts.

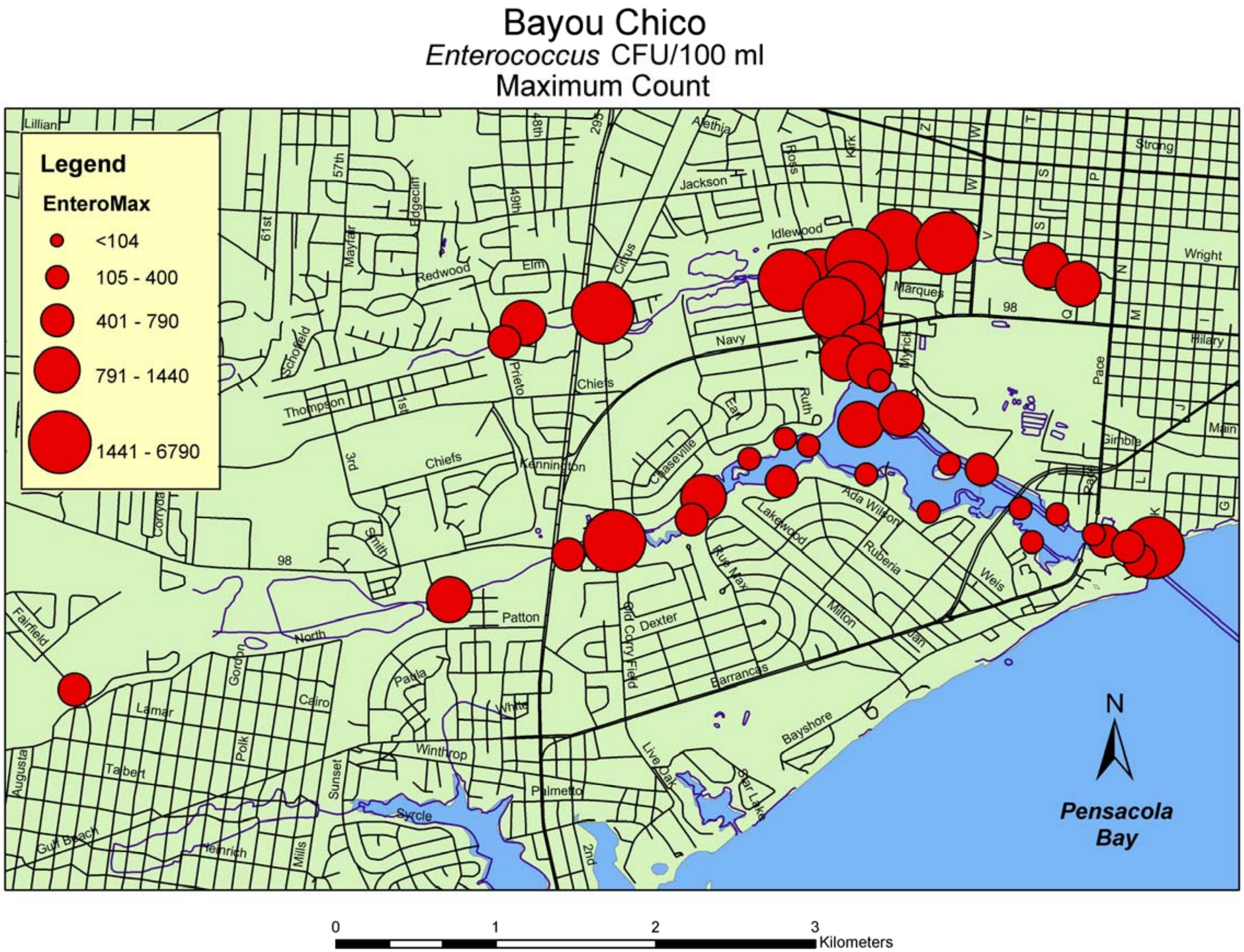

Figure 21. Bayou Chico station data for *Enterococcus* maximum counts.

Using correlation analysis, none of the parameters measured were predictive of fecal bacteria concentrations within the system. The highest correlation found with rainfall data was for *Enterococcus* and rain total on the day of sampling (0.23). Correlations with the previous day rainfall and the sum of rainfall for up to 7 days prior to sampling were much lower (data not shown).

Analysis of the entire *Enterococcus* data against the amount of rainfall in the previous 48 hours shows a pattern similar to that found in Bayou Grande, yet more pronounced, with the highest recorded counts occurring during moderate rainfall (0.5-1.0”) and lower counts obtained following heavier rainfall (Figure 22). Regression analysis of the *Enterococcus* count dependence on rainfall by station is shown in Figure 23 and summarized in Table 9. Stations 39-42 were excluded from this analysis due to too few data points (4-5). The data for a majority of stations returned significant slope and intercept estimates. Those with insignificant slope estimates tended to have high intercept values. Indeed, these parameters were negatively correlated (-0.732). The analysis indicates strong rain dependence for the *Enterococcus* loading into the lower portion of Bayou Chico, and chronic loading in fresher upper reaches. Slope and intercept estimates are shown plotted in GIS analysis in Figure 24 (slopes) and Figure 25 (intercepts).

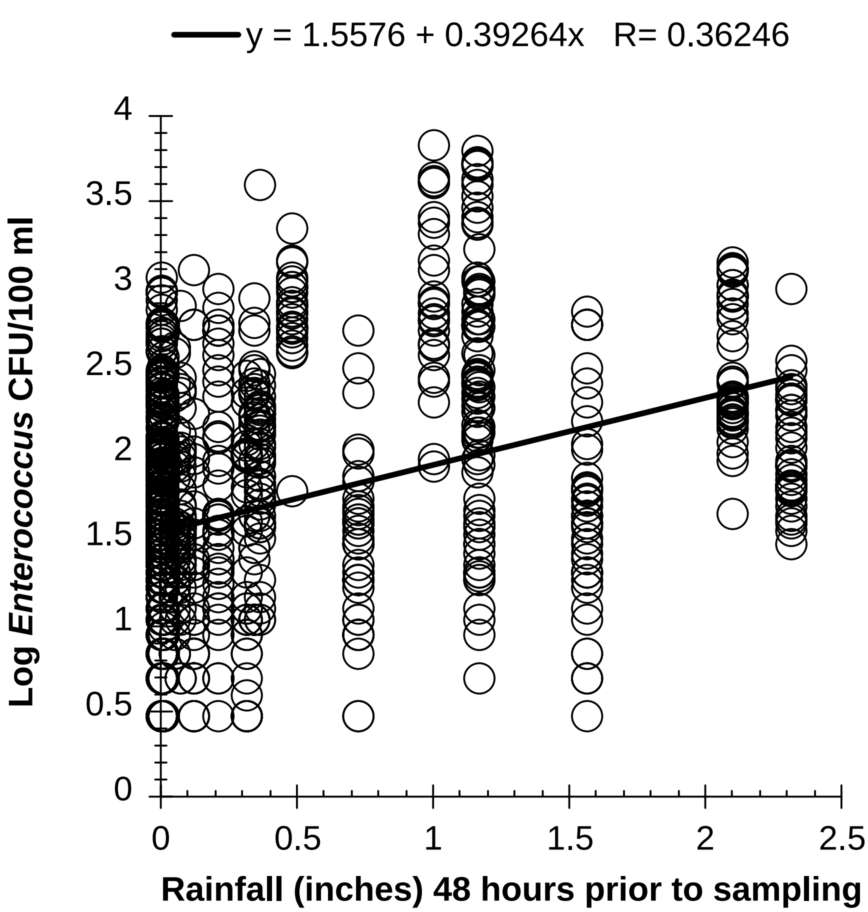

Figure 22. Bayou Chico *Enterococcus* as a function of rainfall in the 48 hours prior to sampling.

Table 9. Regression of Bayou Chico station data as a function of rainfall < 2 inches 48 hours prior to sampling. Significant parameter estimates ($p < 0.06$) are indicated in bold.

Site ID	Site Description	R^2	Slope	p value	Intercept	p value	Geomean @ zero rain
1	PYC Boat Ramp	0.135	0.410	0.122	**1.184**	**1.85E-07**	**15.29**
2	**Bahia Mar Fuel Dock**	**0.297**	**0.628**	**0.016**	**1.160**	**9.07E-08**	**14.44**
3	**Pace Storm Drain**	**0.204**	**0.569**	**0.052**	**1.308**	**1.42E-07**	**20.34**
4	Runyan's Seawall	0.092	0.332	0.206	**0.946**	**3.87E-06**	**8.83**
5	**Scrapyard Fragmites**	**0.205**	**0.481**	**0.052**	**1.117**	**1.20E-07**	**13.08**
6	**Midbayou (Scrapyard/Island)**	**0.368**	**0.608**	**0.006**	**0.920**	**1.58E-07**	**8.32**
7	Pensacola Shipyard A-10	0.018	0.176	0.584	**1.066**	**1.32E-05**	**11.65**
8	Pensacola Shipyard end	0.024	0.154	0.522	**1.141**	**1.28E-07**	**13.83**
9	**Tressle Apartments**	**0.323**	**0.644**	**0.004**	**1.569**	**1.31E-12**	**37.04**
10	**Vince Whibbs GMC Storm Drain**	**0.247**	**0.633**	**0.014**	**1.580**	**3.15E-11**	**38.00**
11	**Navy Boulevard Bridge**	**0.339**	**0.945**	**0.003**	**1.641**	**4.40E-10**	**43.71**
12	**Church Fragmites**	**0.174**	**0.587**	**0.043**	**1.724**	**9.72E-11**	**52.98**
13	**Sawgrass at Tin Boat House**	**0.307**	**0.884**	**0.005**	**1.712**	**2.21E-10**	**51.58**
14	**NE Branch Mouth**	**0.312**	**0.816**	**0.005**	**1.708**	**4.12E-11**	**51.07**
15	**NE Branch Midway**	**0.341**	**0.895**	**0.003**	**1.855**	**1.38E-11**	**71.66**
16	**NE Branch East End**	**0.169**	**0.565**	**0.046**	**1.961**	**5.47E-12**	**91.50**
17	**NW Branch Gazebo**	**0.167**	**0.541**	**0.047**	**1.897**	**5.03E-12**	**78.92**
18	**NW end**	**0.241**	**0.698**	**0.015**	**1.965**	**4.12E-12**	**92.28**
19	**Rip Rap**	**0.322**	**0.894**	**0.004**	**1.316**	**1.64E-08**	**20.71**
20	**Juncus at Apartments**	**0.263**	**0.747**	**0.010**	**1.124**	**1.26E-07**	**13.32**
21	**Channel Marker 17**	**0.231**	**0.625**	**0.037**	**0.832**	**5.09E-05**	**6.79**
22	Rope Fence	0.064	0.318	0.297	**1.133**	**2.88E-06**	**13.57**
23	Lakewood Park	0.163	0.395	0.087	**1.011**	**2.20E-07**	**10.25**
24	West Branch Cattails	0.017	0.145	0.593	**1.258**	**1.80E-07**	**18.13**
25	West Branch Marsh Point	0.087	0.419	0.183	**1.625**	**1.07E-08**	**42.18**
26	West end Last Dock	0.086	0.316	0.289	**1.654**	**6.67E-07**	**45.05**
27	Swamplillies at Green Roof	0.116	0.436	0.154	**1.288**	**4.49E-07**	**19.39**
28	**Tire Pole**	**0.259**	**0.576**	**0.026**	**1.243**	**3.88E-08**	**17.48**
29	**Bell Marine Fragmites**	**0.230**	**0.597**	**0.038**	**1.170**	**4.39E-07**	**14.80**
30	**Pelican Pole**	**0.255**	**0.652**	**0.027**	**1.108**	**1.21E-06**	**12.82**
31	Mahogany Landing	0.161	0.498	0.089	**1.144**	**1.02E-06**	**13.93**
32	Marker 10/ Pilings	0.039	0.245	0.417	**0.930**	**2.99E-05**	**8.50**
33	Ditch	0.000	0.002	0.994	**2.253**	**1.45E-11**	**178.92**
34	S-Street	0.001	0.019	0.912	**2.611**	**6.65E-19**	**408.78**
35	**Corry Field Road North**	**0.368**	**0.612**	**0.006**	**2.373**	**3.81E-13**	**236.01**
36	Corry Field Road South	0.143	0.396	0.069	**2.152**	**4.69E-15**	**141.94**
37	Brigadier	0.042	0.225	0.385	**2.167**	**5.06E-12**	**146.95**
38	Fairfield	0.106	0.380	0.121	**1.536**	**5.21E-11**	**34.35**

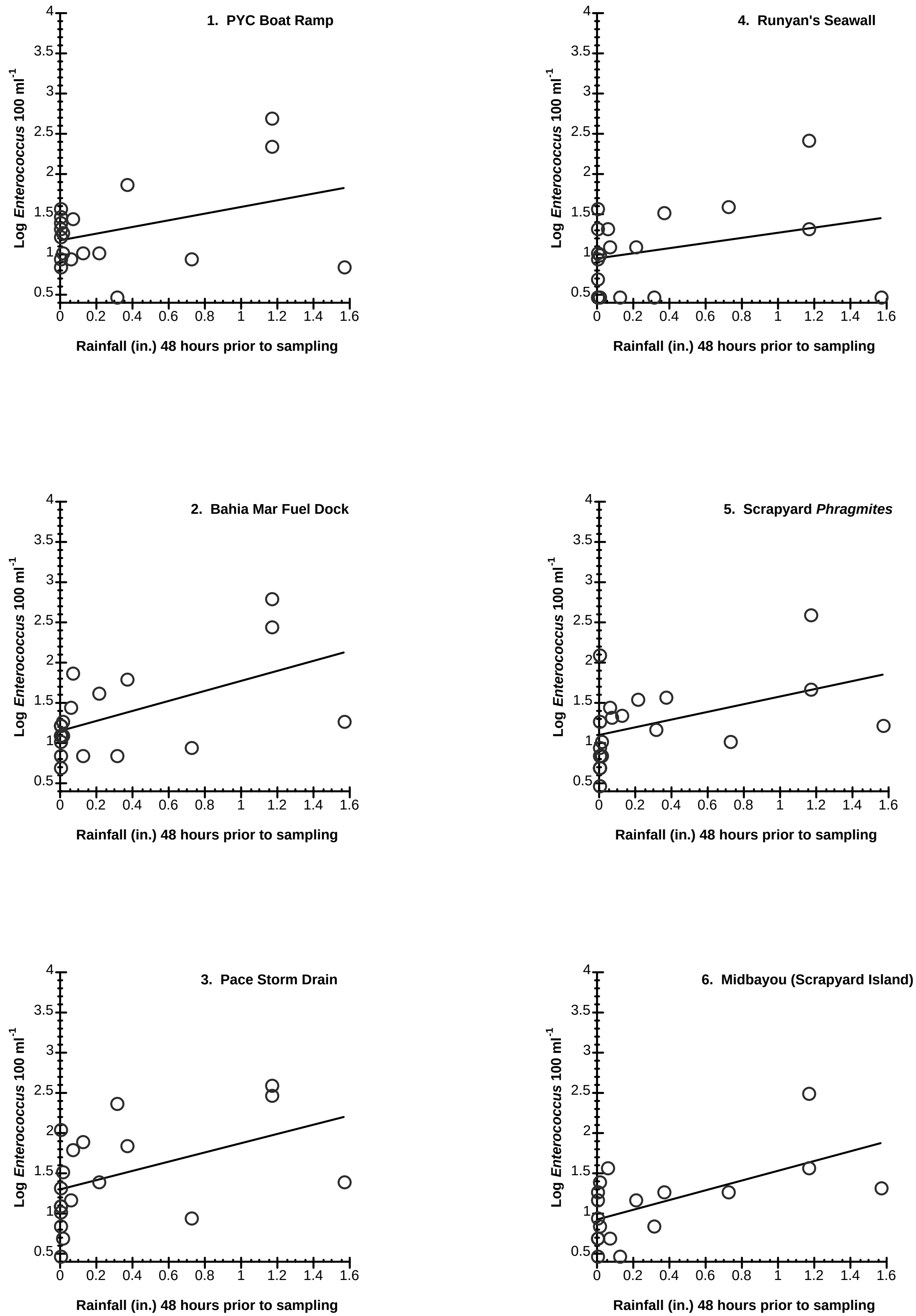

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Figure 23. *Enterococcus* dependence on rainfall by station for Bayou Chico.

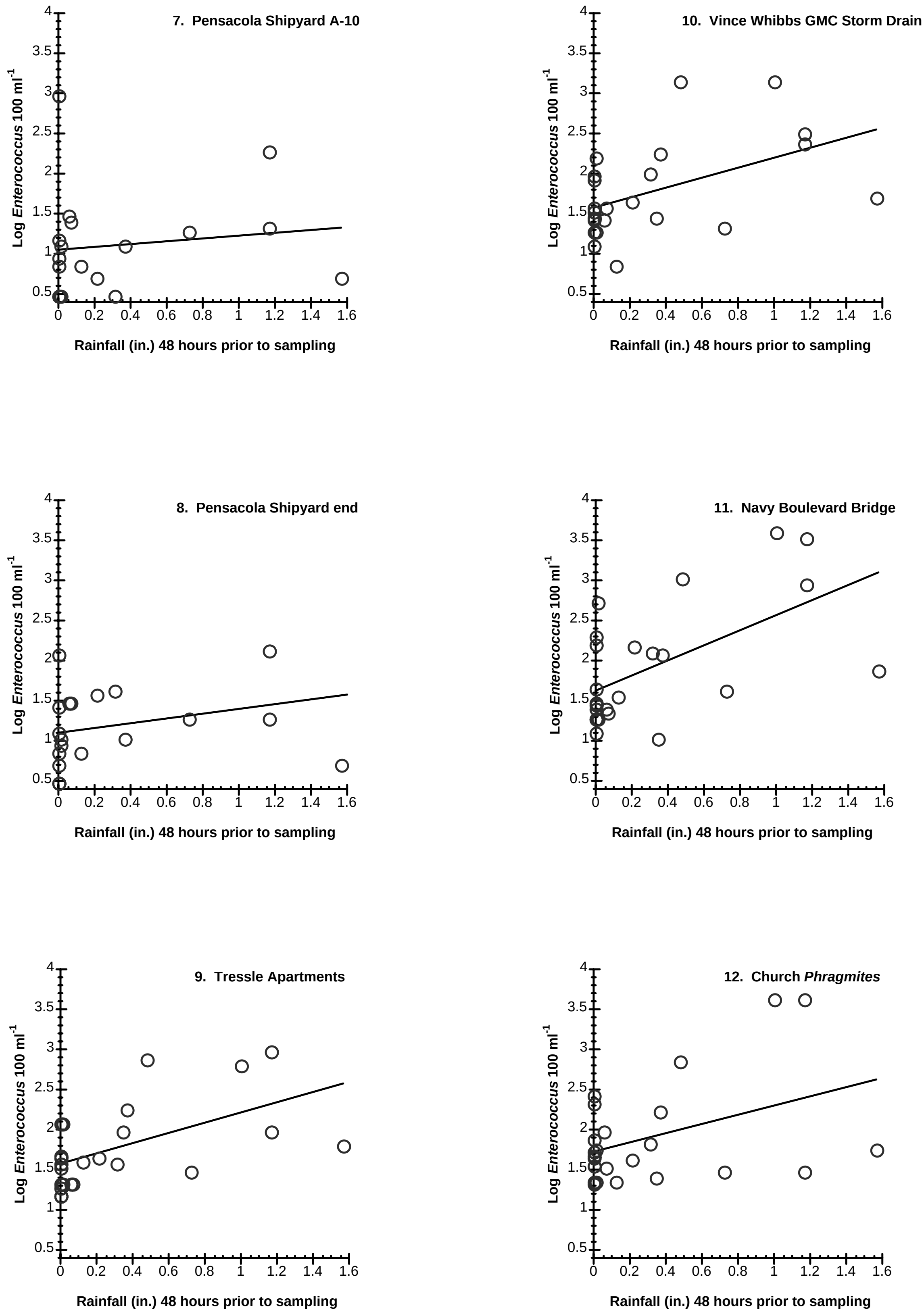

Figure 23, continued. *Enterococcus* dependence on rainfall by station for Bayou Chico.

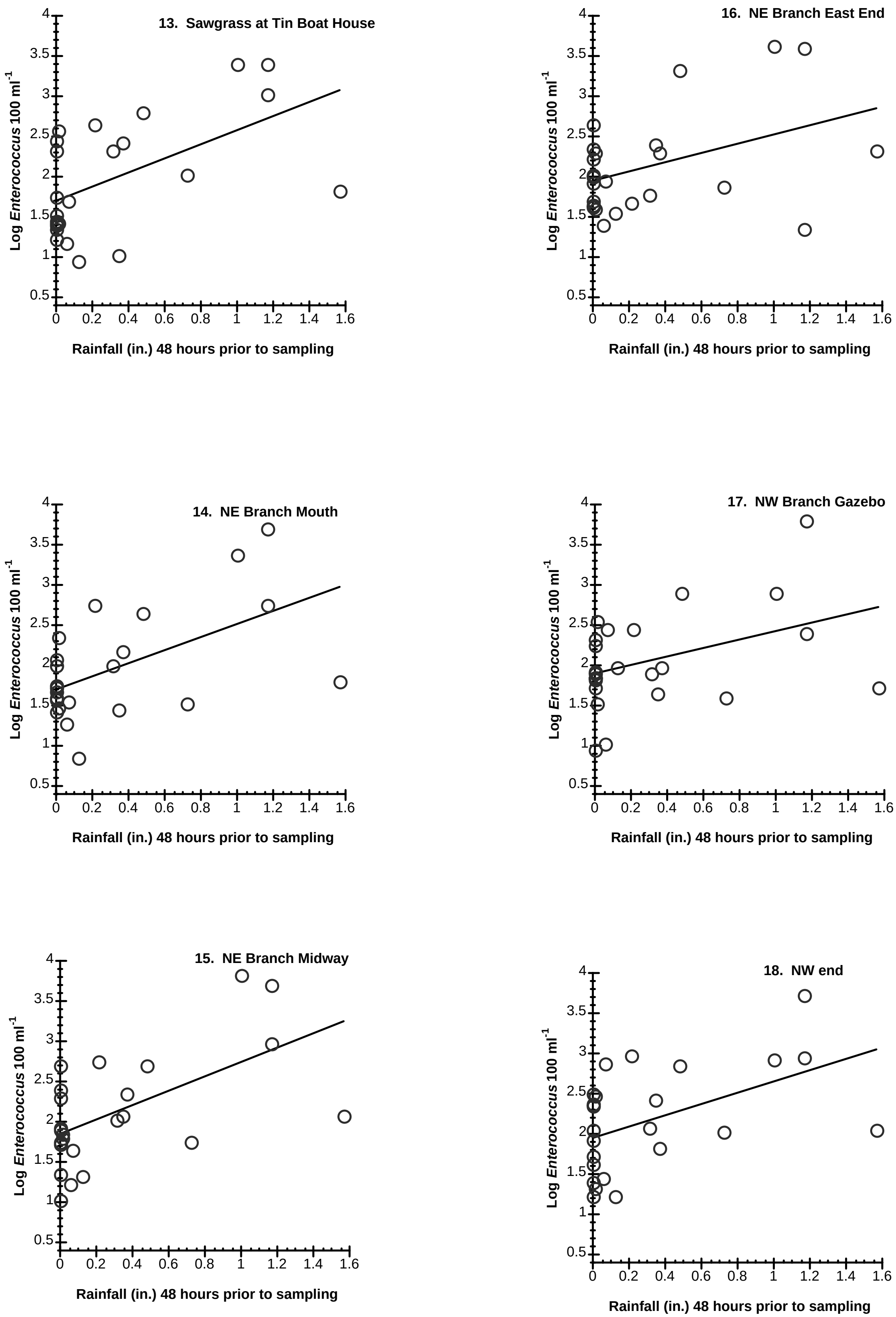

Figure 23, continued. *Enterococcus* dependence on rainfall by station for Bayou Chico.

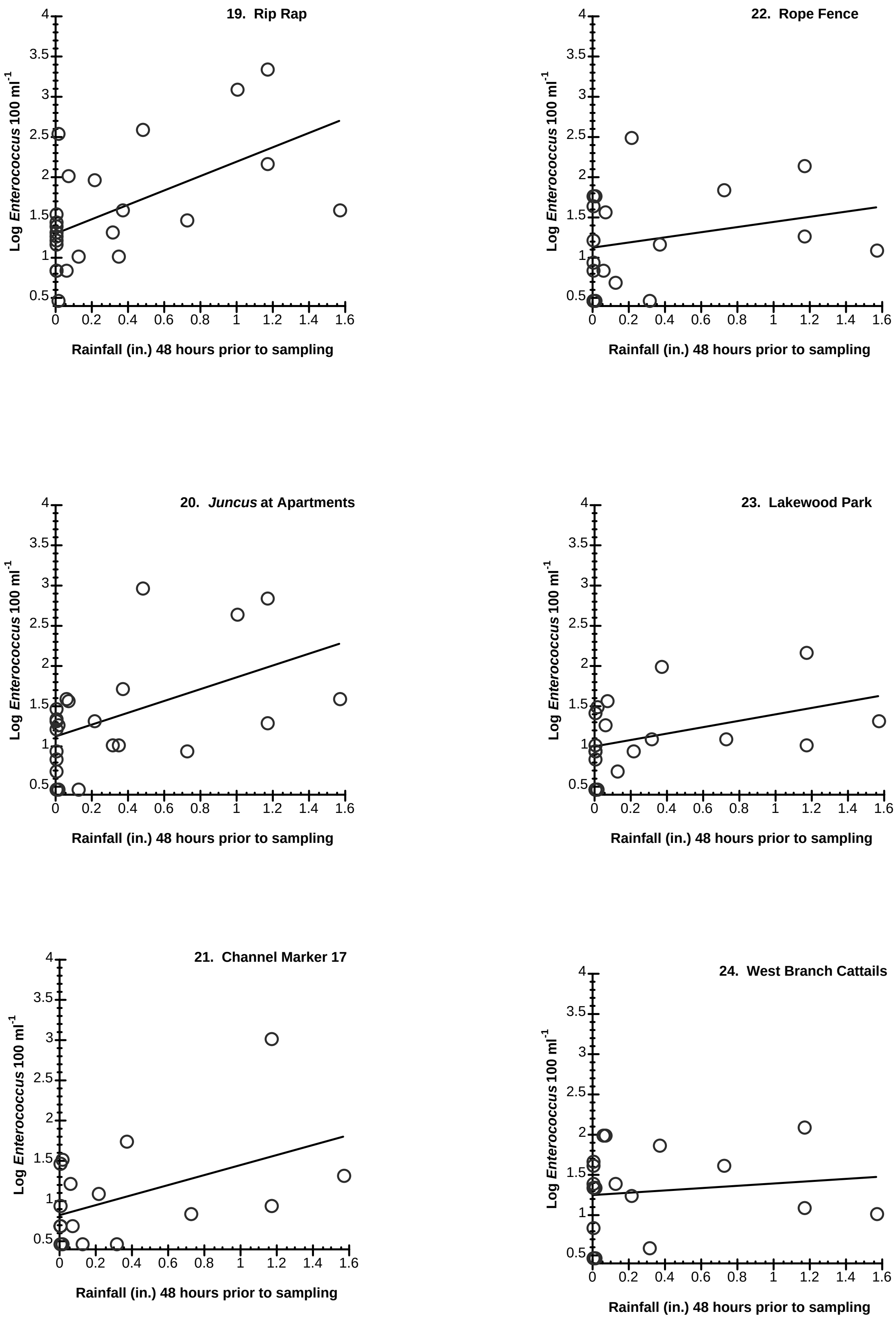

Figure 23, continued. *Enterococcus* dependence on rainfall by station for Bayou Chico.

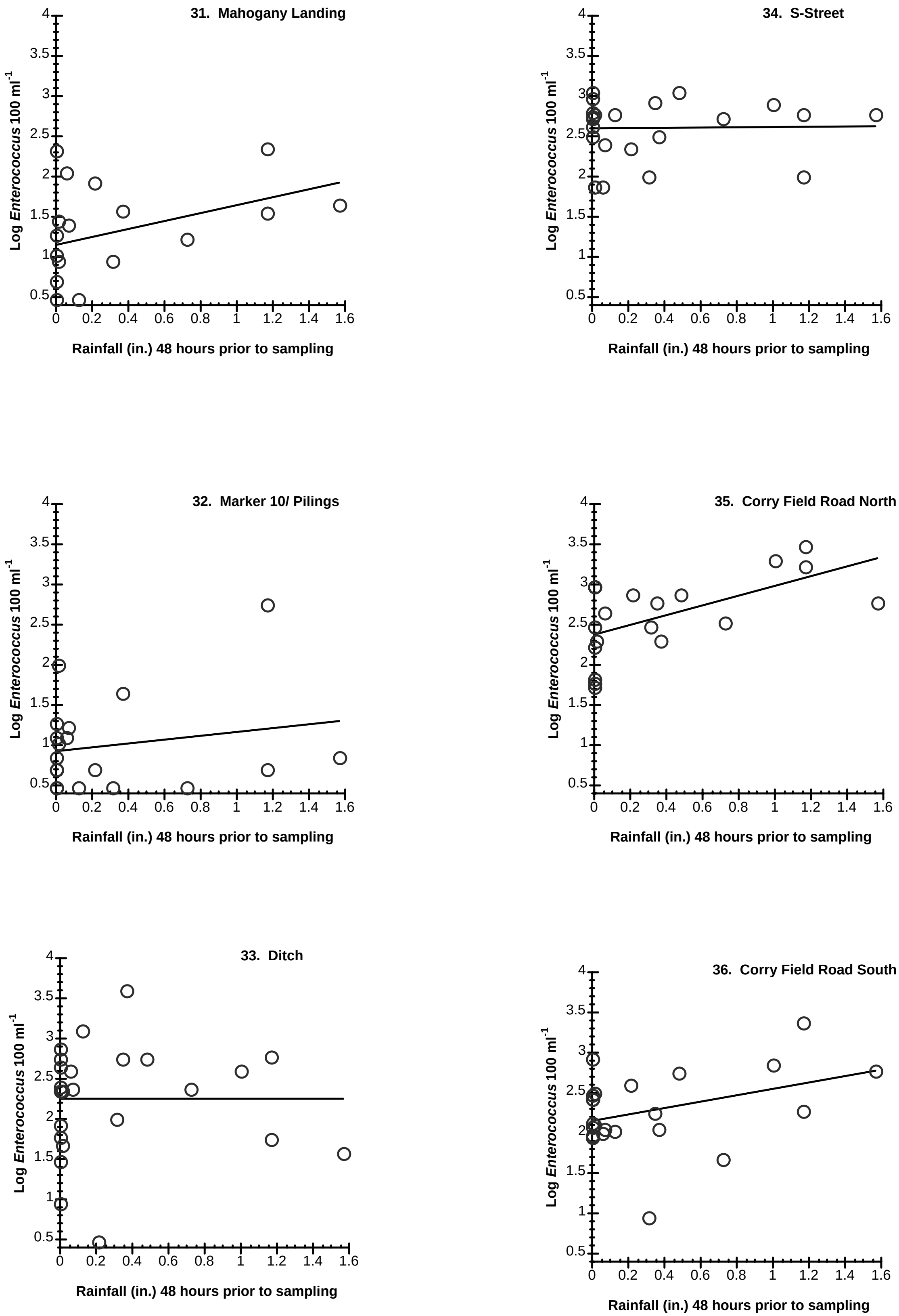

Figure 23, continued. *Enterococcus* dependence on rainfall by station for Bayou Chico.

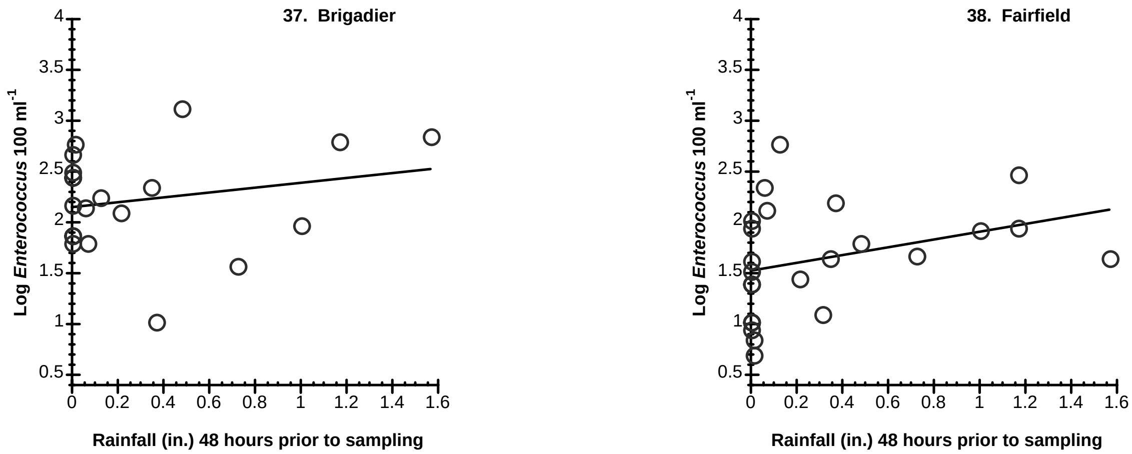

Figure 23, concluded. *Enterococcus* dependence on rainfall by station for Bayou Chico.

Bayou Chico
Enterococcus Rain Dependence

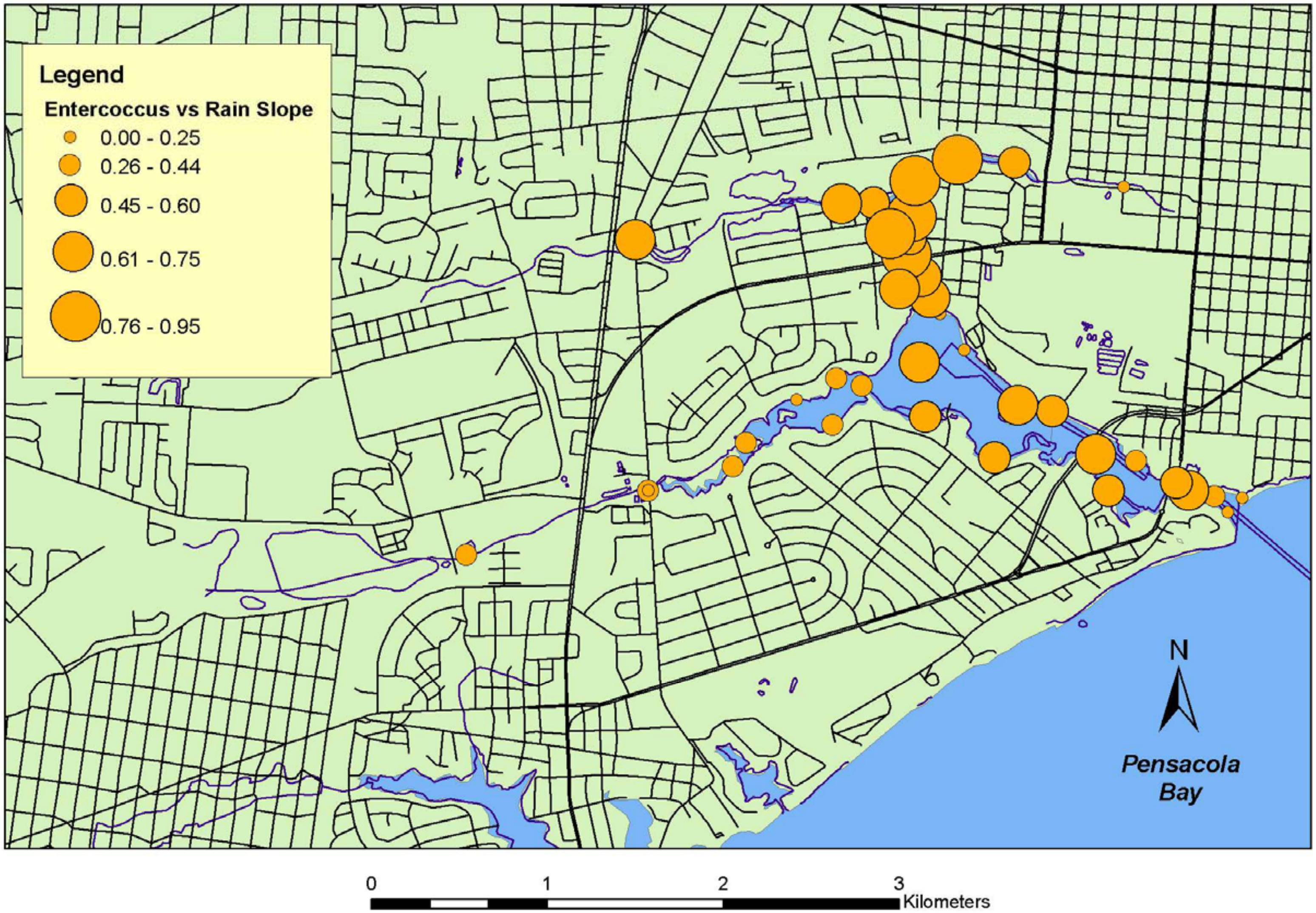

Figure 24. Distribution of slope values for Bayou Chico station rain dependence.

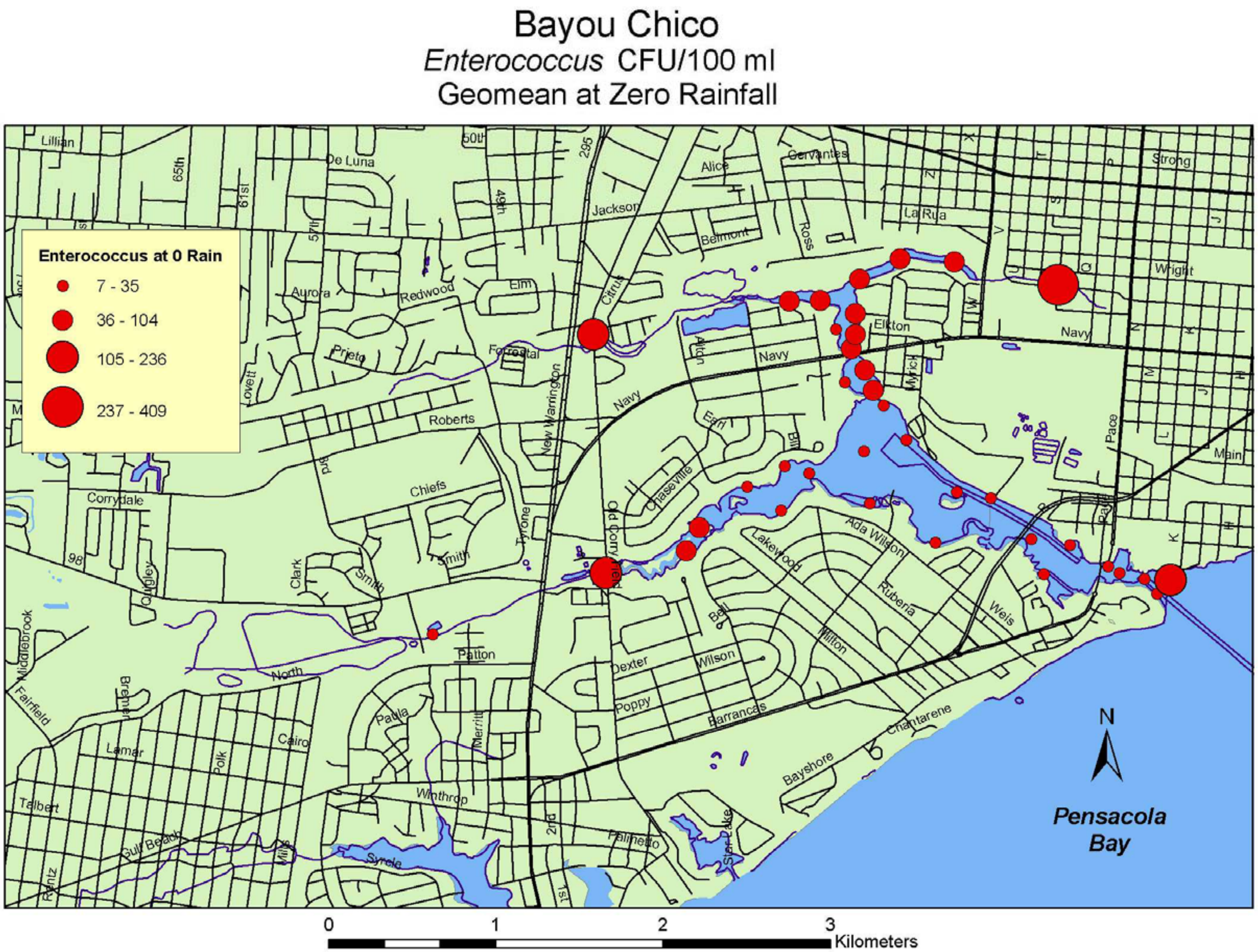

Figure 25. Distribution of y-intercept values (geomeans at zero rainfall) for Bayou Chico Stations..

Bayou Texar

A total of 893 samples were taken over a time period from 14 November 2001 to 30 December 2003. The summary data are presented in Tables 10 and 11.

A conservative mixing analysis for Bayou Texar nutrient data is shown in Figure 26. Nitrate+ nitrite and phosphate show similar patterns as Bayou Chico, with the nitrogen sources having more of a freshwater origin and the phosphate tending to have an open bay source. However, the trend was not as clear nor were nitrogen concentrations as high as those recorded for Bayou Chico.

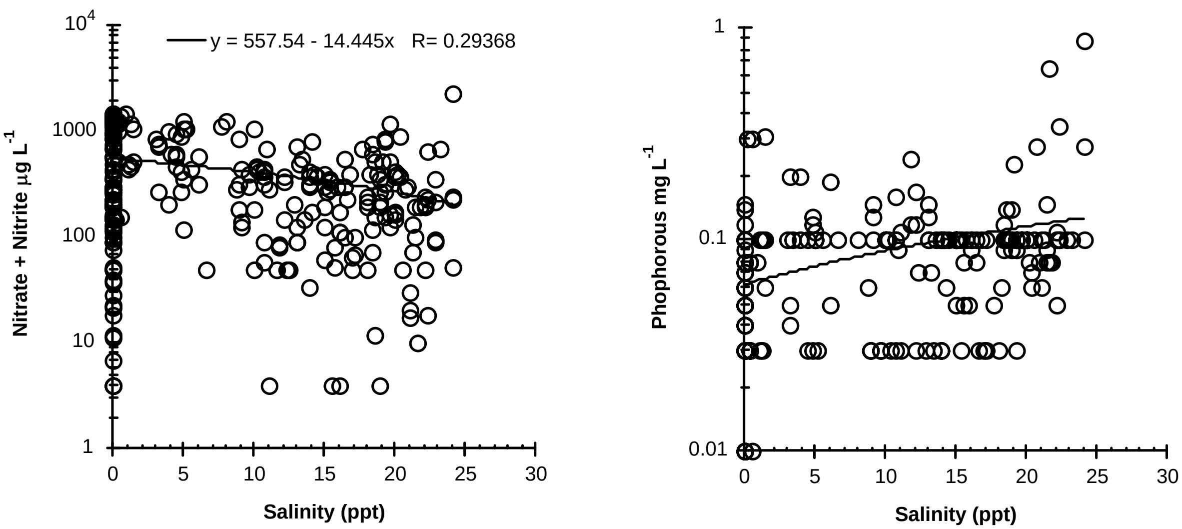

Figure 26. Conservative mixing diagrams for Nitrate + Nitrite and Phosphate in Bayou Texar.

GIS maps for the distribution of Nitrogen, Phosphate and Biological Oxygen Demand (BOD) are shown in Figures 27, 28, & 29.

Table 10. Physico-chemical water quality measures from Bayou Texar sampling.

station code	station name	Temp	std	Ph	std	salinity	std	DO mg/L	std	BOD mg/L	CV	$NO_{3/2}$ µg/L	CV	TP mg/L	CV
1	Cervantes Bridge	21.543	6.618	7.645	0.429	16.675	6.266	7.491	2.033	1.360		200		0.050	
2	Brainerd St. pond	21.757	6.422	7.565	0.552	15.577	6.688	6.482	2.230	1.360		100		0.100	
3	Bayview Park pvc SD	21.484	6.615	7.709	0.283	17.444	5.746	7.587	1.762	1.510		200		0.080	
4	Tree Roots	21.331	6.724	7.710	0.281	18.428	5.110	7.742	1.631						
5	Boathouse (point)	22.123	6.778	7.703	0.350	16.253	5.715	7.339	2.187						
6	Rocks/Gazebo	21.273	6.622	7.672	0.364	17.788	5.537	7.942	1.873						
7	Oriental Garden	21.422	6.596	7.637	0.357	17.292	5.761	7.886	1.759						
8	South Whaley fragmites	21.284	6.488	7.629	0.360	17.488	5.769	7.843	1.512	1.380		200		0.080	
9	Whaley Ditch storm drain	22.106	6.670	7.767	1.003	15.322	6.190	7.676	1.845	1.240		200		0.090	
10	Birnam Woods green SD	21.642	6.438	7.650	0.365	17.232	5.785	8.144	1.466						
11	Blackshear Ave. SD	22.597	6.587	7.450	0.297	14.195	6.185	7.356	1.847	1.297	0.098	170.71	0.003	0.080	0.332
12	Blanford place FW seep	22.748	6.691	7.203	0.300	11.733	6.610	7.258	1.811						
13	34th St. storm drain	22.308	6.302	7.100	0.312	12.196	7.325	7.512	1.534	1.207	0.157	422.26	0.001	0.112	0.221
14	Six Cement poles	23.082	6.009	7.043	0.357	12.496	7.170	7.562	1.684						
15	Carpenter Creek center	22.963	5.643	6.888	0.316	9.960	7.184	7.242	1.042	0.860		900		0.070	
16	Driftwood 4 SD	23.117	6.425	6.896	0.290	10.798	7.033	6.514	1.918	1.467	0.186	470.59	0.001	0.078	0.322
17	Texar Woods SD	23.254	6.290	7.272	0.408	13.745	6.446	7.474	1.973						
18	Seville Dr. (2) SD	22.901	6.406	7.352	0.345	14.346	6.065	7.048	1.931	1.360		400		0.080	
19	Banquos Court SD	22.661	6.609	7.510	0.419	14.320	6.523	7.532	1.835	1.472	0.117	113.44	0.005	0.089	0.491
20	Bayou Blvd./Perry SD	22.429	6.825	7.687	0.320	15.938	5.877	7.671	1.968						
21	12th Ave. bridge	21.939	4.323	6.768	0.401	1.681	3.480	6.379	1.736	1.134	0.115	1247.40	0.000	0.031	0.310
22	9th Ave.	21.072	3.064	6.649	0.435	0.000	0.000	7.434	1.559	2.428	0.268	1.22	0.121	0.332	
23	Airport Blvd.	20.861	5.607	6.697	0.347	0.000	0.000	7.290	2.020	1.340	0.158	260.10	0.002	0.088	0.096
24	Born Court	19.650	5.210	6.561	0.699	0.004	0.021	5.608	1.875	1.742	0.035	332.95	0.001	0.031	0.356
25	Boiling Brook	20.181	5.386	6.733	0.553	0.002	0.015	6.142	1.783	1.893	0.105	1088.64	0.000	0.040	0.225
26	Sears Warehouse	18.789	4.574	6.092	0.917	0.000	0.000	2.495	1.444	2.209	0.078	33.34	0.003	0.017	0.348
27	Interstate 10-Hist. Dist.	21.395	6.359	6.696	0.343	0.005	0.022	5.233	2.561						
28	Olive Road	22.392	6.523	6.569	0.323	0.000	0.000	4.046	2.606	1.994	0.027	17.89	0.017	0.027	0.224
29	Walton/Davis	20.456	6.491	6.842	0.512	0.000	0.000	4.768	2.657	0.865	0.220	72.50	0.008		
30	Brookside Place	21.213	3.808	6.405	0.200	0.000	0.000	5.815	1.416	1.277	0.086			0.005	0.000
31	Creekside Office	22.731	7.591	6.723	0.102	0.000	0.000	4.362	1.559	1.839	0.142	6.84	0.042	0.055	0.369
32	Springhill	21.296	4.063	6.528	0.079	0.000	0.000	7.408	1.331	0.401	0.351	1013.77	0.000		
33	Burgess Road	21.511	4.525	7.168	0.399	0.000	0.000	5.954	0.601	0.327	0.548	199.43	0.000	0.008	0.624

Table 11. Summary fecal indicator data from Bayou Texar sampling.

station code	station name	Entero geomean	CV	min	max	Geomean FC	CV	min	max
1	Cervantes Bridge	15.221	0.450	1	1140	29.008	0.224	20	500
2	Brainerd St. pond	79.743	0.544	1	16000	427.820	0.371	20	16000
3	Bayview Park pvc/storm drain	9.647	0.447	1	172	40.000		40	40
4	Tree Roots	4.650	0.587	1	120				
5	Boathouse (point)	6.745	0.525	1	103				
6	Rocks/Gazebo	4.963	0.597	1	188				
7	Oriental Garden	5.224	0.596	1	240				
8	South Whaley fragmites	5.340	0.612	1	380	20.000		20	20
9	Whaley Ditch storm drain	11.396	0.495	1	408	40.000		40	40
10	Birnam Woods green SD	18.988	0.402	1	600	51.837	0.363	20	5000
11	Blackshear Ave. SD	40.575	0.349	2	1770	159.933	0.345	20	16000
12	Blanford place FW seep	55.444	0.308	8	1240	167.949	0.272	20	3000
13	34th St. storm drain	60.579	0.336	11	1180	219.551	0.254	20	3000
14	Six Cement poles-tan house	57.998	0.328	6	1950	161.002	0.323	20	2400
15	Carpenter Creek center	115.489	0.311	7	1990	417.943	0.220	40	16000
16	Driftwood 4 SD	105.768	0.307	5	2200	343.619	0.241	20	3000
17	Texar Woods SD	34.677	0.346	2	600	104.168	0.319	20	2200
18	Seville Dr. (2) SD	68.320	0.297	7	660	151.024	0.343	20	9000
19	Banquos Court SD	55.676	0.510	1	16000	398.377	0.401	20	16000
20	Bayou Blvd./Perry SD	20.915	0.501	1	3010	58.954	0.391	20	5000
21	12th Ave. bridge	283.488	0.236	18	5000	783.117	0.259	20	16000
22	9th Ave.	326.239	0.184	34	11800	313.807	0.240	20	5000
23	Airport Blvd.	187.684	0.222	20	1100	279.237	0.310	20	16000
24	Born Court	308.484	0.250	4	2220	214.076	0.265	20	5000
25	Boiling Brook	299.474	0.225	18	3120	147.352	0.283	20	1700
26	Sears Warehouse	108.716	0.381	1	3350	421.949	0.452	20	16000
27	Interstate 10-Historical Dist.	151.069	0.269	4	1700	218.682	0.422	20	30000
28	Olive Road	88.224	0.325	1	1500	171.900	0.290	40	3000
29	Walton/Davis	548.073	0.208	18	6800				
30	Brookside Place	495.211	0.066	260	940				
31	Creekside Office	60.371	0.315	20	680				
32	Springhill	475.892	0.143	83	2360				
33	Burgess Road	575.627	0.108	200	1340				

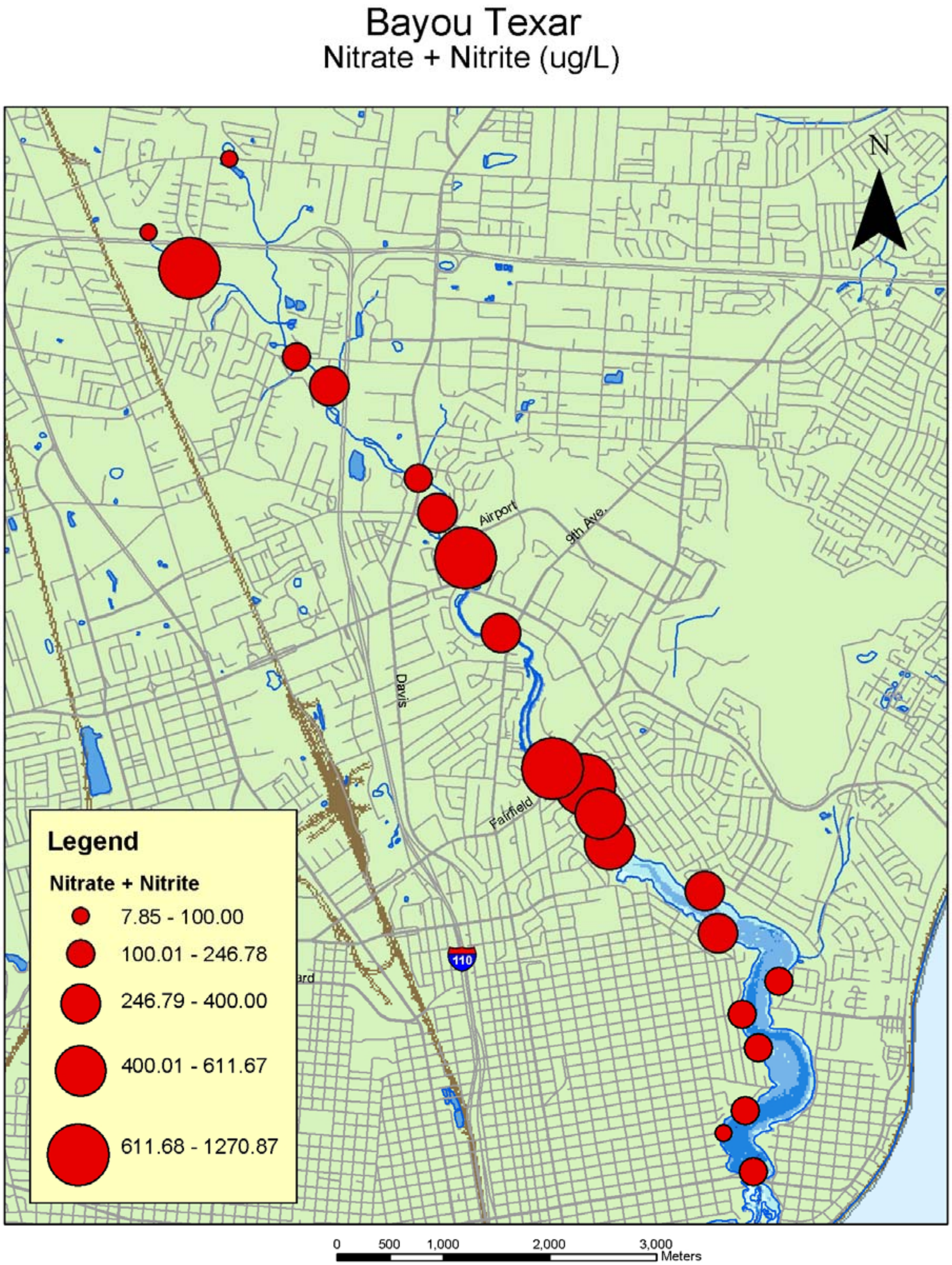

Figure 27. Distribution of mean Nitrate+Nitrite values in samples from Bayou Texar stations.

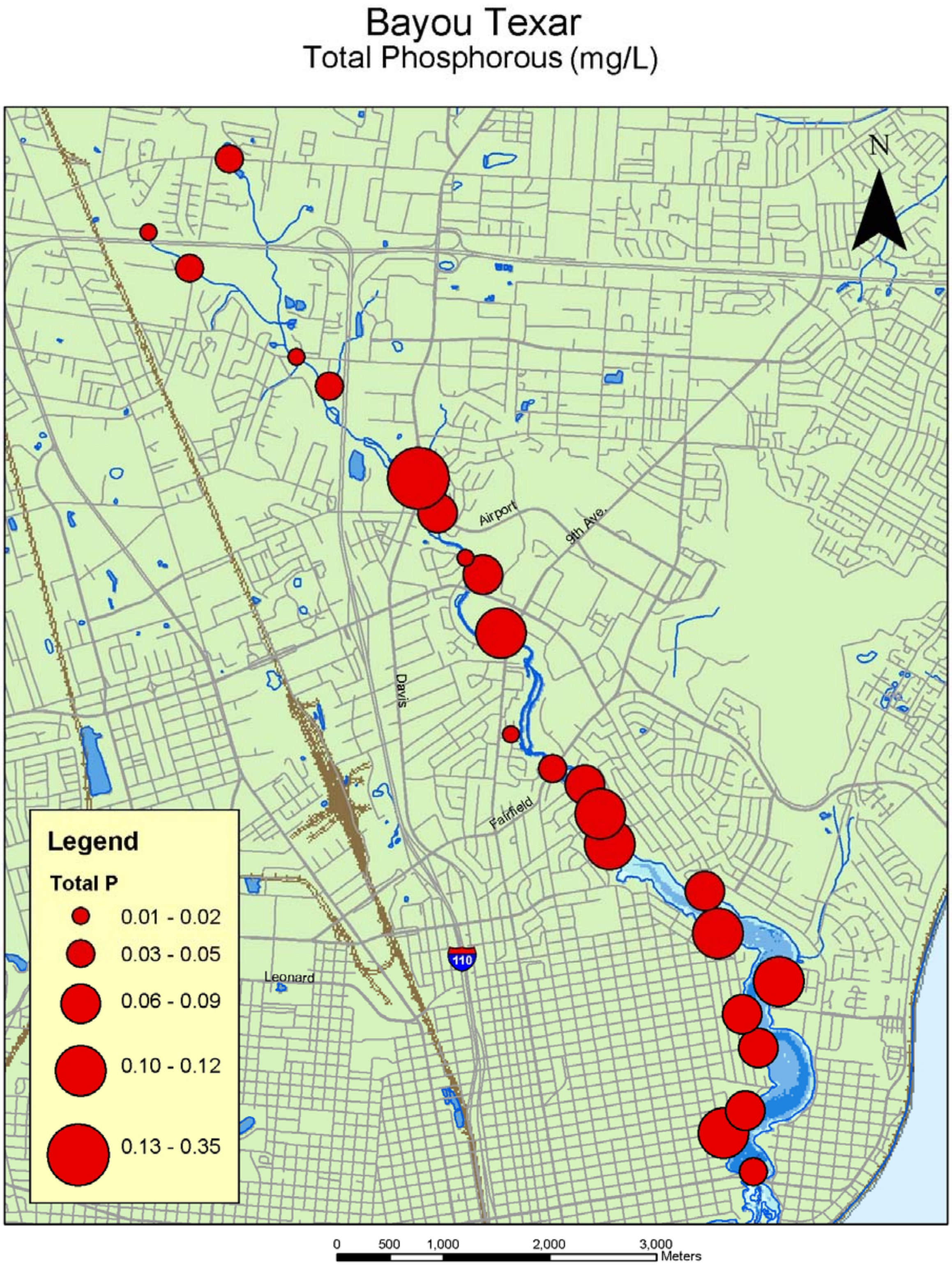

Figure 28. Mean Phosphate values in samples from Bayou Texar stations.

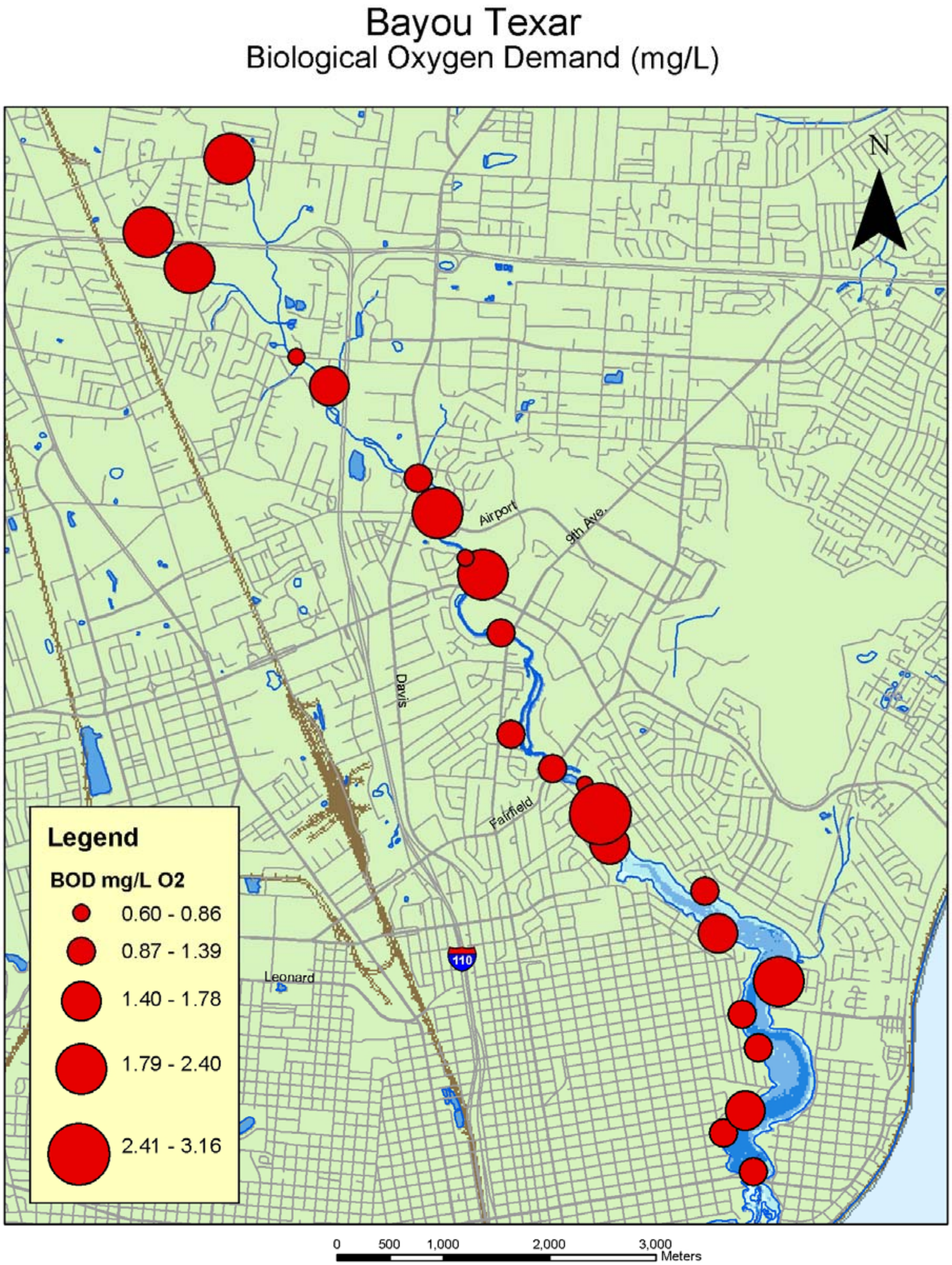

Figure 29. Mean BOD values in samples from Bayou Texar stations.

Enterococcus counts as a function of salinity indicate a predominantly freshwater source for fecal contamination within the saline portions of Bayou Texar (Figure 30), although considerable variation is apparent.

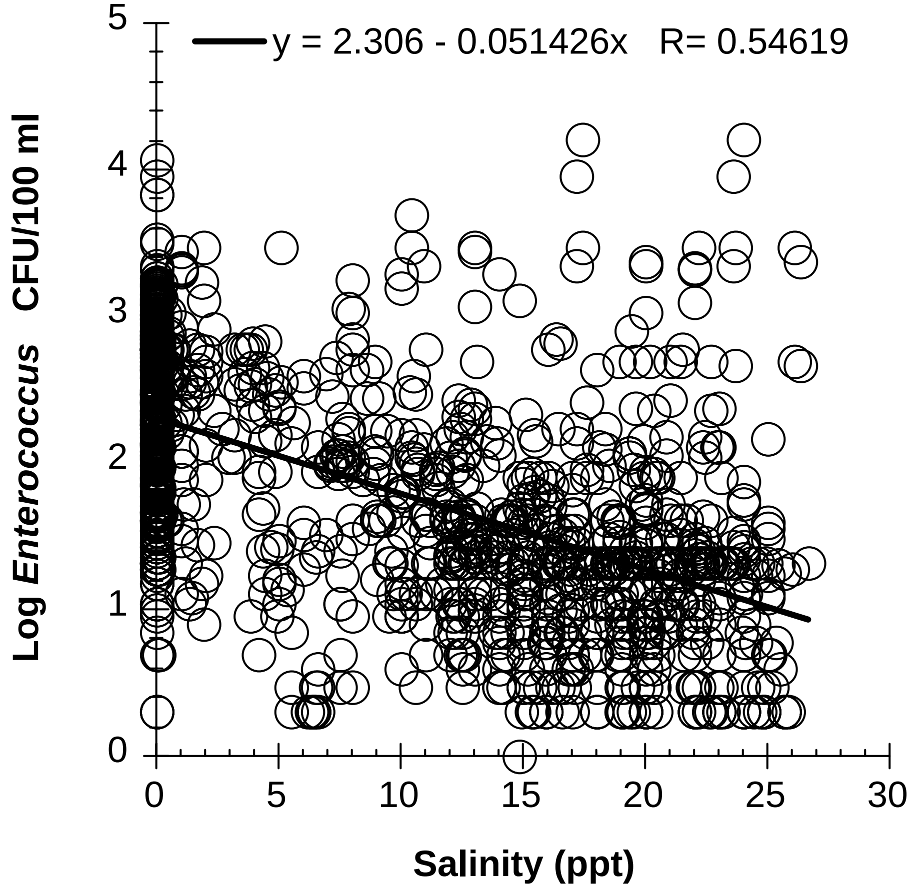

Figure 30. Conservative mixing diagrams for *Enterococcus* in Bayou Texar, including only stations south from the 12 Avenue Bridge.

Geomeans for each station's data is plotted by GIS in Figure 31. These data clearly show the upper reaches of the bayou and Carpenter's Creek Stations as dominating the loading of fecal material. This pattern is further accentuated by examining the chronically loaded stations with the plot of minimum *Enterococcus* counts (Figure 32). Maximum counts recorded show the influence of storm water runoff in the bayou (Figure 33), with the highest counts occurring in the main part of the bayou as well as up into Carpenters Creek.

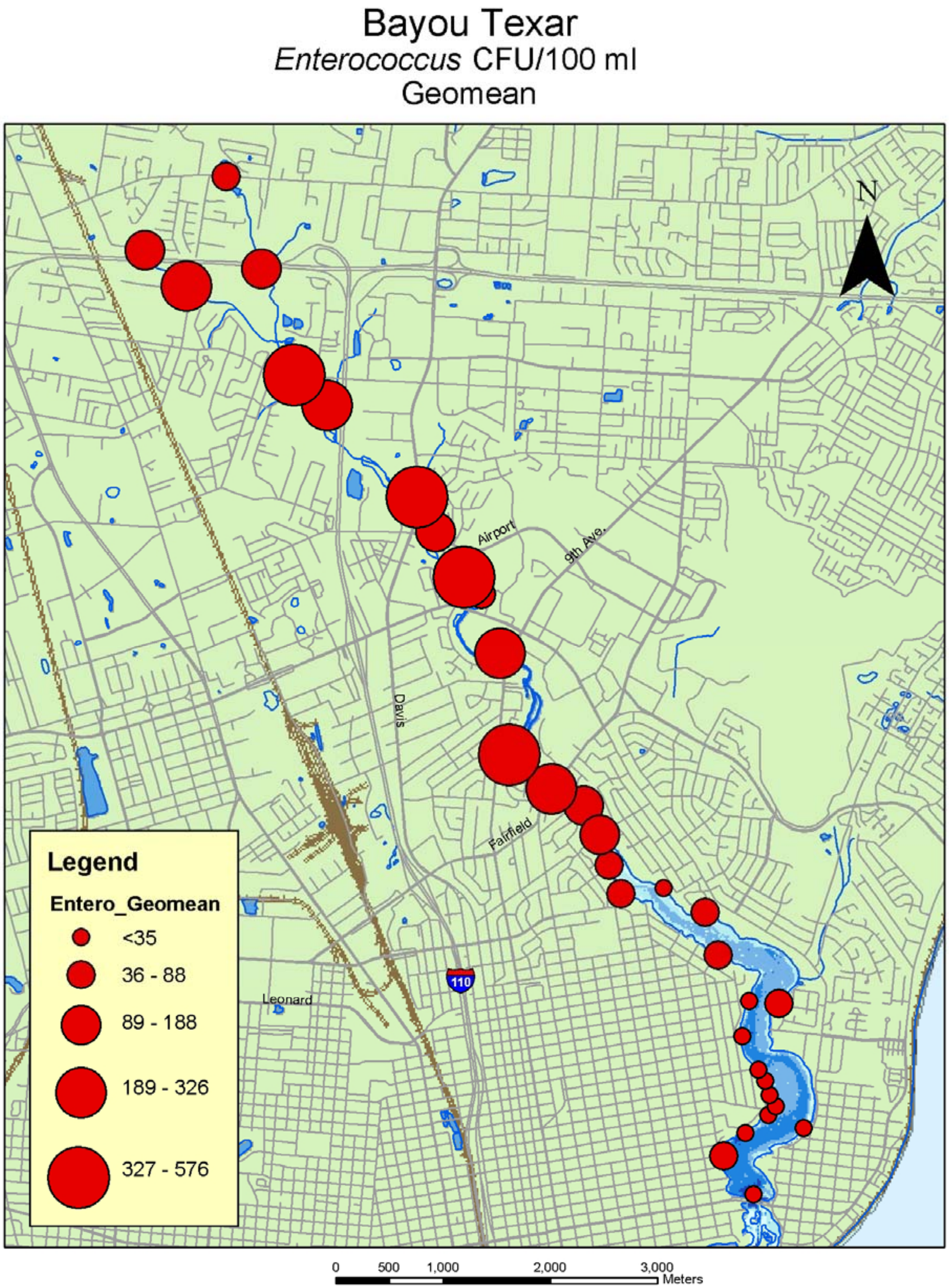

Figure 31. Geomeans for *Enterococcus* counts at each station in Bayou Texar.

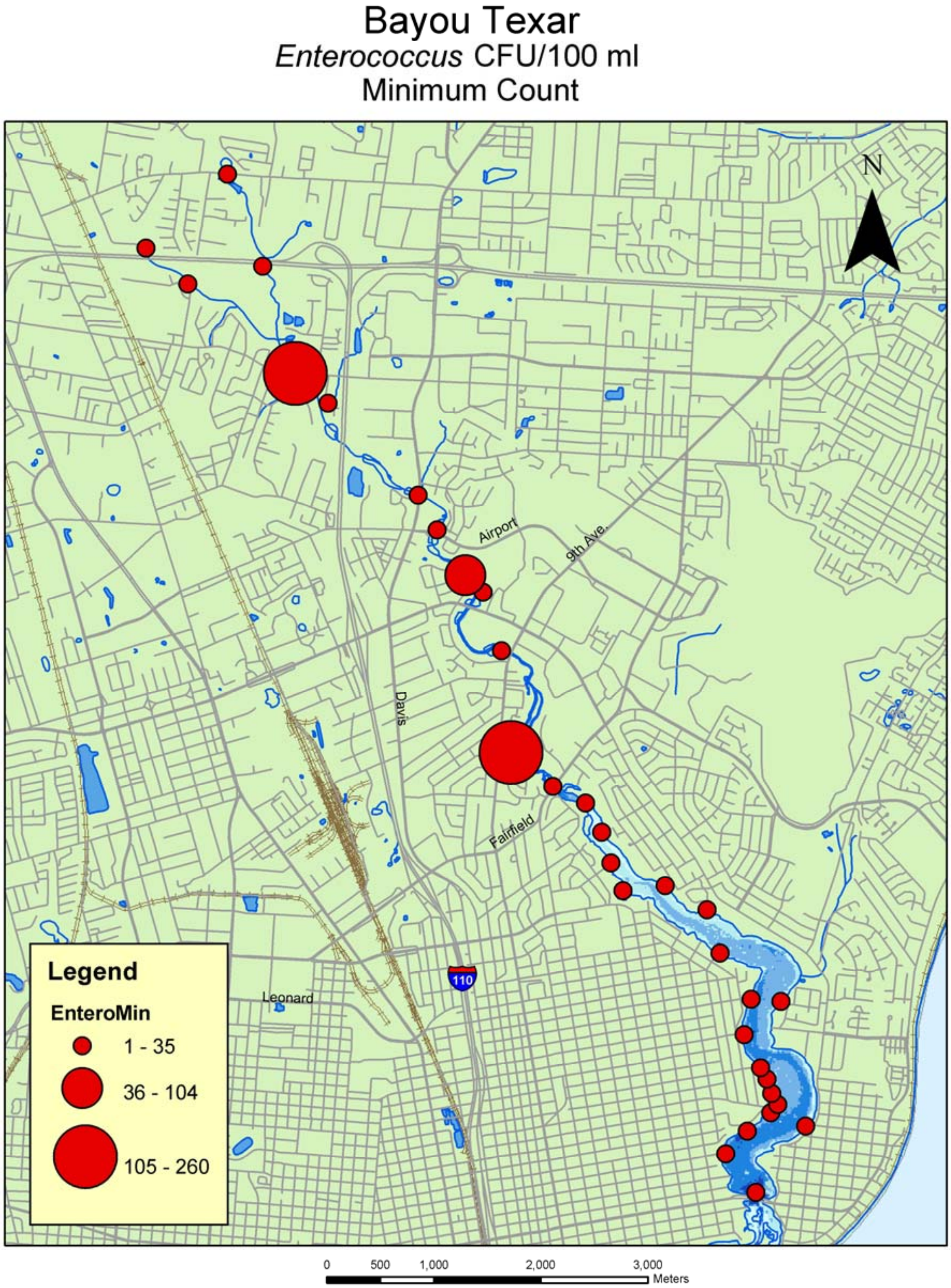

Figure 32. Minimum *Enterococcus* counts recorded from each station in Bayou Texar.

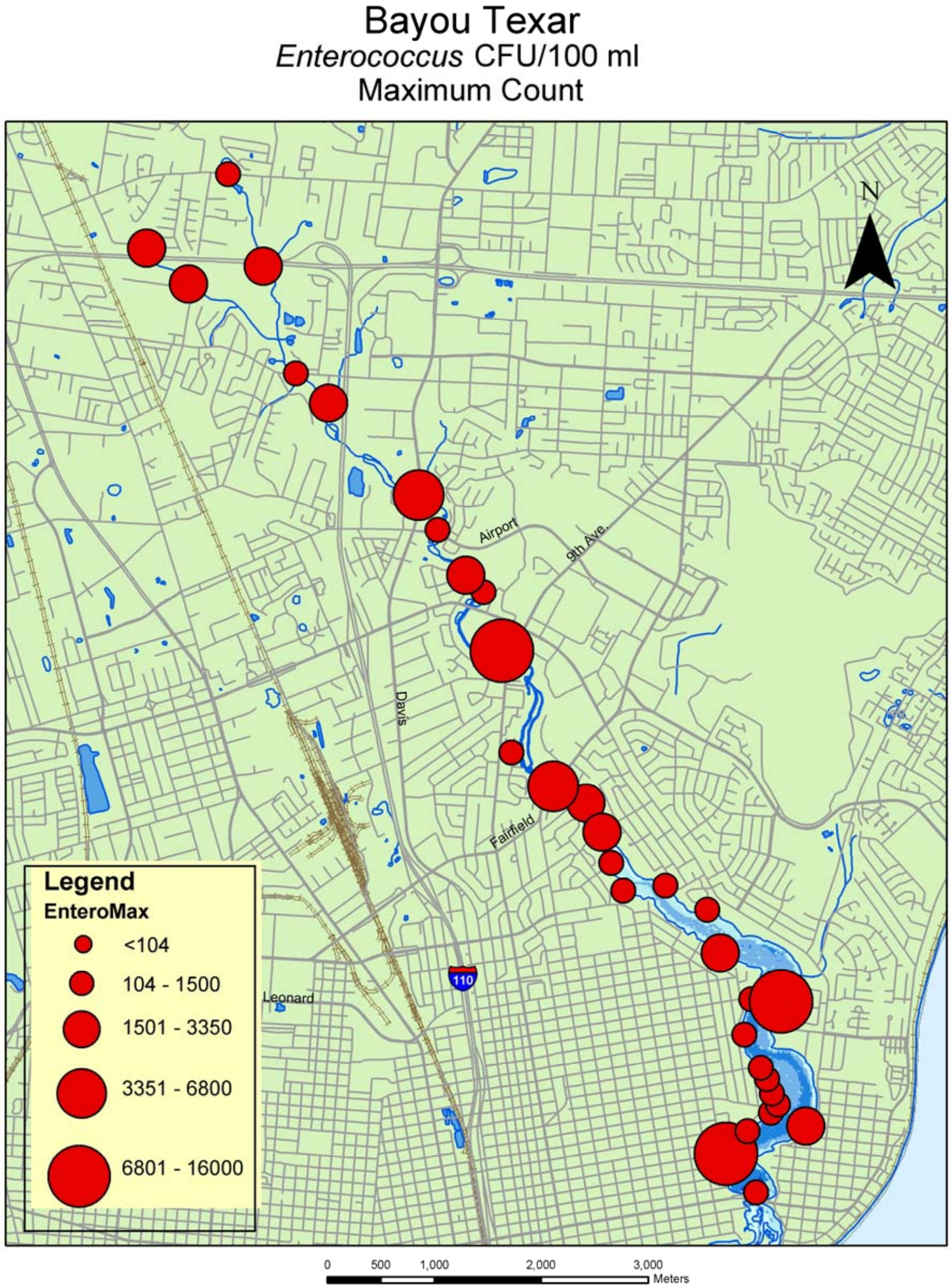

Figure 33. Maximum *Enterococcus* counts recorded from each station in Bayou Texar.

Using correlation analysis, none of the parameters measured were predictive of fecal bacteria loadings within the system. The highest correlation found with rainfall data was for fecal coliforms and the rain total for the 48 hours prior to sampling (0.316). By regression analysis (Figure 34), Bayou Texar had the clearest rain influence of all three bayous. The pattern of reduced variance in *Enterococcus* numbers with high rainfall seen in the other bayous was also found in Bayou Texar, but the reduction of variance was due more to the loss of low counts within the system than decreased high counts from dilution (Figure 34). The impact of rain on Bayou Texar was also reflected in the number of stations with data yielding significant slope estimates for *Enterococcus* dependence on rainfall (Table 12; Figure 35). As with Chico, these slope and intercept estimates were negatively correlated (-0.587), suggesting some separation between groundwater and storm water influences by station. The geospatial distribution of the slope estimates indicates fecal loadings associated with rainfall and storm water runoff throughout the system (Figure 36), but the chronically impaired stations showing high *Enterococcus* counts without any rain prior to sampling as occurring within Carpenters Creek and not in the main part of Bayou Texar (Figure 37)

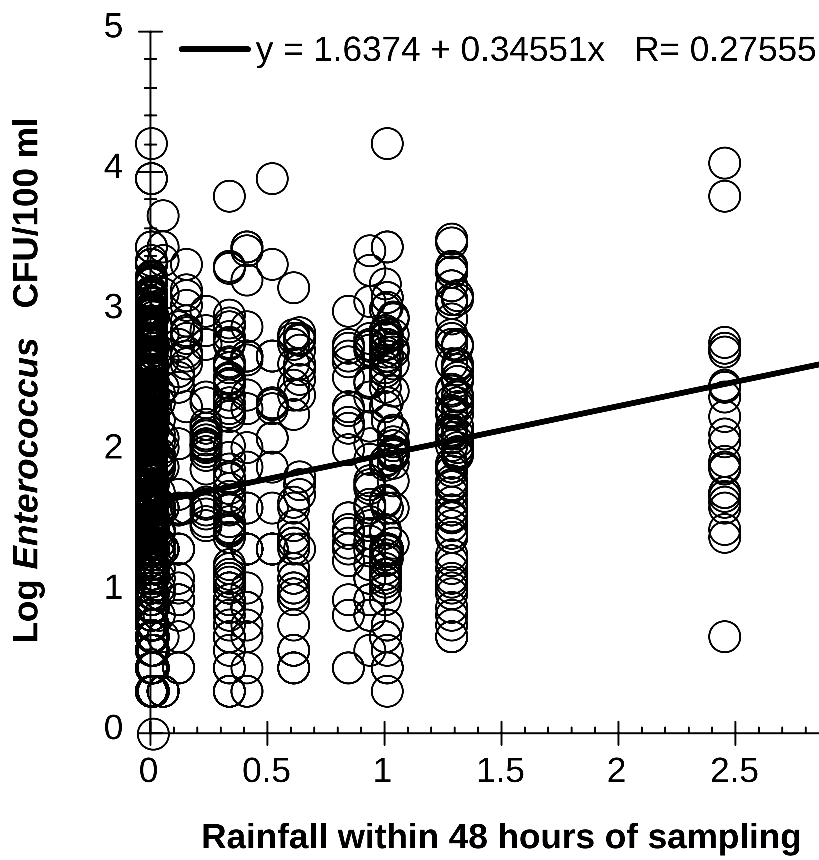

Figure 34. *Enterococcus* counts from Bayou Texar as a function of rainfall in the 48 hours prior to sampling.

Table 12. Regression of Bayou Texar station data as a function of rain. Significant parameter estimates ($p < 0.06$) are indicated in bold.

station code	station name	R^2	Slope	p value	Intercept	P value	geomean at 0 rain
1	**Cervantes Bridge**	**0.103**	**0.355**	**0.043**	**1.087**	**7.61E-15**	**12.213**
2	Brainerd St. pond	0.021	0.345	0.205	**1.782**	**1.08E-20**	**60.593**
3	Bayview Park pvc/storm drain	0.030	0.171	0.164	**0.966**	**8.02E-23**	**9.237**
4	Tree Roots	0.141	0.334	0.064	**0.651**	**2.52E-07**	**4.476**
5	**Boathouse (point)**	**0.175**	**0.432**	**0.008**	**0.768**	**1.35E-11**	**5.857**
6	Rocks/Gazebo	0.072	0.239	0.195	**0.694**	**1.75E-07**	**4.940**
7	Oriental Garden	0.090	0.265	0.146	**0.700**	**1.14E-07**	**5.015**
8	**South Whaley fragmites**	**0.169**	**0.370**	**0.037**	**0.673**	**7.02E-08**	**4.713**
9	Whaley Ditch storm drain	0.030	0.205	0.283	**1.029**	**7.74E-13**	**10.688**
10	Birnam Woods green SD	0.080	0.284	0.172	**1.183**	**9.22E-11**	**15.228**
11	Blackshear Ave. SD	0.066	0.320	0.023	**1.503**	**2.19E-33**	**31.821**
12	**Blanford place FW seep**	**0.174**	**0.502**	**0.007**	**1.594**	**1.26E-19**	**39.233**
13	34th St. storm drain	0.044	0.277	0.303	**1.674**	**1.05E-11**	**47.245**
14	Six Cement poles-tan house	0.142	0.469	0.064	**1.601**	**7.94E-12**	**39.893**
15	**Carpenter Creek center**	**0.238**	**0.702**	**0.013**	**1.825**	**4.45E-12**	**66.833**
16	**Driftwood 4 SD**	**0.111**	**0.474**	**0.036**	**1.873**	**5.30E-19**	**74.714**
17	Texar Woods SD	0.045	0.251	0.187	**1.460**	**1.25E-17**	**28.830**
18	**Seville Dr. (2) SD**	**0.182**	**0.515**	**0.006**	**1.662**	**2.86E-20**	**45.871**
19	**Banquos Court SD**	**0.238**	**1.014**	**0.001**	**1.466**	**1.05E-11**	**29.226**
20	**Bayou Blvd./Perry SD**	**0.178**	**0.584**	**0.007**	**1.169**	**1.72E-13**	**14.747**
21	**12th Ave. bridge**	**0.152**	**0.530**	**0.0001**	**2.294**	**1.59E-51**	**196.602**
22	9th Ave.	0.034	0.174	0.218	**2.427**	**3.81E-33**	**266.995**
23	**Airport Blvd.**	**0.215**	**0.550**	**0.007**	**2.103**	**2.30E-20**	**126.772**
24	Born Court	0.004	0.091	0.676	**2.447**	**2.97E-25**	**280.159**
25	Boiling Brook	0.046	0.270	0.163	**2.392**	**1.75E-26**	**246.456**
26	Sears Warehouse	0.182	0.679	0.069	**1.806**	**7.12E-08**	**64.036**
27	**Interstate 10-Historical Dist.**	**0.105**	**0.425**	**0.047**	**2.034**	**3.55E-20**	**108.098**
28	Olive Road	0.019	0.197	0.463	**1.898**	**6.86E-14**	**79.095**
29	Walton/Davis	0.130	0.458	0.129	**2.478**	**4.84E-12**	**300.913**

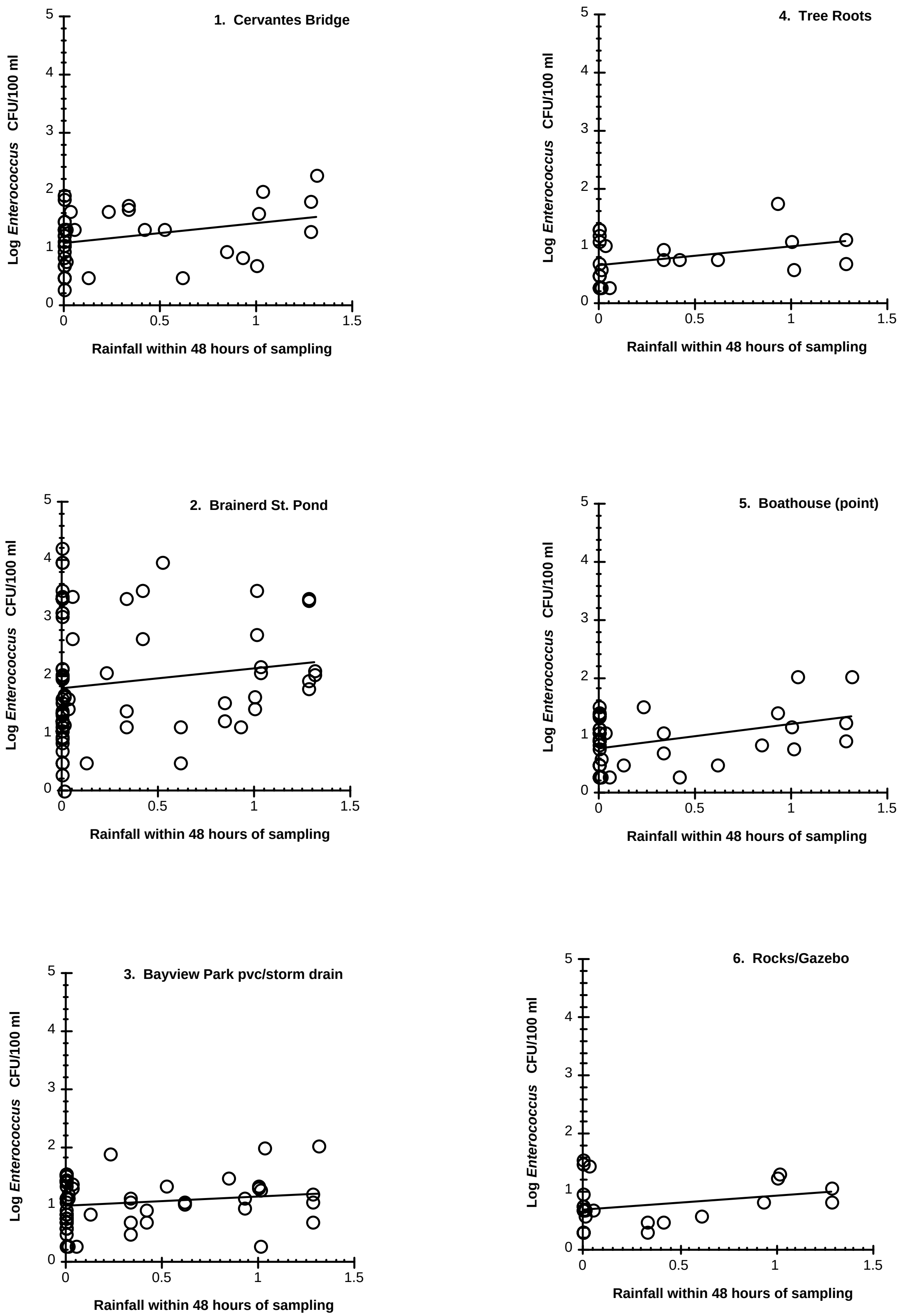

Figure 35. Regression analysis of *Enterococcus* count dependence on rainfall by station in Bayou Texar.

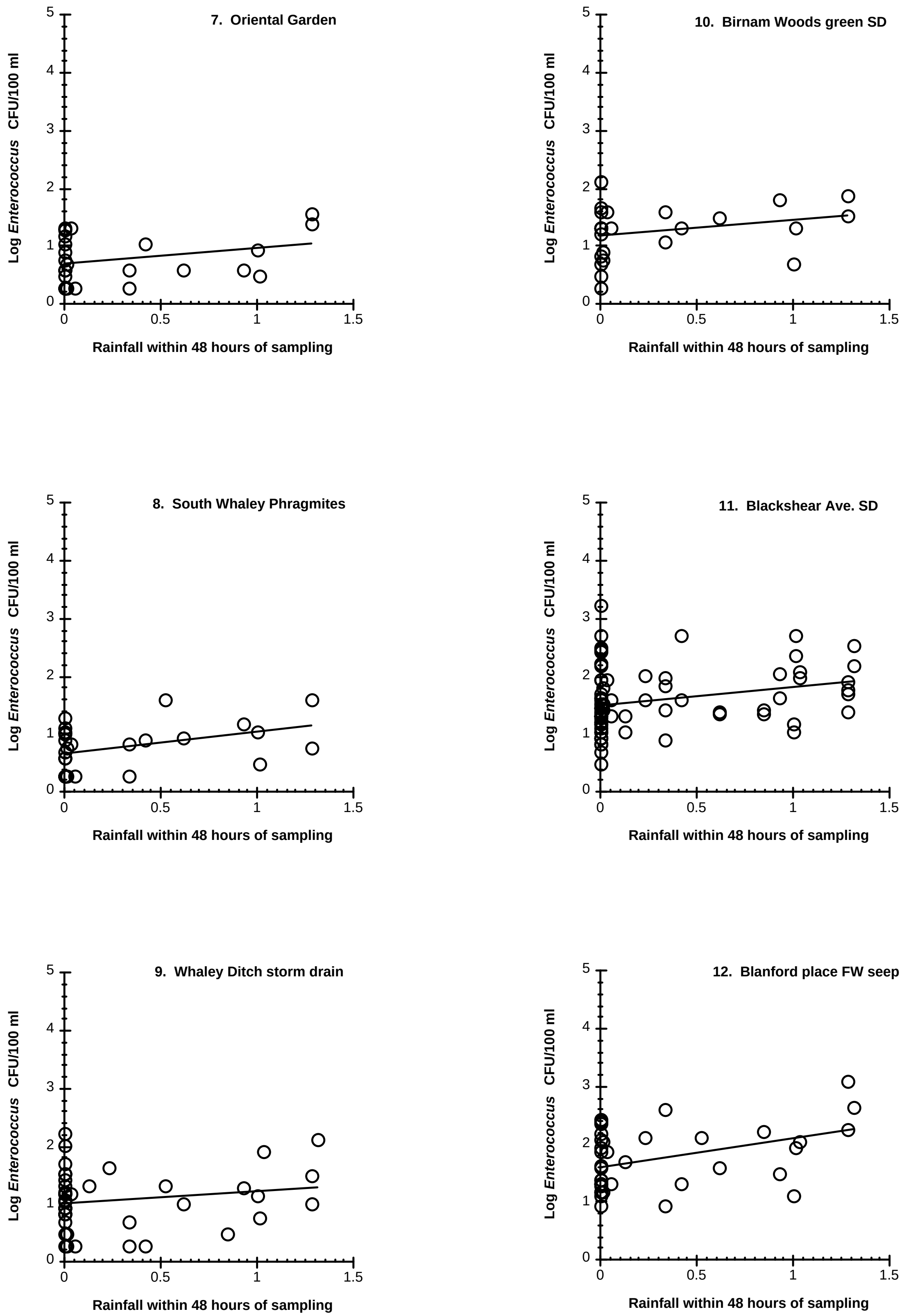

Figure 35, continued. Regression analysis of *Enterococcus* count dependence on rainfall by station in Bayou Texar.

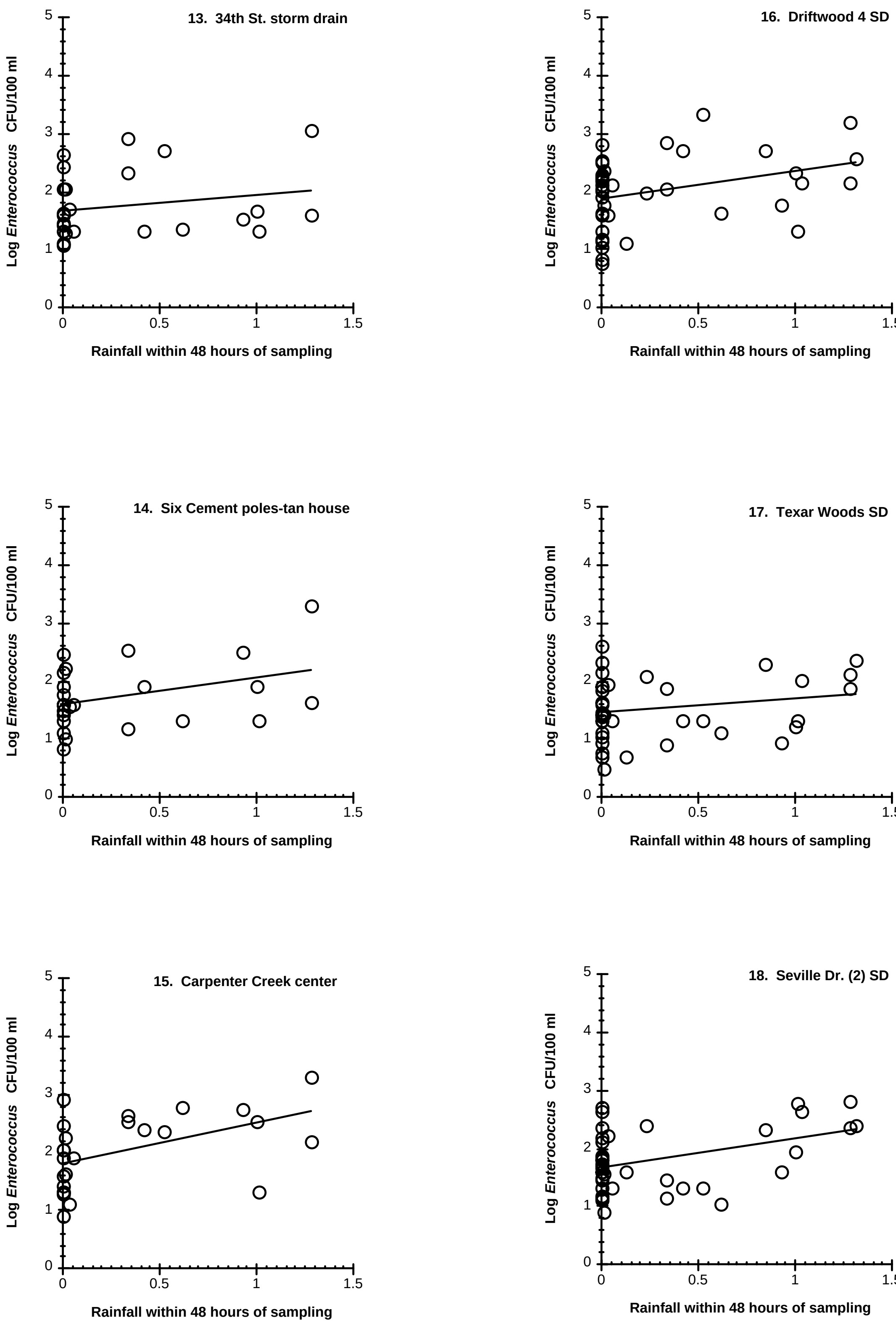

Figure 35, continued. Regression analysis of *Enterococcus* count dependence on rainfall by station in Bayou Texar.

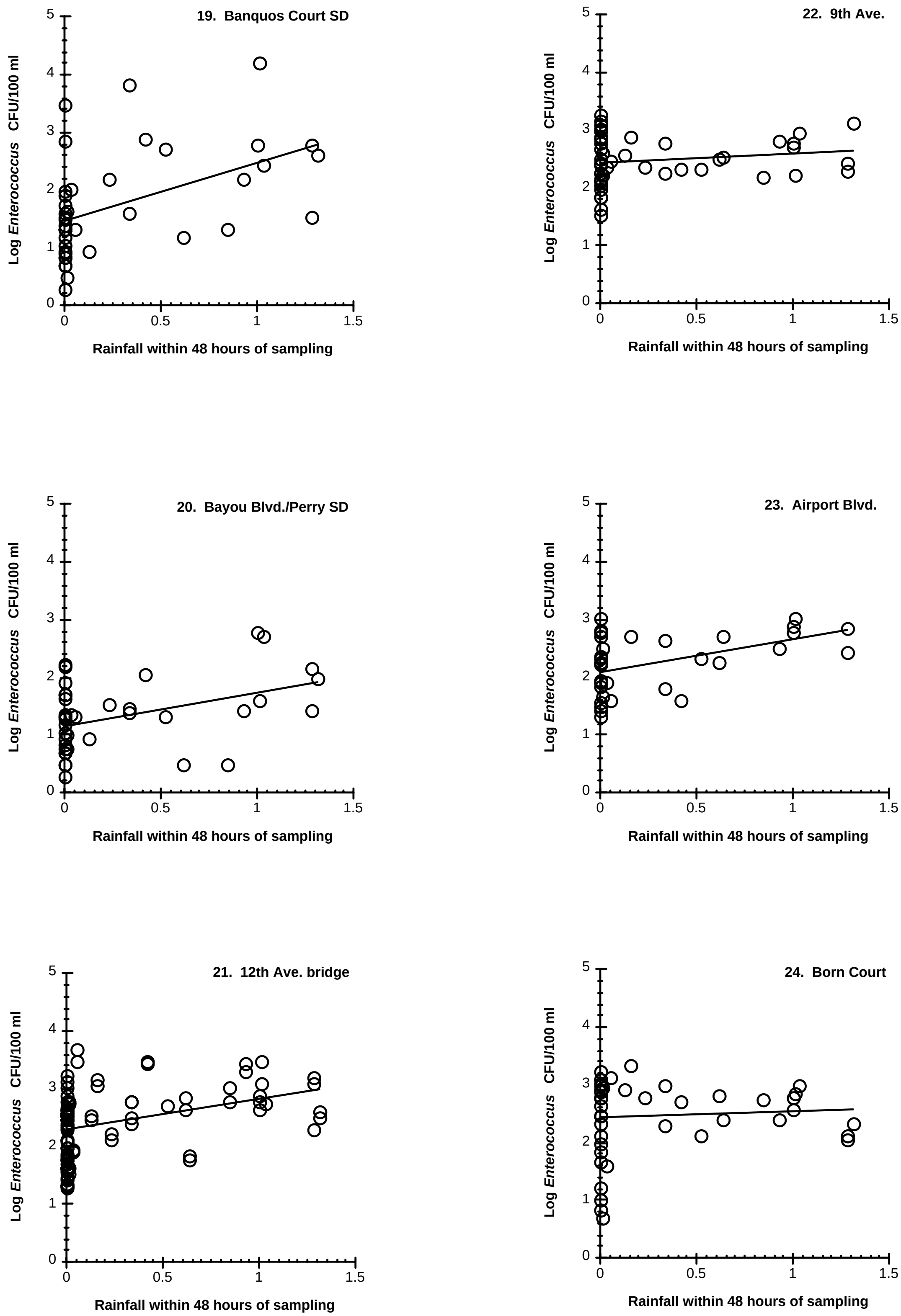

Figure 35, continued. Regression analysis of *Enterococcus* count dependence on rainfall by station in Bayou Texar.

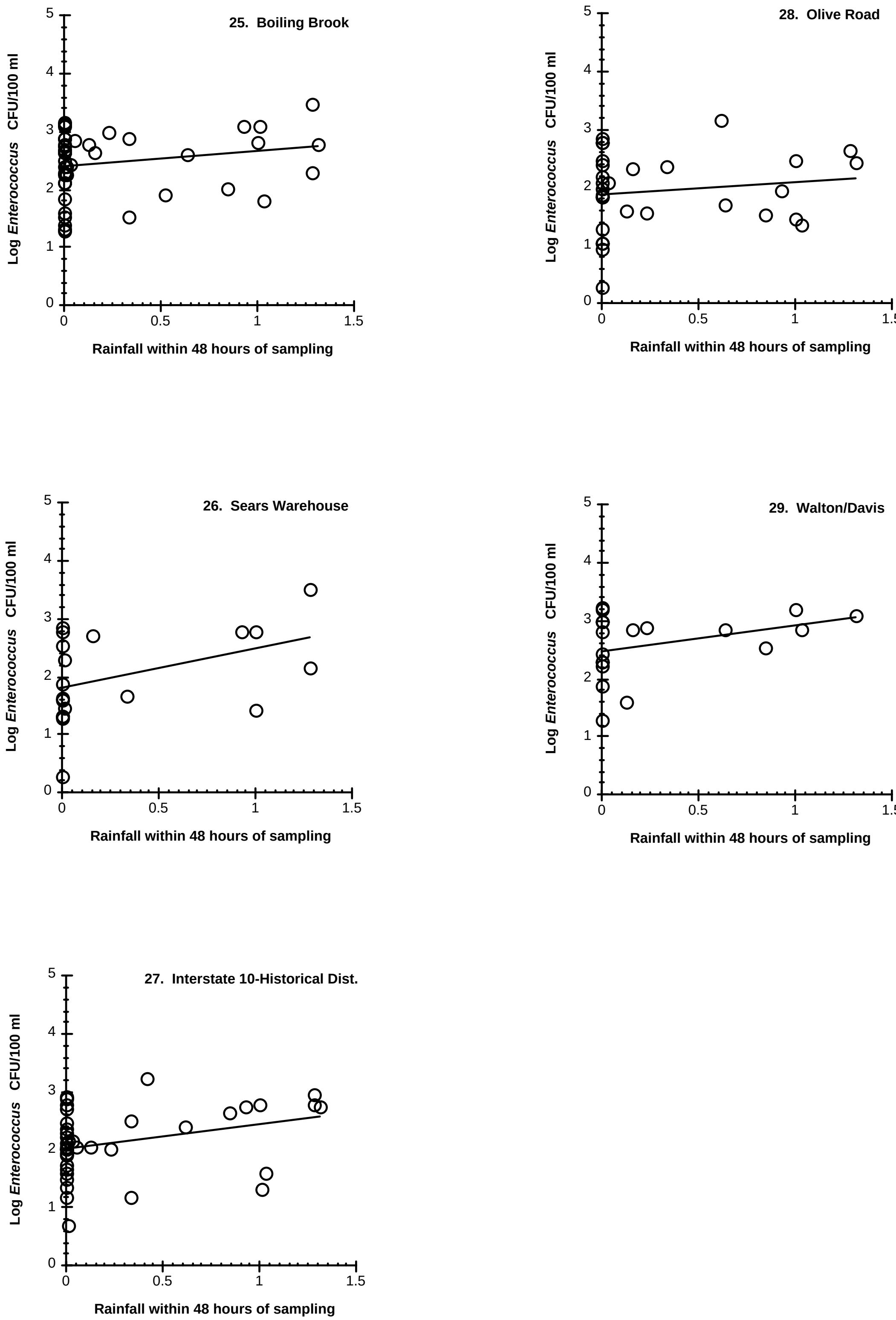

Figure 35, concluded. Regression analysis of *Enterococcus* count dependence on rainfall by station in Bayou Texar.

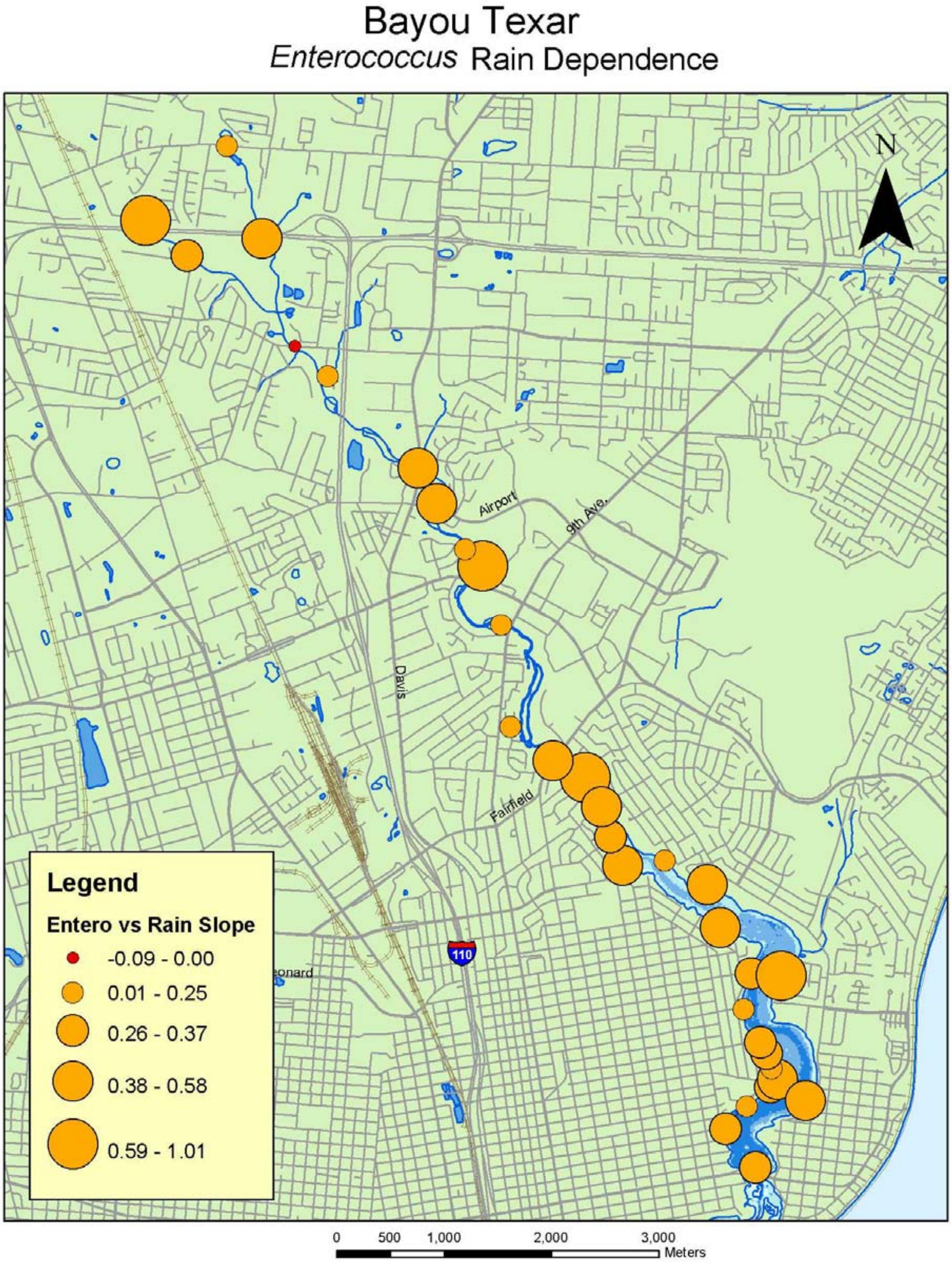

Figure 36. Distribution of slope values for Bayou Texar station rain dependence.

Bayou Texar
Enterococcus CFU/100 ml
Geomean at Zero Rainfall

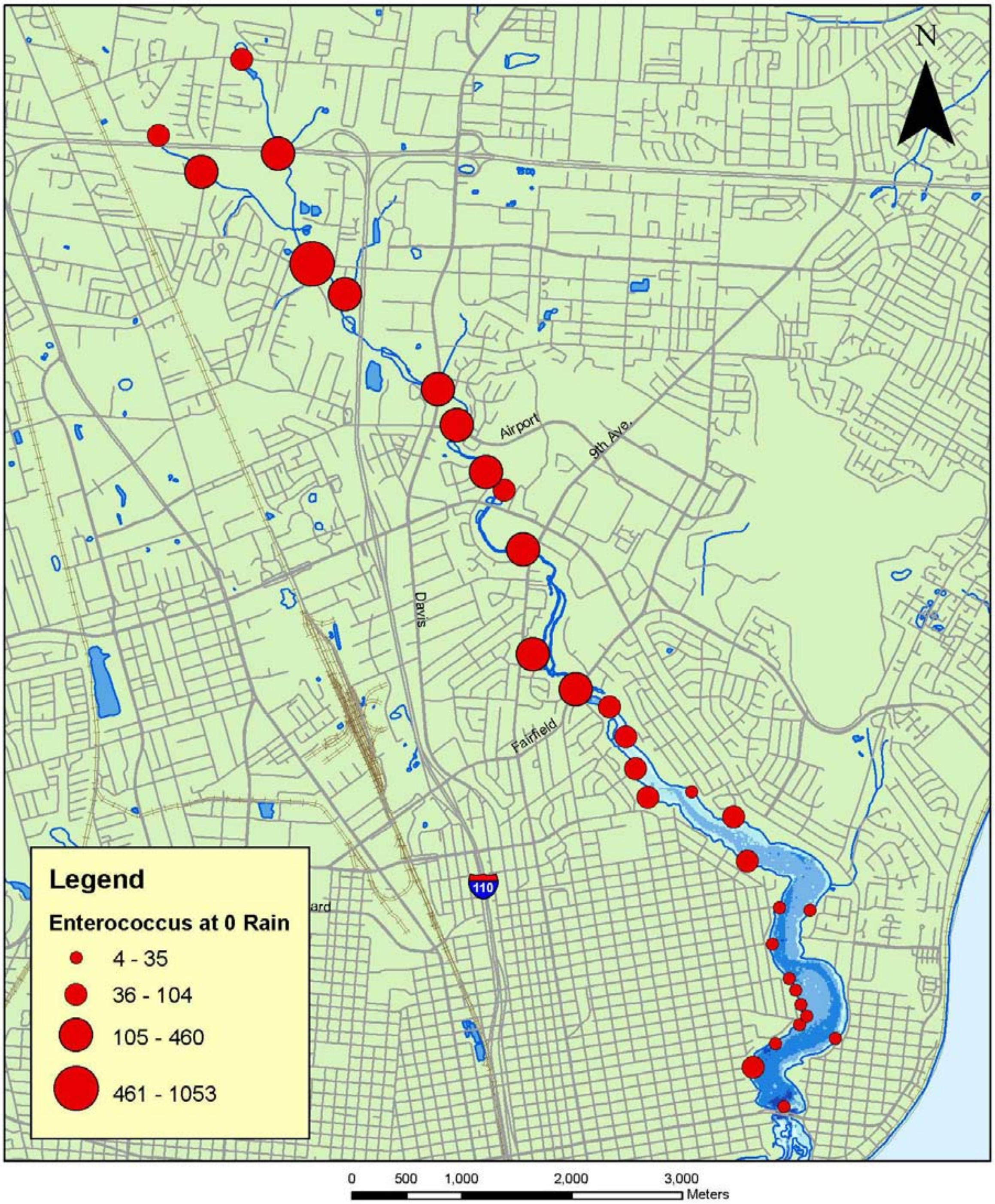

Figure 37. Distribution of y-intercept estimates (*Enterococcus* at zero rainfall) for bayou Texar.

Site-specific Ground water sampling and Infrared (IR) camera assisted sampling

The station-specific nature of the fecal contamination observed in the bayous led us to investigate finer scale loading points to the systems. It was hypothesized that if septic tanks were a major contributor, as they appear to be, then ground water sources to the Bayous needed to be examined. This also was seen as a test of the assumptions that drain field effluents were being diffused and filtered by passage through the vadose zone and with distance through setbacks from surface water as prescribed by current regulations.

In Bayou Grande, extreme low tides in the winter of 2001 were targeted for sampling exposed groundwater flows across the intertidal areas into Bayou Grande. These groundwater discharges were visible as streams flowing out of the shoreline across the intertidal zone (Figure 38), plumes of water emerging from invertebrate burrows under hydrostatic pressure, and as less well defined broad seepage areas emerging from the sands and muds of the intertidal zone. For Bayou Grande, sample locations were identified by eye, and by gauging the rate of fill (if any) in shallow (6-8”) holes dug in the upper intertidal zone.

Results from the sampling in Bayou Grande revealed significant fecal contamination of these ground water sources (Table 13). Sample processing for this lot did not anticipate the high numbers of Enterococci found, and many results were qualitatively recorded as “too many to count” (TMTC), or a lawn of bacteria (Lawn) resulting from too many cells in the sample to allow individual colonies to be distinguished. A Lawn would represent greater contamination than a TMTC sample. This artificial upper limit on quantification limits options for quantitative analysis, but the qualitative results are dramatic enough to illustrate the point.

Figure 38. In the north arm of Bayou Grande, a ground water stream is pictured leaving the shoreline below the wetland vegetation under the high tide mark and traversing the intertidal zone.

Table 13. *Enterococcus* counts for sampling of groundwater in Bayou Grande. Surface water stations are indicated by the bold font.

				Enterococcus (CFU/100 mL)		
Sta #	Latitude	Longitude	Notes	11 Jan 01	20 Jan 01 Site Notes	20 Jan 01
1	30.3827	87.2863	Middle set of pilings	0		
3	30.3831	87.2886	house #309	12		
4	30.3832	87.2890	house #312	44		
5	30.3832	87.2892	house #313	590		
6	30.3833	87.2898	seep	34		
7	30.3834	87.2898	stream	133	~50m further up creek	Lawn[2]
8	30.3837	87.2901	seep	TMTC[1]		90
9	30.3838	87.2900	seep	23		
10	**30.3835**	**87.2893**	**DOH #18**	**99**		**Lawn[2]**
11	30.3838	87.2886	seep	113		
12	30.3844	87.2872	Drain Pipe	269		Lawn[2]
13	**30.3846**	**87.2837**	**DOH #16**	**326**	**~20' from water line**	**1216[3]**
14	30.3852	87.2838	Stream	668		TMTC[1]
15	30.3851	87.2835	seep	435		TMTC[1]
15	30.3851	87.2835	seep		~10' from water/behind seawall	340[3]
16	30.3846	87.2833	seep	18		
17	30.3844	87.3332	seep between seawalls, right pine tree	Lawn[2]		Lawn[2]
17	30.3844	87.3332	seep between seawalls, right pine tree		~6" from water	Lawn[2]
18	30.3836	87.2823	Plastic 18" Drain pipe	398	Waterfowl in area	TMTC[1]
19	**30.3833**	**87.2812**	**DOH # 15**	**44**		**1568[3]**
20	30.3846	87.2801	Stream	80		2600[3]
21	30.3842	87.2803	Between 1st & 2nd Docks	Lawn[2]		TMTC[1]
21	30.3842	87.2803	Between 1st & 2nd Docks ground water			36
22	30.3830	87.2809	Broad seep area, Field dup	73		
22	30.3830	87.2809	Broad seep area, Field dup	76		
23	**30.3823**	**87.2814**	**DOH # 14**	**11**		**1716[3]**

TMTC[1]: too numerous to count.

Lawn[2]: too many bacteria to form distinct colonies on the plate

[3]: result estimated, greater than 60 colonies per plate counted

The use of the infrared (IR) video camera was very effective at identifying the thermal signal from ground water flow into the cooler winter water of Bayou Chico. Thermal plumes could be found leaving the intertidal zone and mixing in with the bayou water. Figure 39 displays visible and IR images of an intertidal beach area experiencing ground water seepage, and an area of higher thermal signature than the surrounding ground water thermal signature. This technology allows the pinpointing of preferential flow paths for ground water entering the bayou when obvious sources as shown in Figure 43 are not apparent.

Sample locations, physico-chemical properties of water samples and the magnitude of *Enterococcus* counts from sampling sites suggested by the use of IR video listed in Table 14. Plots of *Enteroccous* by salinity show high levels in the Bayou itself and generally low numbers in the ground water samples (Figure 40). Three out of 17 ground water samples were equal or greater than 102 colonies per 100 ml (Table 14), but none were high enough to account for the contamination found in the open bayou water. Two of those three samples had elevated salinities of 8.8, 10.4 ppt (Table 14; Figure 40) relative to the third at 4.5 ppt, suggesting that the contamination could have been from bayou water mixing with the ground water on the previous high tide. Chico Bulge #11 had a count of 232 CFU $100ml^{-1}$ (Figure 40) at relatively low salinity (4.5 ppt) suggesting a ground water source for this contamination. This sample tested positive using the molecular test for fecal *Bacteroide*s, indicating a relatively fresh contamination source. A drainage stream to the north near the Navy Boulevard Bridge (Rt. 98) (Figure 41) had elevated *Enterococcus* numbers accounting for one of the two lower surface water *Enterococcus* counts, but a vagrant encampment was the likely source of this contamination.

Residences in the vicinity of the Bayou Grande samples were older and likely had septic tank emplacements prior to current restrictions concerning distances to ground and surface waters. In Bayou Chico, residences along the shoreline up gradient hydrologically to Chico Bulge #11 (Pinewood Avenue) are also served by septic tanks. Elevations for the properties from a USGS topographic map indicate a platform at 10 to 15 ft, and a more rapidly sloping shoreline near the bayou from 10 feet to sea level. A total of 7 properties on the east side (Bayou waterfront) of Pinewood Avenue have had septic tank and drain field inspections between 2000 and 2004. All of these inspections reported sandy loam (one sand), and the observed and seasonal water table in the vicinity of the drain fields as undetectable in a 72” auger sample. Drain field locations were all in excess of 100 ft from the Bayou shoreline. One property owner reported installing a 20 ft irrigation well reaching ground water at 18 ft during a drought year. Total residential units on any of the lots alone the waterfront did not exceed the regulatory limits of 2500 gallons per day per acre disposal capacity, minimum 100 ft from open water, and minimum 24 inches of vadose zone beneath the drain field (Escambia County Ordinance 99-23). State prescriptions for septic tank placement are less restrictive with 75 feet required between OSTDs and surface waters (State of Florida Administrative Code Chapter 64E-6.005(3)).

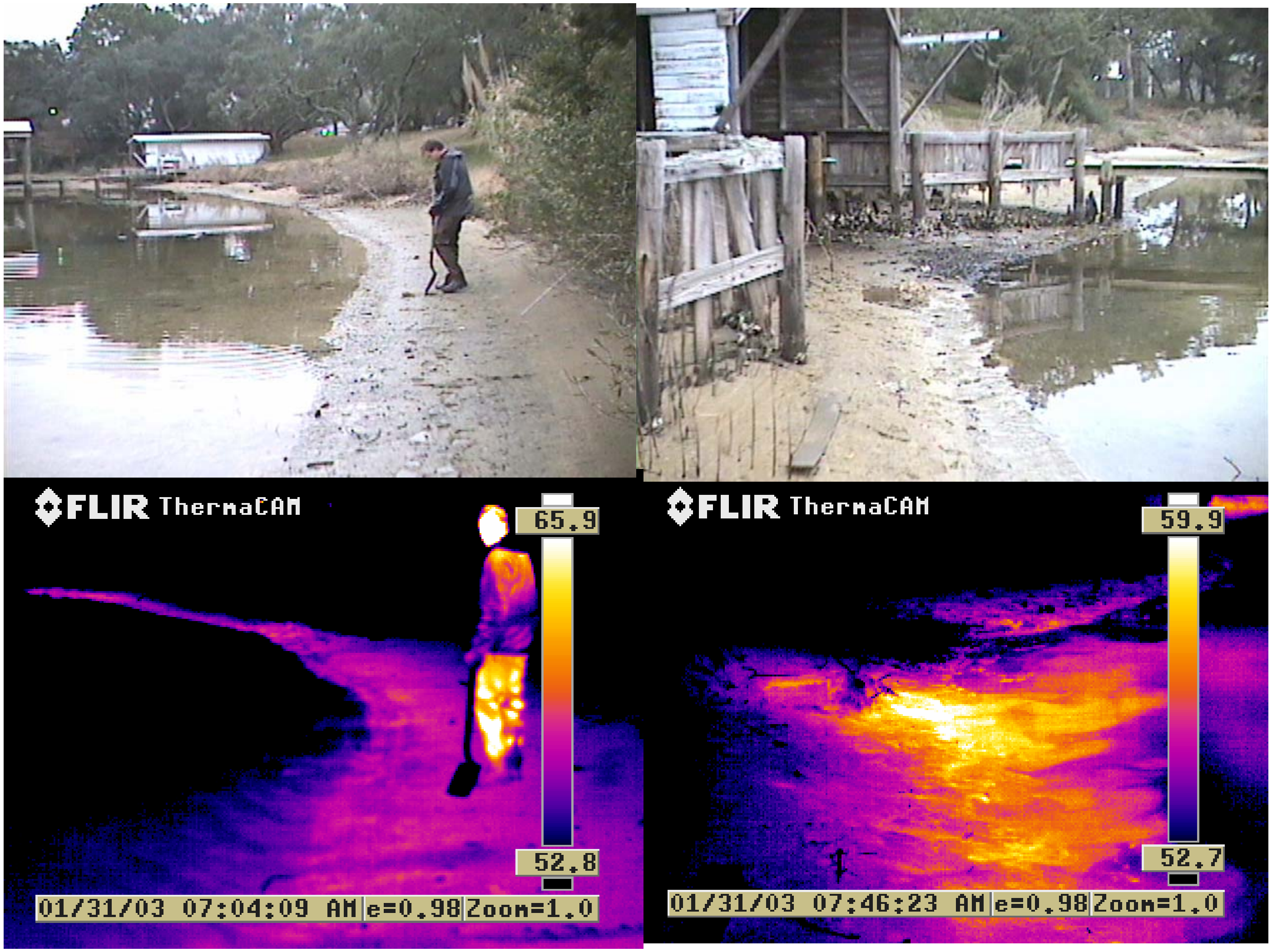

Figure 39. Visible light (top) and infrared (bottom) images of the inter tidal beach of Bayou Chico in winter looking south(left) and north (right) towards the arrow in Figure 28. The two images on the left show warmer ground water seepage out of the intertidal sand and plumes extending into the colder bayou water. The Images on the right display a ground water discharge area with elevated temperature relative to the surrounding groundwater seepage indicating a preferential flow path for groundwater entering the bayou (Chico Bulge #10).

Table 14. Data from IR assisted sampling in Bayou Chico.

Sampling Date	Station ID	Latitude	Longitude	Temp*	Salinity (ppt)	O2 (mg/L)	Entero (CFU/100mL)	Water source
31-Jan-03	Chico Bulge #4(pier)	30.40933	87.25887	13.6	13.1	9.6	680	surface
31-Jan-03	Chico Bulge #9	30.40989	87.2593	13.6	14.8	9.5	780	surface
31-Jan-03	Bulge Jungle	30.41083	87.25926	12.2	12.2	6.6	240	surface
31-Jan-03	Upper WF 1	30.4137	87.26029	14.3	11.9	4.4	170	surface
31-Jan-03	Chico Bulge #1	30.40896	87.25865	13.9	2.85	3.3	26	ground
31-Jan-03	Chico Bulge #2	30.409	87.25079	14.3	8.2	2.6	14	ground
28-Jan-03	White Apartments	30.40906	87.25748	13.8	2.3		35	ground
31-Jan-03	Chico Bulge #3	30.40933	87.25904	13.7	7.8	6.1	26	ground
31-Jan-03	Chico Bulge #5	30.40949	87.25913	12.3	9	1.4	66	ground
31-Jan-03	Chico Bulge #7	30.40971	87.25945	15.5	0.42	5	6	ground
31-Jan-03	Chico Bulge #6	30.40974	87.25935	13.2	4.36	1.6	10	ground
31-Jan-03	Chico Bulge #10	30.40998	87.2595	16.8	0.81	4.5	2	ground
31-Jan-03	Chico Bulge #11	30.41021	87.25947	15.7	4.5	2.6	232	ground
31-Jan-03	Chico Bulge #12	30.41038	87.25945	16.3	0.565	5.2	4	ground
31-Jan-03	Chico Bulge #12.5	30.41055	87.25933	17.2	0.96	3.2	38	ground
28-Jan-03	Worm Tube(wreck)	30.41273	87.25855	13.5	2.89	4	56	ground
28-Jan-03	Pier	30.41303	87.25845	16.4	6.03	3.6	9	ground
31-Jan-03	Upper WF 4	30.41364	87.26102				12	ground
31-Jan-03	Upper WF 2	30.41374	87.26068	15.7	8.8	6.1	102	ground
31-Jan-03	Upper WF 5	30.41384	87.2618	15.2	1.99	6.8	20	ground
31-Jan-03	Upper WF 3	30.41386	87.26071	15	10.4	3.5	144	ground

*from sampled water exposed to cold air, does not represent an ambient groundwater temperature.

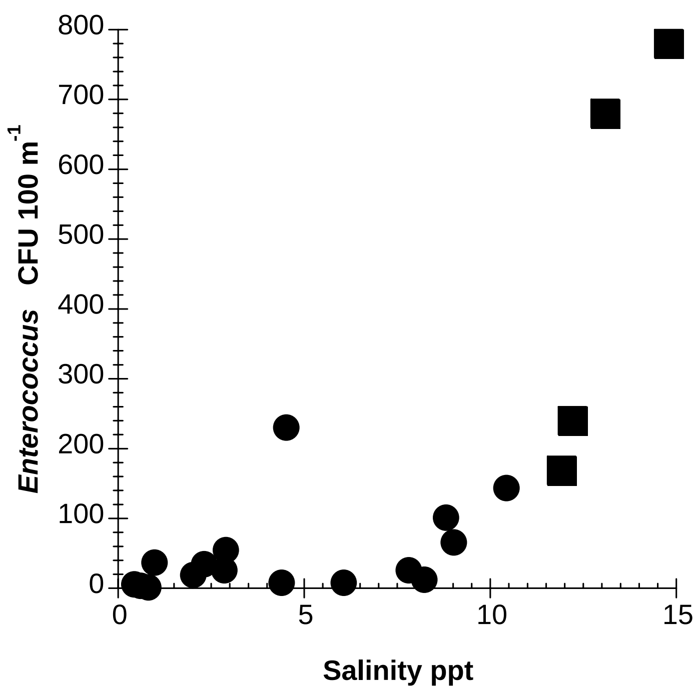

Figure 40. *Enterococcus* counts relative to Salinity for IR assisted point sampling Circles are ground water samples. Squares are surface water samples of the Bayou.

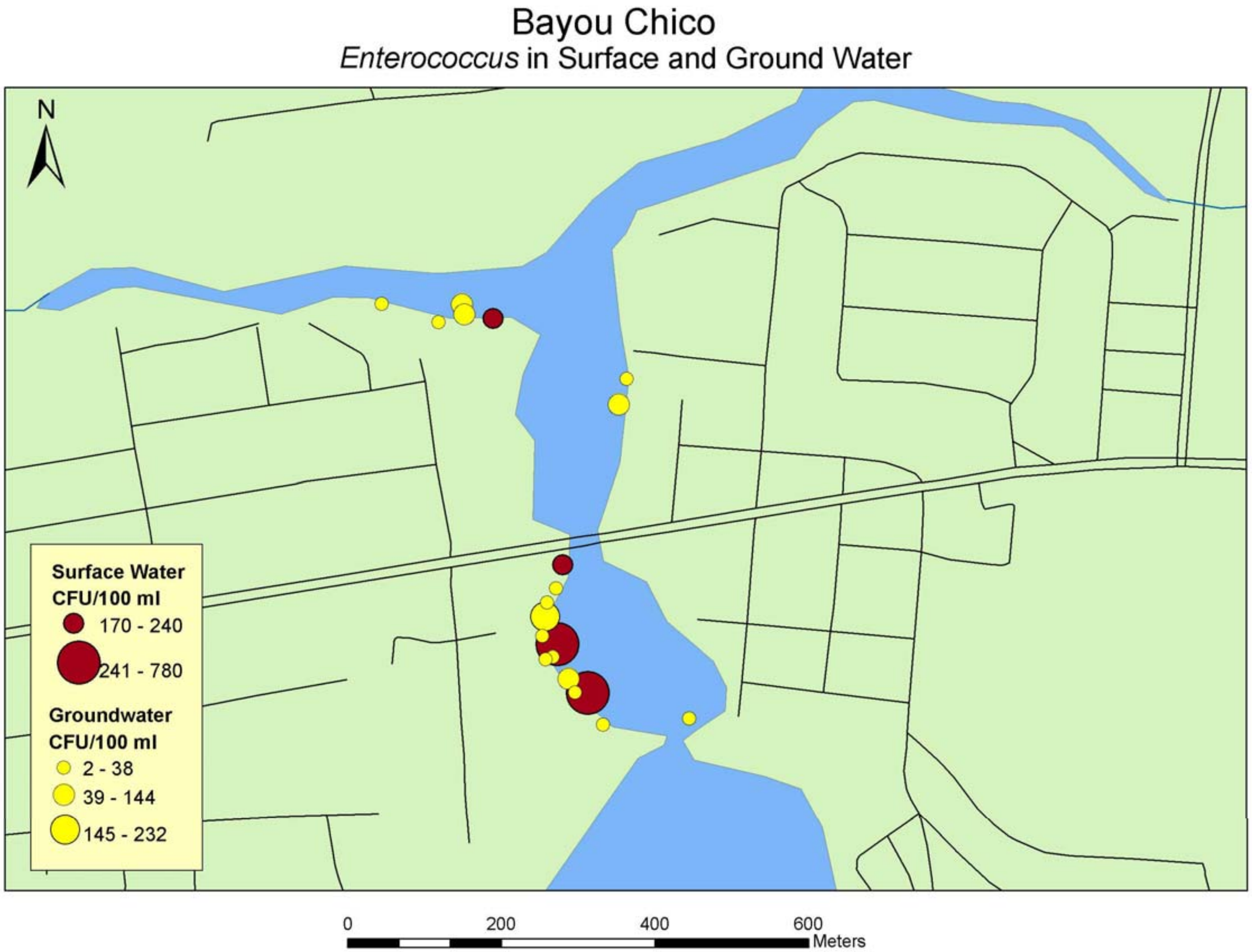

Figure 41. Bayou Chico *Enterococcus* counts at ground water seeps.

Discussion and Conclusions

Fecal contamination in the urban bayous of Pensacola Florida was highly localized, as revealed by intensive sampling focused on potential loading zones. Chronically impaired stations, as indicated by high geomeans of *Enterococcus* counts, high minimum counts, and high zero rainfall geomeans, were found in low elevation residential areas serviced by septic tank systems. During non-rain periods, stations along the open bayou shoreline and drainages of the Naval Air Station covered by golf course and woods had relatively minor concentrations of *Enterococci,* as did the lower industrialized portion of Bayou Chico and the lower part of Bayou Texar serviced by central sewer. These areas showed contamination that was more episodic and storm water related, especially the lower part of Bayou Texar, which seems to receive a large influx of storm-related fecal material.

Terrestrial wildlife and domestic animal sources would be dominant contributors to the storm water loadings, especially in Bayou Grande with the undeveloped shoreline. Waterfront dog owners should be encouraged to clean up after their animals to limit this source of runoff and infiltration of fecal matter. Waterfowl should be more of a widespread background source, except in the case of feral waterfowl and other birds being actively fed in residential waterfront areas. Release of feral waterfowl should be discouraged, existing birds removed, and feeding discouraged. Not only do feral waterfowl contribute to fecal contamination, but they also increase nutrients and organic loadings leading to eutrophication and associated water quality problems.

Rain effects on fecal concentrations in all three bayous were most apparent for moderate rainfall levels (~ 1.5 inches within 48 hours). In Bayous Grande and Chico, high rainfall resulted in some dilution of counts in those systems and loss of variation among stations. Moderate rainfall effects were highly localized by station, with rain effects damped by chronic loadings at zero rainfall at some stations. Rain effects and storm water contamination were most apparent in the lower parts of Bayous Chico and Texar, where contamination at zero rainfall was low.

Patterns of fecal contamination in Bayou Grande emerge as unique relative to Bayous Chico and Texar, which share overall loading patterns. However, these overall differences and similarities belie underlying patterns that involve more commonality than differences. All three Bayous have significant land area not covered by residential development relying on septic tanks. In Bayou Grande, this region is occupied by the Naval Air Station, which runs nearly the length of the southern shoreline as golf course and undeveloped wooded areas. This arrangement results in fecal concentrations along the salinity gradient from drainages of the residential areas of the northern shoreline. In Bayou Chico, the lower bayou is dominated by industrial land use and has a relatively minor residential component, resulting in the loadings being more restricted to the fresher reaches of the system. In Bayou Texar, the lower bayou is surrounded by residential development, but it is serviced by central sewer, and the chronically loaded stations are nearly all within Carpenter's Creek, representing the major freshwater inflow to that system. Some of this area is serviced by older sewer lines and lift stations, which may be contributing to the problem.

Direct sampling of ground water seepages found substantial contamination of groundwater at very specific locations along a shoreline in Bayou Grande. However, in an area of Bayou Chico, serviced by septic tanks in good soils, vadose zone distances many fold over the 24" drain field distance requirements, and shoreline setbacks well in excess of the 100ft minimum county requirement, counts were substantially lower. The one high sample from this area of Bayou

Chico (sample #11) does raise a concern, but requires further characterization. This sampling effort targeted ground water discharge at the water table/intertidal zone interface. Subtidal groundwater discharge as a route for fecal loading to these systems remains uncharacterized.

Although variance in the datasets precluded any significant correlations between nutrient concentrations, BOD, and fecal contamination, geospatial visual analysis strongly suggests that elevated nitrogen species and BOD are associated with stations also experiencing chronic fecal contamination. Resolving the fecal loading problems will likely ameliorate eutrophication stress as well.

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Acknowledgements

This work was supported by a contract from ECHD to UWF for the analysis of fecal contamination in area waterways. The assistance, support, and patience of the ECHD personnel, especially Robert Merritt, Lisa Lavoie, and Mary Beverly is gratefully acknowledged. Thanks also to Jan McCauley, David Polk, and staff at the WRL of UWF for processing of samples. Dr. Kendall Martin, Lori Phillips, Rachel Brooks, and Eric Brewer conducted the *Bacteroides* testing. Kristal Flanders produced the GIS maps. Dr. Ranga Rao, Director of CEDB, provided valuable editorial assistance and advice.