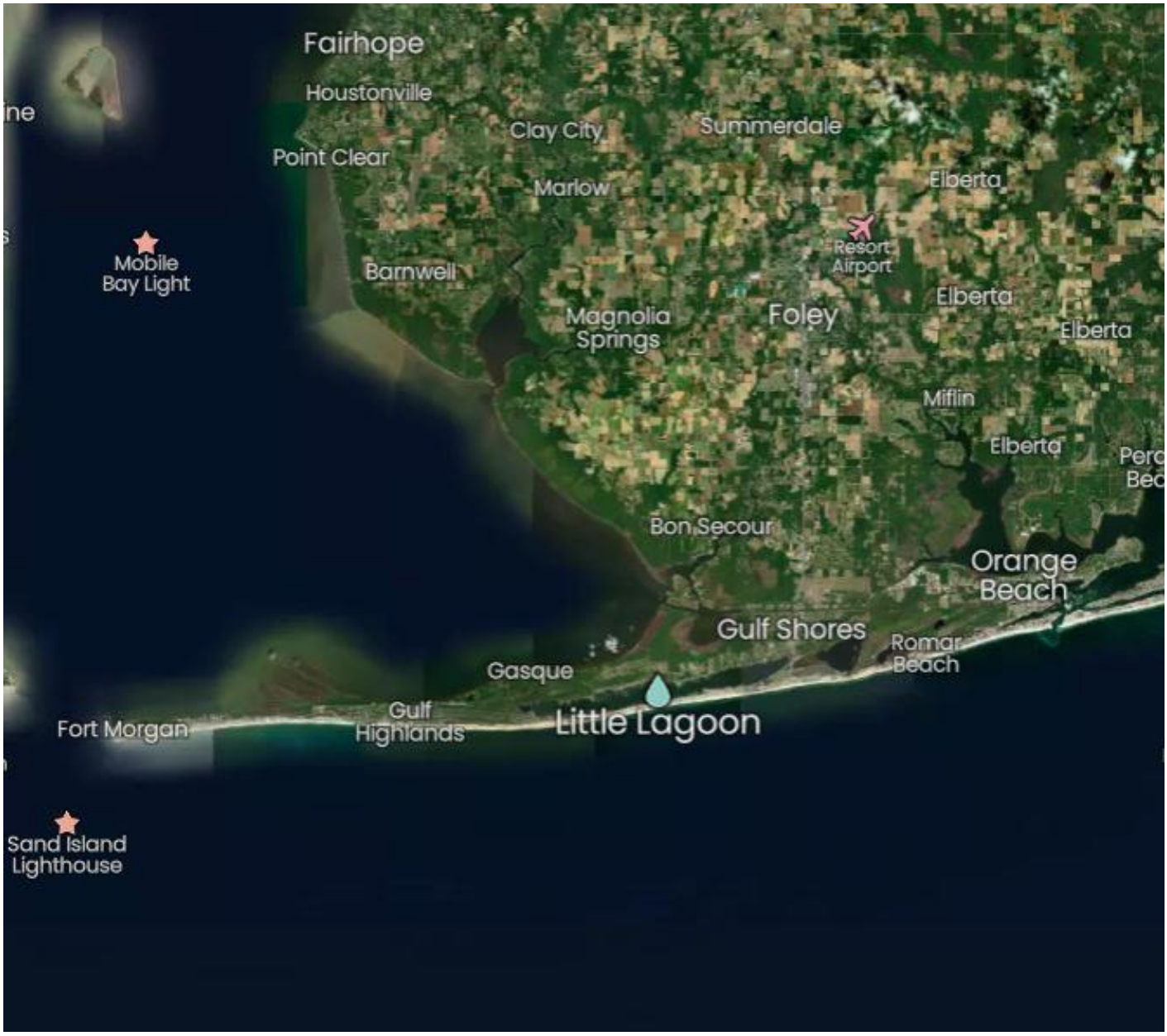
PRE-RESTORATION ANALYSIS OF GROUNDWATER/SURFACE-WATER INTERACTION, WATER QUALITY, AND LAND-USE IMPACTS IN THE LITTLE LAGOON WATERSHED, BALDWIN COUNTY, ALABAMA



Mobile Bay National Estuary Program

BARRY A. VITTOR AND ASSOCIATES

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By

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Funding for this project was provided by the
Mobile Bay National Estuary Program

August 2022

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INTRODUCTION

Little Lagoon is a brackish lagoon on the Alabama Gulf of Mexico coast, covering 2,480 acres. (Little Lagoon Preservation Society, 2022) (fig. 1). The city of Gulf Shores, including the Little Lagoon watershed is among the fastest growing areas in Alabama with a 26 percent (%) population increase between 2010 and 2020, compared to a 2.9% growth rate for the state during the same period (US Census, 2020, World Population Review, 2022). However, with rapid growth comes quality of life issues, including traffic, increasing water demand, increasing wastewater treatment and discharge, loss of natural landscapes and habitats, and watershed degradation. Previous investigations of sediment transport and general water quality have shown dramatic increases in nutrient rich runoff, sediment transport, and loss of biological habitat in watersheds in the Mobile Bay and Gulf Coastal areas. These deleterious impacts originate from land uses dominated by impervious surfaces, deforestation, and transition of land uses from vegetated and agriculture to commercial and residential. The Little Lagoon watershed fits into this categorization as an area with beautiful natural coastal landscapes but rapidly expanding residential and commercial development. The lagoon has a history of documented environmental issues, including excessive fecal coliform bacteria, excessive nutrients, and toxic algal blooms. Results of these investigations are valuable in quantifying impacts and determining contaminant sources, so that limited regulatory and remedial resources may be focused to remediate problem areas and preserve remaining natural landscapes.

The purpose of this investigation is to assess general hydrogeologic and water quality conditions with a focus on groundwater movement, characterization of groundwater/surface-water interactions, groundwater and surface-water contaminants, nutrient concentrations, and determination of possible contaminant sources that impact water quality in Little Lagoon.

ACKNOWLEDGMENTS

Ms. Roberta Swann, Director, Mr. Christian Miller, Watershed Management Coordinator, and Mr. Jason Kudulis, Restoration Project Manager, Mobile Bay National Estuary Program, provided administrative and coordination assistance for the project. Mr. Dennis Hatfield, Little Lagoon Preservation Society, provided logistical and technical guidance and access to wells in the study area. Mr. Wade Burcham, Principal Water

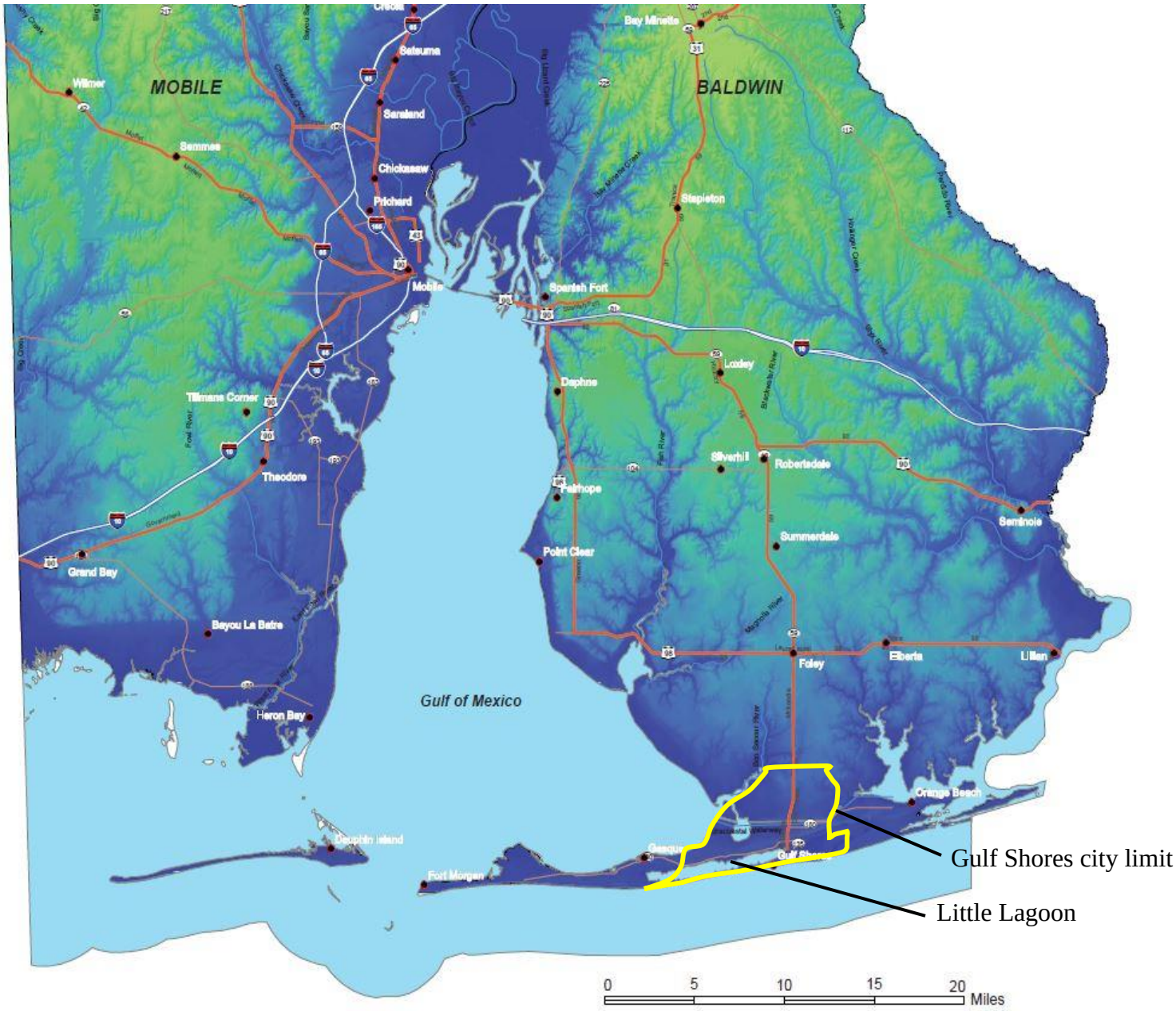


Figure 1.—Mobile and Baldwin Counties with Little Lagoon and Gulf Shores.

Resources Engineer, Geosyntec Consultants, provided technical guidance. Mr. Steven Owens, Plant Manager, Baldwin County Sewer Service Fort Morgan Wastewater Treatment Plant, provided technical reports and information.

HYDROGEOLOGIC CHARACTERISTICS

Little Lagoon receives flow from four lakes further east along the coast, including Lake Shelby, Middle Lake, Little Lake, and Gator Lake, totaling 1,018 acres (fig. 2). Lake Shelby is connected to Little Lagoon by a 1.3-mile-long channel and Little Lagoon is connected to the Gulf of Mexico by Little Lagoon Pass, a man-made channel, 2.9 miles west of Alabama Highway 59, that facilitates tidal water exchange (fig. 2). Other surface-water inflow comes from Long Bayou, a perennial stream on the north side, near the midpoint of the lagoon, which drains the Peninsula Golf community, and a large wetland at the east end of the lagoon (fig. 2). Additional surface-water enters the lagoon from intermittent flow of small channels and topographic low areas that drain residential and commercial development on the north and south sides of the lagoon.

Groundwater in the Little Lagoon watershed flows through two stratigraphic zones, designated as the A_1 and A_2 aquifers. The A_2 aquifer is unconfined to partially confined and is composed of 200 to 250 ft of fine- to very coarse-grained sand, carbonaceous in part, gravel, and interbedded with sandy, silty, clay (Chandler and others, 1985). The overlying A_1 aquifer is unconfined and is composed of 20 to 60 feet (ft) of fine- to coarse-grained sand with interbedded, thin, discontinuous layers of silt, clay, and shell hash (Chandler and others, 1985). Little Lagoon, along with the other coastal lakes, receives much of its inflow from groundwater that discharges in stream channels and areas of low elevation, north of the lagoon, and directly into the lagoon as submarine groundwater discharge (SGD) (Colburn, 2021).

PROJECT PURPOSE

This project has three primary purposes. The first is to document surface-water and groundwater flow characteristics and interaction as a vehicle for introduction of contaminants into Little Lagoon. The second is to document the occurrence and concentrations of chemical constituents in surface water and groundwater that flows into Little Lagoon. These chemical constituents include toxic metals, nutrients, and organic compounds. The third is to identify land covers and uses in the Little Lagoon watershed

Figure 2.—Little Lagoon watershed.

that may be likely sources of contaminants that impact water quality in Little Lagoon.

PROJECT MONITORING STRATEGY AND SITE CHARACTERISTICS

The strategy employed for the Little Lagoon project included selection of monitoring sites on all major surface-water drainages, selected accessible wells, and Little Lagoon/Gulf of Mexico water exchange through Little Lagoon Pass. Each surface-water site was monitored during a high flow event and two sites were monitored during low, base flow conditions. Base flow, composed primarily of groundwater from the A_1 aquifer, discharges on the land surface north of the lagoon in stream channels and areas of low elevation. High-flow monitoring includes surface-water runoff from overland flow and impervious surfaces within the watershed boundary. Discharge was measured and water samples were collected at strategically located surface-water sites (table 1, fig. 3).

Table 1.—Little Lagoon watershed surface-water monitoring sites.

LL1	Little Lagoon Pass tidal channel. Lat 30.241287°N Long -087.737814°W
LL2	Lake Shelby inflow to Little Lagoon at AL Highway 59. Lat 30.254686°N Long -087.693729°W
LL3	Wetland, commercial, and residential drainage from northeast side of Little Lagoon. Lat 30.259975°N Long -087.688637°W
LL4	Long Bayou. Peninsula Golf Resort drainage to Little Lagoon at AL Highway 180. Lat 30.248183°N Long -087.770853°W
LL5	Groundwater discharge point at intersection of Brigadoon Trail and Lagoon Winds Dr. Lat 30.252211°N Long -087.733994°W
LL6	Little Lagoon unnamed intermittent tributary drainage from Gulf Shores Country Club at AL Highway 180. Lat 30.258862°N Long -087.707062°W

On June 23, 2020, Cook Hydrogeology performed a field reconnaissance of the north side of the Little Lagoon watershed along Alabama Highway 180 to identify land-surface groundwater discharge sites. Eleven land-surface exposures of the A_1 aquifer were identified (fig. 3). Records for 34 wells in the Little Lagoon watershed were identified in state of Alabama files. These records were used for well locations, static water levels, and well construction information. Static water levels were identified or

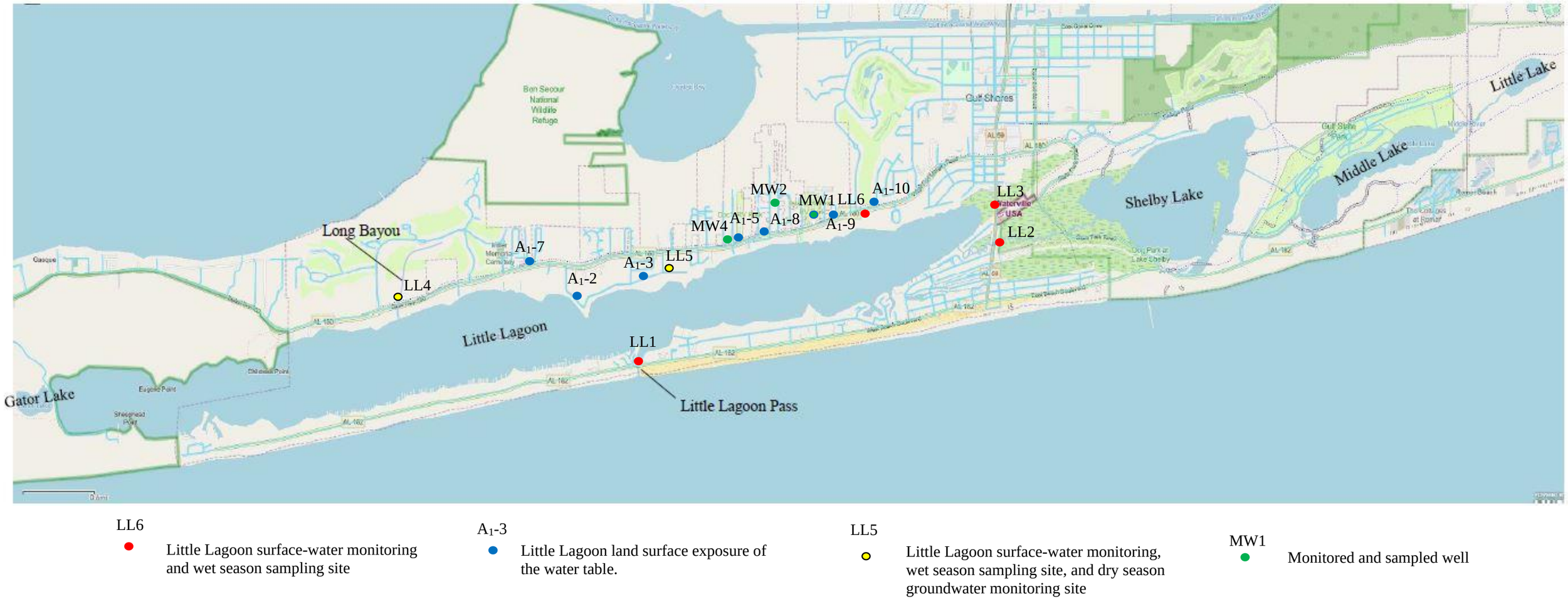


Figure 3.—Little Lagoon watershed surface-water and groundwater monitoring and sampling sites, water table land surface exposure sites, and sampled wells.

were measured in 18 wells, constructed in the A_1 aquifer, five wells constructed in the A_2 aquifer, and three wells for which a depth and aquifer could not be determined (table 2, fig.3). Water samples were collected from two wells, constructed in the A_1 aquifer and from one well, constructed in the A_2 aquifer (fig. 3). A pumping test was performed on well MW4 (Hatfield deep well), constructed in the A_1 aquifer, to determine aquifer hydraulic parameters and to determine groundwater flow rates. Monitoring well characteristics and locations are shown in table 2 and figure 3.

Table 2.--Little Lagoon watershed monitoring well characteristics and locations.

Well	Description	Location lat-long	Well depth ft	Aquifer	Static water level below land surface (ft)		Static water level below land surface (elevation msl ft)	
					Dry season	Wet season	Dry season	Wet season
MW1	Irrigation well at Island Retreat RV Park	30.25811 -87.71381	100	A_2	12.0	11.6	1.0	1.4
MW2	Langston 2387 Ridge Road East	30.25866 -87.71863	N/A	N/A	N/A		N/A	
MW4	Hatfield deep well Henrietta Fulton Place	30.25527 -87.72461	29.3	A_1	2.1	1.4	6.9	7.6
LLW1	15th Avenue near Wal-Mart	30.26843 -87.68721	86	A_2	13.0		2.0	
LLW2	Former Gulf Coast Zoo site	30.26230 -87.68689	105	A_2	3.0		1.0	
LLW4	Marks 401 Sunset Dr	30.25930 -87.69518	30	A_1	3.0		3.0	
LLW5	Russell 413 Sunset Dr	30.25899 -87.69610	25	A_1	3.0		3.0	
LLW6	Holy Spirit Episcopal Church	30.26091 -87.70172	21	A_1	3.0	3.4	10.0	9.6
LLW7	Helton 1377 W Fairway Dr	30.26486 -87.70773	70	A_2	10.5	10.0	0.5	1.0

Well	Description	Location lat-long	Well depth ft	Aquifer	Static water level below land surface (ft)		Static water level below land surface (elevation msl ft)	
					Dry season	Wet season	Dry season	Wet season
LLW8	Bacon 1352 W Fairway Dr	30.26278 -87.70768	50	A_1	11.0		1.0	
LLW9	Bacon 1352 W Fairway Dr	30.26278 -87.70768	85	A_2		19.0		-7.0
LLW10	Kutter 1333 W Fairway Dr	30.26097 -87.70780	25	A_1		8.0		7.0
LLW13	Wallace Wallace Dr	30.26047 -87.71700	22	A_1	8.0		11.0	
LLW16	Hatfield shallow well 2031 Norman Lane	30.25372 -87.72476	N/A	A_1	1.8	1.0	0.2	1.0
LLW17	Adams 2013 Minnesota Lane	30.25385 -87.72684	20	A_1	10.0		7.0	
LLW19	Bruce White & Asso	30.25623 -87.72809	30	A_1				
LLW23	Galle	30.24859 -87.76443	20	A_1	6.0		-1.0	
LLW24	Muldoon 14186 AL Hwy 180	30.24566 -87.78058	32	A_1	16.2		-9.2	
LLW25	Lagoon Mobile Home Subdivision	30.25440 -87.73813	100	A_2	8.0		4.0	
LLW26	Bay Gardens Subdivision	30.25266 -87.81044	45	A_1	8.0		3.0	
LLW27	Bob Inmon 17330 AL Hwy 180	30.25419 -87.72810	15	A_1		5.0		6.0
LLW28	Gulf Shores Country Club Gul 78	30.26623 -87.70519	61	A_1	12.0		-5.0	
LLW29	Gulf Shores Country Club Gul 79	30.27483 -87.70456	90	A_2	30.0		-25.0	
LLW30	Our Lady of the Gulf Catholic Church	30.27605 -87.68231	40	A_1	11.0		-2.0	

Well	Description	Location lat-long	Well depth ft	Aquifer	Static water level below land surface (ft)		Static water level below land surface (elevation msl ft)	
					Dry season	Wet season	Dry season	Wet season
LLW31	Payne 613 Wedgewood Dr	30.27586 -87.70573	130	A_2	3.0		2.0	
LLW32	Mattson 830 Heron Cove	30.27159 -87.71375	35	A_1	3.0		2.0	
LLW33	Meyer Real Est 1585 Gulf Shores Pkwy	30.26788 -87.68944	120	A_2	15.0		-4.0	
LLW34	Retinas 2367 Wallace Ln	30.25922 -87.71575	27	A_1	6.0		7.0	
LLW35	Southport Seafood E. 1st St.	30.28162 -87.68564	140	A_2	12.0		-3.0	
LLW36	Ellis 501 Wedgewood Dr	30.27421 -87.70124	45	A_1		10.0		-4.0
LLW37	Wright 1320 E Fairway Dr	30.26048 -87.70471	17	A_1	7.0		4.0	
LLW38	McMenas 825 E. 24th St.	30.27783 -87.67161	57	A_1	10.0		-1.0	
LLW39	Schamberger 224 W. 19th St.	30.27273 -87.69091	50	A_1	15.0		1.0	
LLW40	Dameworth 936 E. 22nd Ave.	30.27952 -87.66961	35	A_1	12.0		-5.0	
LLW41	Eddings 613 Forestwood Dr.	30.26275 -87.70152	67	A_1		10.0		12.0
LLW42	Brown 348 W. 23rd Ave.	30.27680 -87.69381	70	A_2	10.0		-4.0	
LLW43	Beck 1445 W. 2nd St.	30.26401 -87.69203	69	A_2	17.0		3.0	
LLW44	Gulf Shores Utilities Well #3	30.29248 -87.68582	225	A_2	11.0	11.0	5.0	5.0
LLW45	Gulf Shores Utilities Well #4	30.27470 -87.68555	138	A_2		8.1		-0.1
LLW46	Gulf State Park	30.26588 -87.67672	33	A_1	8.4	6.9	4.6	6.1

Well	Description	Location lat-long	Well depth ft	Aquifer	Static water level below land surface (ft)		Static water level below land surface (elevation msl ft)	
					Dry season	Wet season	Dry season	Wet season
LLW47	Peteet Mariculture Center	30.283491 -87.66612	144	A_2	13.5		-5.5	
LLW48	White Knight Seafood	30.278147 -87.68509	106	A_2		14.0		-6.0
LLW49	Payne 613 Wedgewood Dr	30.27586 -87.70573	65	A_1	8.0		-3.0	
LLW50	Gulf Shores Baptist Church	30.27494 -87.68787	118	A_2	12.0		1.0	
Baldwin County Sewer Service Fort Morgan Treatment Plant Monitoring Wells (*water levels are below top of casing)								
MW1		30.25469 -87.73637	20	A_1	7.64	6.30	8.95	10.29
MW2		30.25561 -87.73417	20	A_1	5.62	4.40	9.05	10.27
MW3		30.25745 -87.73427	10	A_1	3.57	2.98	9.29	9.88
MW5		30.25747 -87.73675	25.1	A_1	6.63	5.78	10.53	11.38
MW6		30.25600 -87.73818	21	A_1	5.77	4.84	9.88	10.81
MW7		30.25717 -87.73800	16.5	A_1	5.58	4.71	7.34	11.96
MW8		30.25479 -87.73543	16.5	A_1	9.69	8.41	5.53	10.54
Peninsula Golf Resort Irrigation Wells								
IWA		30.25479 -87.73543	N/A	N/A	13.2		1.8	
IWB		30.25479 -87.73543	N/A	N/A	13.8		-1.8	

GROUNDWATER LEVELS, RECHARGE, AND MOVEMENT

A potentiometric groundwater level is the elevation to which water rises in a well that penetrates a confined aquifer. The potentiometric surface is a virtual surface representing the confined pressure (hydrostatic head) throughout all or part of a confined aquifer (Driscoll, 1986). A water table is the spatial distribution of water levels in wells in an unconfined aquifer and is a type of potentiometric surface. Commonly, land surface topography influences recharge and groundwater movement in unconfined aquifers. These surfaces are helpful in determining directions of ground-water movement, hydraulic gradients, and depths from which water can be pumped at specific locations. Water table maps were constructed from water levels collected during dry and wet seasons to determine directions of groundwater movement, hydraulic gradients, and the recharge area for aquifers on the north side of Little Lagoon.

Static water levels were identified or were measured in 33 wells, constructed in the A_1 aquifer, 16 wells constructed in the A_2 aquifer, and two wells for which a depth and aquifer could not be determined (table 2). Eleven land-surface exposures of the A_1 aquifer water table, in stream channels and areas of relative low elevation, were identified along the northern shore of the lagoon (table 3, fig. 3).

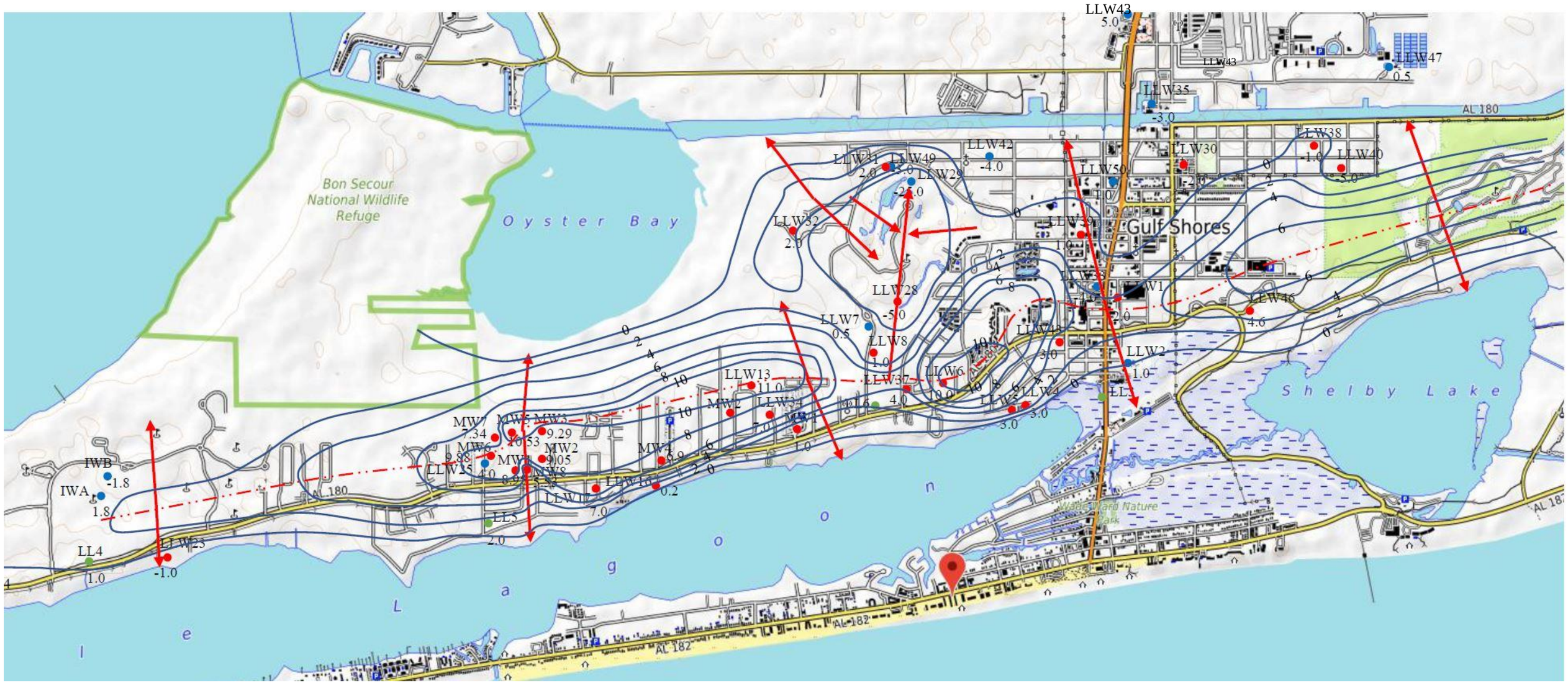
Figures 4 and 5 show the configuration of the water table for the north side of the Little Lagoon watershed for dry and wet seasons. Groundwater levels measured in wells, constructed in the upper A_2 aquifer, show some confinement, but generally conform to the A_1 aquifer water table surface. Therefore, the upper A_2 aquifer is unconfined or partially confined and is hydraulically connected to the overlying A_1 aquifer. The maps show that movement of shallow groundwater in the A_1 aquifer and upper A_2 aquifer is influenced by land-surface topography and conforms to surface-water drainage patterns. Directions of surface-water drainage and groundwater movement in the area between Little Lagoon and the Intercoastal Waterway are determined by a drainage divide that extends along the entire length of Little Lagoon (figs. 4, 5). Groundwater on the north side of the divide flows northward to the Intercoastal Waterway and groundwater on the south side of the divide flows southward to Little Lagoon. Dry season hydraulic gradients vary from 0.006 ft/ft (31.7 ft/mile) in the Baldwin County Sewer Service Fort Morgan Treatment Plant area, 0.003 (15.6 ft/mile) in the Gulf Shores Country Club area, and at the eastern end of the lagoon (fig. 4). Maximum dry season groundwater level elevations

Table 3.—Surface exposures of the A_1 aquifer water table along the north shore of Little Lagoon.

A_1 aquifer surface site	Description	Location lat-long	Elevation ft msl
LL3	Wetland on the northeast side of Little Lagoon	30.26097 -87.70780	0-7
A_1-2	Wetland near the west end of Brigadoon Trail	30.24921 -87.74405	1
A_1-3	Unnamed tributary to Little Lagoon at Brigadoon Trail	30.25091 -87.73727	2
LL5	Groundwater discharge point near Brigadoon Trail and Lagoon Winds Dr	30.25221 -87.73399	2
A_1-5	Doc's RV Park	30.25510 -87.72397	5
LL4	Long Bayou at AL Hwy 180	30.24818 -87.77085	1
A_1-7	Twin Pines Circle and AL Hwy 180	30.25286 -87.75241	9
A_1-8	Lagoon Baptist Church	30.25592 -87.71986	6
A_1-9	Buskin Lane and AL Hwy 180	30.25872 -87.70847	5
A_1-10	Gulf Shores Country Club East Fairway Dr.and AL Hwy 180	30.25898 -87.70515	7
LL6	Gulf Shores Country Club near West Fairway Dr.and AL Hwy 180	30.25886 -87.70706	6

occur in well MW5 at the Baldwin County Sewer Service Fort Morgan Treatment Plant (10.53 ft above mean sea level (msl)), well LLW6 at Holy Spirit Episcopal Church (10.0 ft msl), and well LLW46 at Gulf Shores State Park (4.6 ft msl). Figures 6 and 7 show groundwater level elevation profiles for the Baldwin County Sewer Service Fort Morgan Treatment Plant and Gulf Shores Country Club areas.

The recharge area for the A_1 aquifer on the north side of Little Lagoon covers 3.7 square miles (mi^2) (fig. 4). Cook and others (2018) estimated recharge rates for the undifferentiated Miocene aquifer in Alabama, using four different methods, that varied



Water level elevation (MSL) contours (2 ft contour interval)

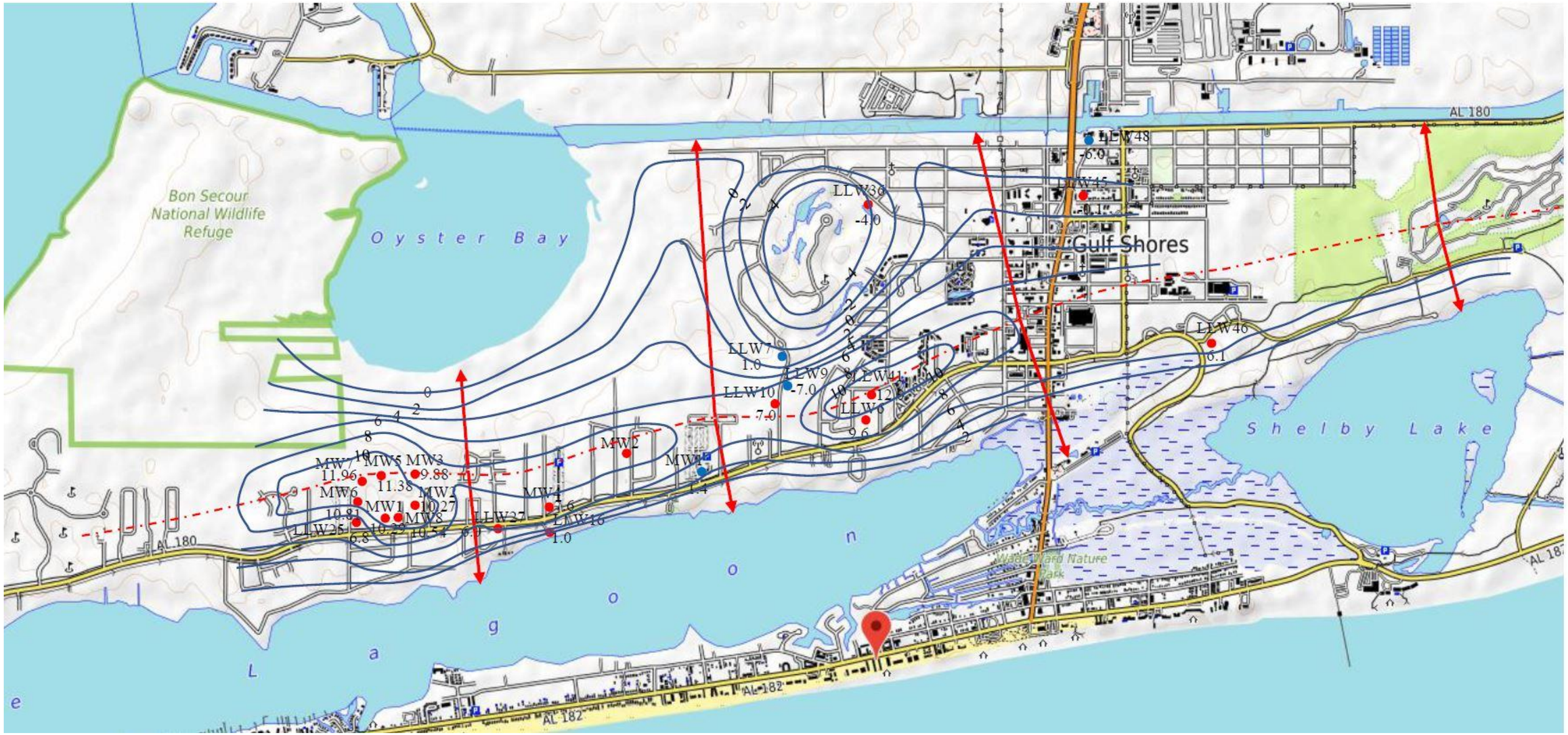
MW3 9.29 — A_1-aquifer well and dry season static water level (*Water levels for BCSS monitor wells are from top of casing. Elevations from Hatfield and Eberly).

LLW7 0.5 — A_2-aquifer well and dry season static water level elevation

Direction of groundwater movement

Groundwater divide

Figure 4.—Configuration of the dry season water table surface for the north shore of Little Lagoon.



Water level elevation (MSL) contours (2 ft contour interval)

MW5 11.38 — A_1-aquifer well and wet season static water level elevation (MSL) (*Water levels for BCSS monitor wells are from top of casing. Elevations from Hatfield and Eberly).

LLW7 1.0 — A_2-aquifer well and wet season static water level elevation (MSL)

Direction of groundwater movement

Groundwater divide

Figure 5.-- Configuration of the wet season water table surface for the north shore of Little Lagoon.

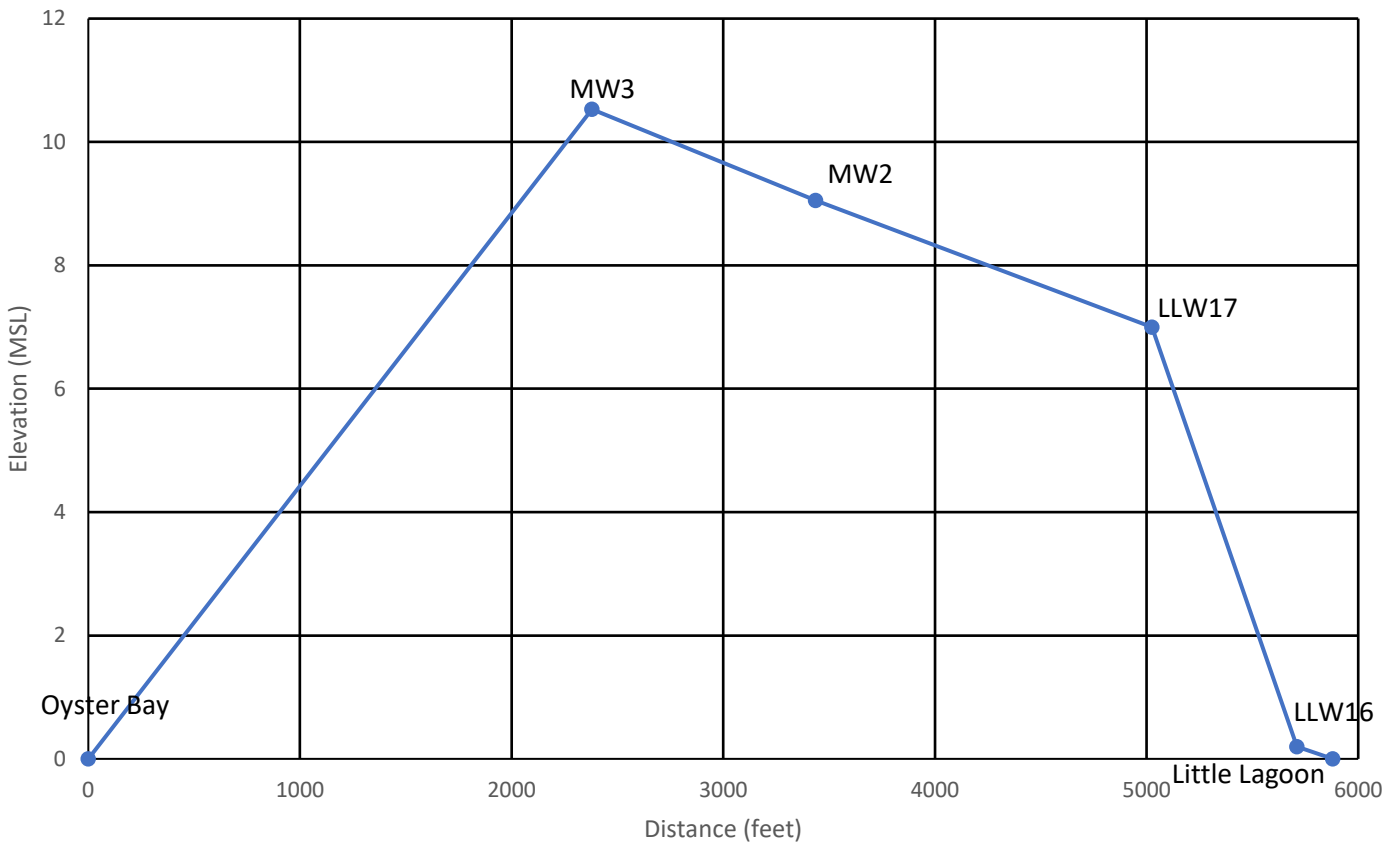


Figure 6.—Water table elevation profile from Oyster Bay through the Baldwin County Sewer Service Fort Morgan Treatment Plant to Little Lagoon.

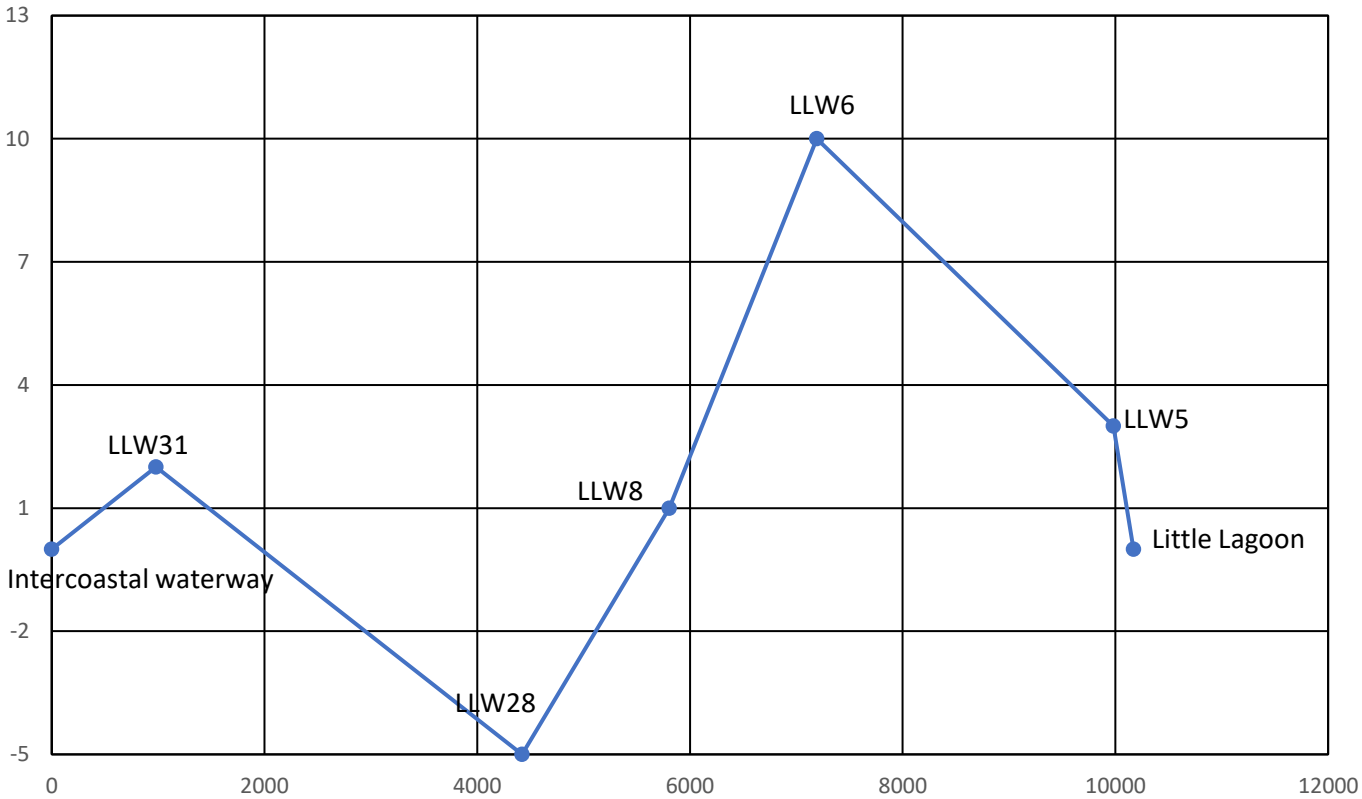


Figure 7.—Water table elevation profile from the Intercoastal Waterway through Gulf Shores Country Club to Little Lagoon.

from 12.3 to 15.8 inches per year. The A_1 aquifer is expected to have a similar recharge rate.

Groundwater levels, north of the lagoon, fluctuate seasonally, due to variable precipitation and recharge. Winter and Spring water levels were, on average, 0.9 ft higher than Summer and Fall levels. Figure 8 shows seasonal groundwater level fluctuations in wells where dry and wet season water levels were measured.

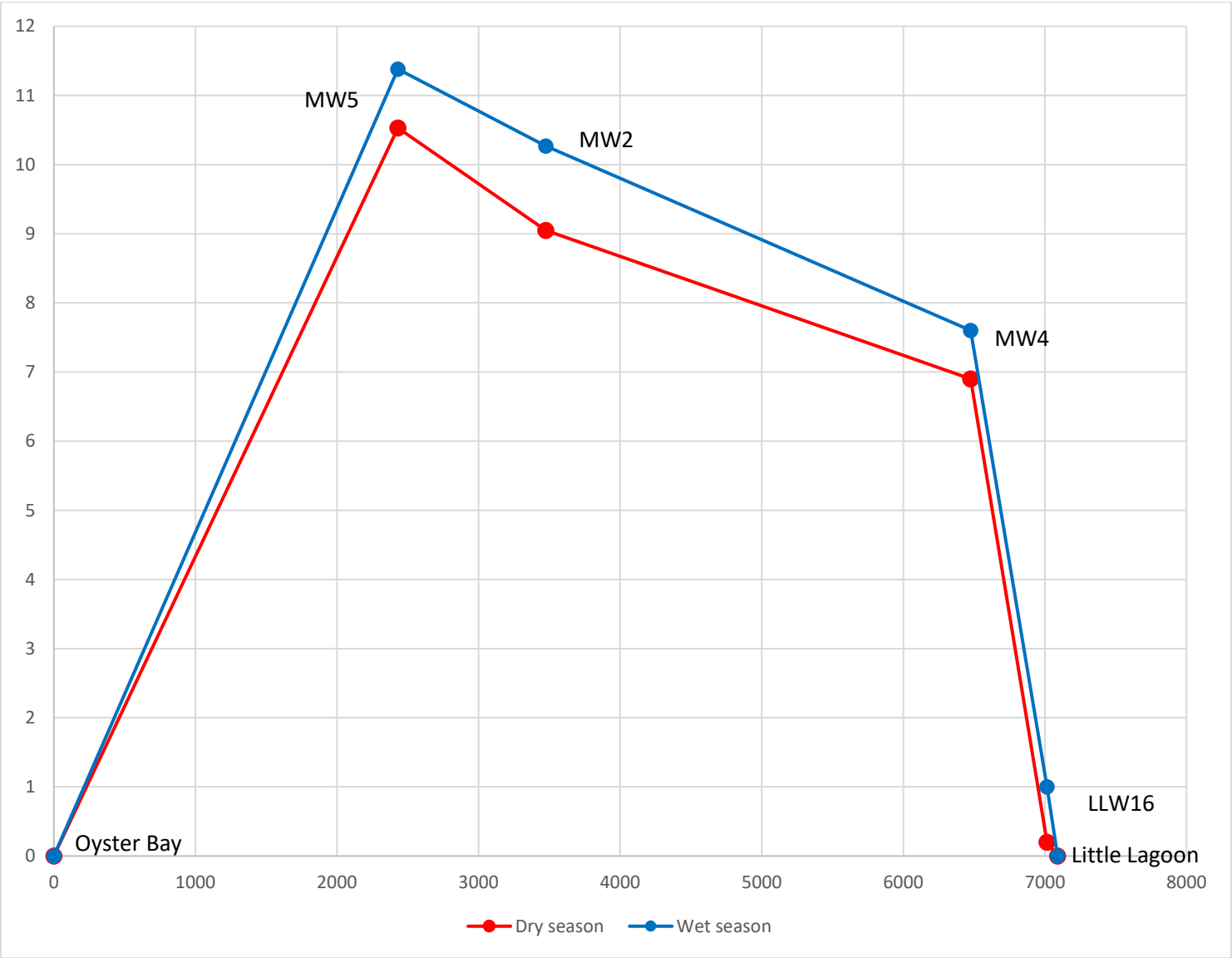


Figure 8.—Seasonal water level fluctuations in the A_1 aquifer in the Baldwin County Sewer Service Fort Morgan Treatment Plant area.

Shallow groundwater in the A_1 aquifer, discharges into Little Lagoon along the northern shore. Exposures of the water table commonly occur along the northern shore in drainage channels and areas of relative low elevation. Eleven land-surface exposures of the water table for the A_1 aquifer were identified during field reconnaissance on June 23, 2020 (table 3, fig. 3).

Pumping tests are performed to determine hydraulic characteristics of an aquifer, using analyses of time-drawdown relationships. Hydraulic characteristics include hydraulic conductivity (a measure of how easily water can pass through soil or rock), transmissivity (the rate at which groundwater flows horizontally through an aquifer), and specific capacity (volume of water produced and resulting water level drawdown). Data collected from pumping tests are valuable to determine the sustainable production rate for a production well and to characterize groundwater movement through an aquifer.

Data from pumping tests performed on two wells on the north side of Little Lagoon were evaluated during this study. Cook Hydrogeology performed a pumping test on the Hatfield deep well (MW4), constructed in the A_1 aquifer at a depth of 29.3 ft. The static water level at the time of the test (June 22, 2021) was 1.95 ft below land surface. The well was pumped at 6 gallons per minute (gpm) but drawdown was too rapid to record. Therefore, water level recovery was measured and used to analyze aquifer hydraulic characteristics. Recovery to the original static level occurred in eight minutes. The data were analyzed using a time-recovery semi log graphical method (Driscoll, 1995), where the slope of the recovery-time curve is used to calculate transmissivity and hydraulic conductivity for a tested aquifer. The pumping test data analysis resulted in hydraulic conductivity of 29.3 ft per day (ft/d) and transmissivity of 878 square ft/day (ft^2/d).

A pumping test was performed in February 1984 on the Fort Morgan Authority Sewer Service Gul-75 well. The well was constructed in January 1984 to a depth of 36 ft with 6-inch screen from 16 to 36 ft. The well was pumped at 135 gpm and the water level stabilized in 26.2 hours with 1.25 ft of drawdown, yielding a specific capacity of 108 gallons per ft of drawdown. Time and drawdown data were analyzed using the USGS Pumping Test Analysis Program, which uses a computerized version of the Cooper-Jacob pumping test formula (USGS, 2002). Analyses of pumping test data resulted in hydraulic conductivity (K) of 57 ft/d and transmissivity of 16,000 ft^2/d).

Assuming porosity in the A_1 aquifer is 30% and using a modification of Darcy's equation to calculate linear groundwater flow velocity (from Driscoll, 1995):

$V_x = (K (h_1 – h_2)/L)/ (\eta)$

$V_x = (57 (0.006)/ (.3)$

$V_x = 1.14$ ft/d

Therefore, effluent from the Baldwin County Sewer Service Fort Morgan Treatment Plant reaches Little Lagoon in about 3.6 years.

WATER QUALITY

Water that flows into Little Lagoon, from the north side, is composed of surface-water runoff and groundwater. Both water sources carry various concentrations of contaminants that include bacteria, nutrients, and metals that occur naturally in sediments and originate from anthropogenic activities in the drainage area. Water is exchanged with the Gulf of Mexico during tidal fluctuations through Little Lagoon Pass.

Water samples were collected from six surface-water sites, two wells, constructed in the A_1 aquifer, one well, constructed in the A_2 aquifer, and Little Lagoon Pass. Surface-water samples were collected during a major storm event in wet season conditions in May 2021 to capture surface-water runoff. A second set of surface-water samples were collected from two sites during dry season, base flow conditions, in November 2021. Dry season samples were composed primarily of groundwater from the A_1 aquifer. Little Lagoon Pass was sampled in May 2021 during low tide, when water was moving rapidly from Little Lagoon into the Gulf of Mexico.

Field water quality parameters, including conductance, temperature, turbidity, pH, dissolved oxygen, salinity, and total dissolved solids, were measured in all samples (appendix A). Water samples were transported to a certified laboratory for analysis of 78 constituents, including 29 pesticide and herbicide compounds, toxic metals and other inorganic constituents, surfactants, total petroleum hydrocarbons, total organic carbon, and nutrients, including total Kjeldahl nitrogen, ammonia, nitrite, nitrate, NO_2 + NO_3 nitrogen, and total phosphorus (appendix A).

SURFACE-WATER QUALITY

Surface-water quality monitoring occurred at six sites in the Little Lagoon watershed. Samples were collected during a storm event on May 5, 2021, when overland runoff was occurring. Field parameters were measured and showed that pH ranged from

6.2 at site LL6 to 7.6 at site LL3. Turbidity ranged from 8 NTU at site LL1 to 40 NTU at site LL3. Specific conductance ranged from 4,360 µS/cm at site LL1 (Little Lagoon Pass) to 74 µS/cm at site LL4 (Long Bayou). Dissolved oxygen ranged from 4.0 mg/L at site LL5 (Brigadoon Trail) to 5.8 at site LL3 (drainage from the northeast side of Little Lagoon). Dissolved oxygen at sites LL2, LL4, LL5, and LL6 was below the ADEM minimum fish and wildlife criterion of 5.0 mg/L (appendix A).

Man-made organic compounds, including pesticides, herbicides, surfactants, total petroleum hydrocarbons, and PCBs were not detected in any samples (appendix A). Some metals occur naturally, are pervasive in the environment, and commonly occur in surface waters, including boron, barium, calcium, iron, magnesium, manganese, rubidium, and strontium. These metals were detected in all samples in relatively small concentrations (appendix A). However, other metals are less common or uncommon in the aquatic environment, are toxic, and may indicate contamination from man's activities. Arsenic was detected in samples from sites LL4, LL5, and LL6, in concentrations of 1.0, 4.0, 7.1 µg/L, respectively (appendix A). Chromium was detected in samples from sites LL3, LL5, and LL6, in concentrations of 1.7, 1.7, and 1.3 µg/L, respectively (appendix A). Copper was detected at site LL3 with a concentration of 5.1 µg/L (appendix A). All detected metals were below USEPA recommended water quality criteria for aquatic life.

Nutrients are chemical elements found in the food that plants and animals need to grow and survive. Although there are many kinds of nutrients, two of the most important and abundant are nitrogen and phosphorus. Nitrogen and phosphorus occur in a variety of forms, or species, and the species present can change as they move between the air, water, and soil. Eutrophication is a natural process that results from accumulation of nutrients in lakes or other bodies of water. Algal growth is usually limited by the available supply of either phosphate or nitrate, and we say that a water body is nitrogen limited if the ratio of nitrogen species to phosphorus species (N:P) is low, or is phosphorus limited if N:P is high. Harmful algal blooms can be triggered by nutrient enrichment. Little Lagoon has a history of toxic algal blooms that have become more frequent in recent years.

NITROGEN

The U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) for nitrate in drinking water is 10 mg/L. Typical nitrate (NO_3 as N)

concentrations in streams vary from 0.5 to 3.0 mg/L. Concentrations of nitrate in streams without significant nonpoint sources of pollution vary from 0.1 to 0.5 mg/L. Streams fed by shallow groundwater draining agricultural areas may approach 10 mg/L (Maidment, 1993). Nitrate concentrations in streams without significant nonpoint sources of pollution generally do not exceed 0.5 mg/L (Maidment, 1993). The critical nitrate concentration in surface water for excessive algae growth is 0.5 mg/L (Maidment, 1993). Although Alabama has no reference guidelines for the 75k Ecoregion, which includes Little Lagoon, ADEM established reference concentrations for ammonia (0.046 mg/L = 90th %ile), nitrate+nitrite nitrogen (0.3470 mg/L = 90th %ile), total Kjeldahl nitrogen (0.4176 mg/L = 90th %ile), total nitrogen (0.7822 mg/L nitrogen = 90th %ile), and total phosphorus (0.0310 mg/L = 90th %ile) for Level IV Ecoregion 65f, immediately north of Little Lagoon (ADEM, 2015).

Analytical results for surface-water samples collected during wet season conditions on May 5, 2021, at Little Lagoon monitoring sites show that ammonia concentrations were below detection limit (0.1 mg/L) at sites LL1, LL2, LL3, LL4, and LL5. The concentration at site LL6 was 0.45 mg/L, which was above the reference guideline (appendix A).

The concentration of nitrate+nitrite nitrogen was below the detection limit of 0.05 mg/L at site LL1. Concentrations at sites LL2, LL3, LL4, LL5, and LL6 were 0.053, 0.32, 0.07, 0.1, and 0.47 mg/L, respectively (fig. 9, appendix A). The reference guideline was exceeded at site LL6 (fig. 10, appendix A).

Concentrations of total Kjeldahl nitrogen were 0.58 mg/L at site LL1, 0.88 mg/L at site LL2, 0.57 mg/L at site LL3, 0.95 mg/L at site LL4, 1.6 mg/L at site LL5, and 2.6 mg/L at site LL6 (fig. 10, appendix A). The reference guideline was exceeded at all sampled sites. The reference guideline for total nitrogen was exceeded at sites LL2, LL3, LL4, LL5, and LL6 (fig. 10).

PHOSPHORUS

Phosphorus in streams originates from the mineralization of phosphates from soil and rocks or runoff and effluent containing fertilizer or other industrial products. The principal components of the phosphorus cycle involve organic phosphorus and inorganic phosphorus in the form of orthophosphate (PO_4) (Maidment, 1993). Orthophosphate is soluble and is the only biologically available form of phosphorus. Since phosphorus

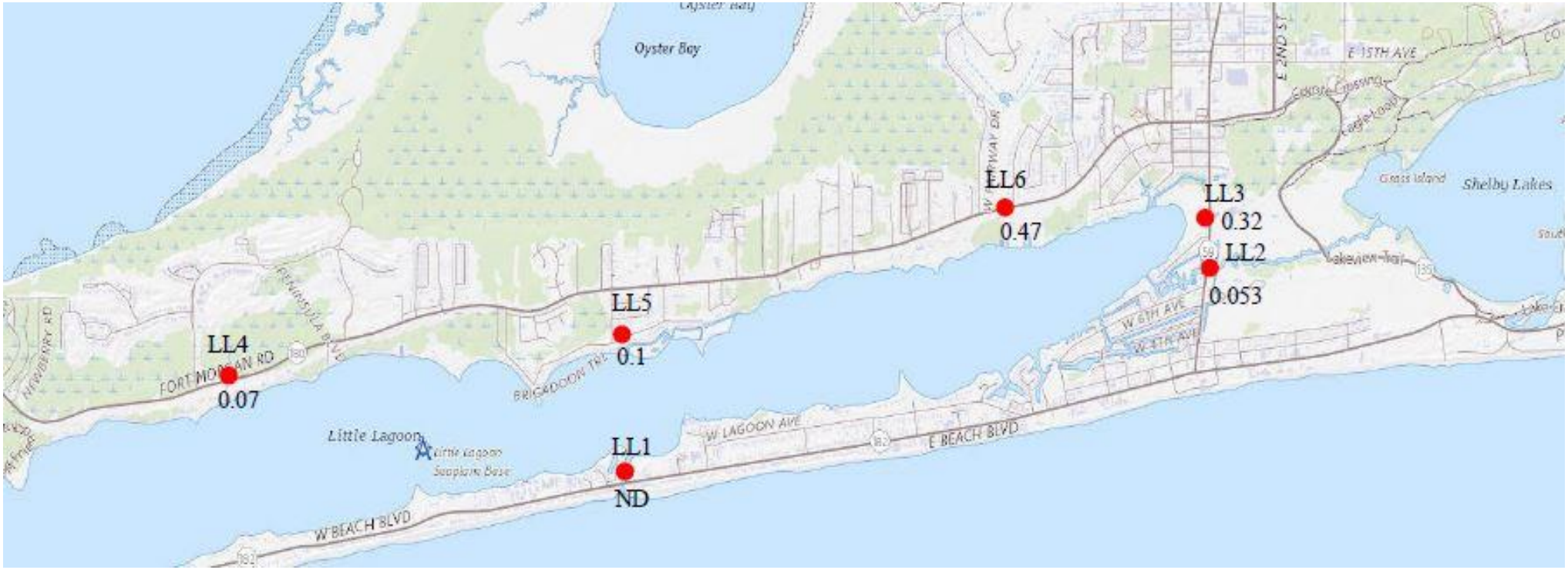


Figure 9.—Concentrations of nitrate+nitrite nitrogen in wet season surface-water samples collected at Little Lagoon sites.

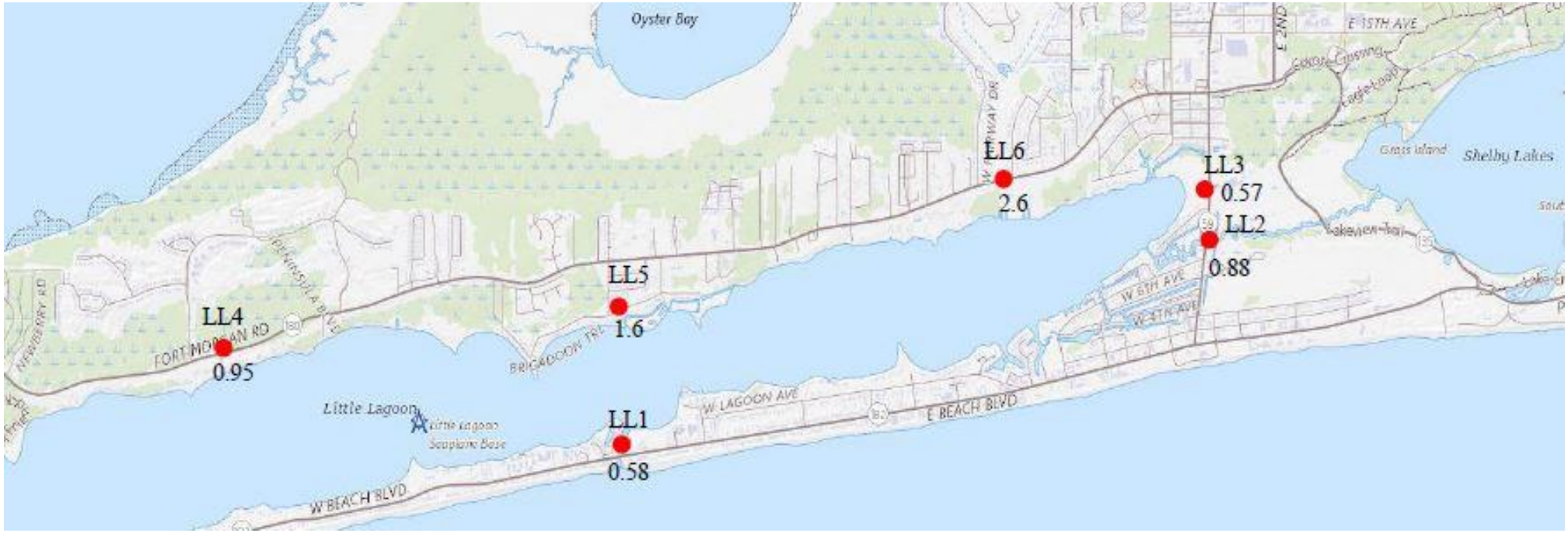


Figure 10.—Concentrations of total Kieldahl nitrogen in wet season surface-water samples collected at Little Lagoon sites.

strongly associates with solid particles and is a significant part of organic material, sediments influence water column concentrations and are an important component of the phosphorus cycle in streams.

The natural background concentration of total dissolved phosphorus is approximately 0.025 mg/L. Phosphorus concentrations as low as 0.005 to 0.01 mg/L may cause algae growth, but the critical level of phosphorus necessary for excessive algae is around 0.05 mg/L (Maidment, 1993). Although no official water-quality criterion for phosphorus has been established in the United States, total phosphorus should not exceed 0.05 mg/L in any stream or 0.025 mg/L within a lake or reservoir in order to prevent the development of biological nuisances (Maidment, 1993). ADEM established a reference concentration for total phosphorus for level IV ecoregion 65f of 0.04 mg/L (90th %ile). In many streams, phosphorus is the primary nutrient that influences excessive biological activity. These streams are termed "phosphorus limited."

Analytical results for surface-water samples collected during wet season conditions on May 5, 2021, at Little Lagoon monitoring sites show that the total phosphorus concentration was below detection limit (0.1 mg/L) at site LL3. The total phosphorus concentration at site LL1 was 0.2 mg/L, site LL2 was 0.54 mg/L, site LL4 was 0.13 mg/L, site LL5 was 0.97 mg/L, and site LL6 was 0.38 mg/L (fig. 11, appendix A). Total phosphorus concentrations at all sites where it was detected was above the ADEM reference guideline.

GROUNDWATER QUALITY

Groundwater samples were collected from three wells (one constructed in the A_1 aquifer, one in the A_2 aquifer, and one with no well construction information) on May 19 and 20, 2021 and June 22, 2021. Samples were also collected at two land surface groundwater discharge points for the A_1 aquifer (sites LL4 and LL5), during base-flow conditions on November 19, 2021. Field parameters were measured, and samples were submitted to a certified laboratory for analysis. Well samples were analyzed for a comprehensive suite of pesticides, herbicides, PCBs, and nutrients. Surface groundwater samples were analyzed for same analytes as surface-water samples.

Field parameters showed that pH ranged from 5.3 in well MW4 (Hatfield deep well) to 6.9 at site LL5 (Brigadoon Trail) (appendix A). Specific conductance ranged from 98 µS /cm in well MW2 (Langston well) to 596 µS/cm at site LL5 (Brigadoon

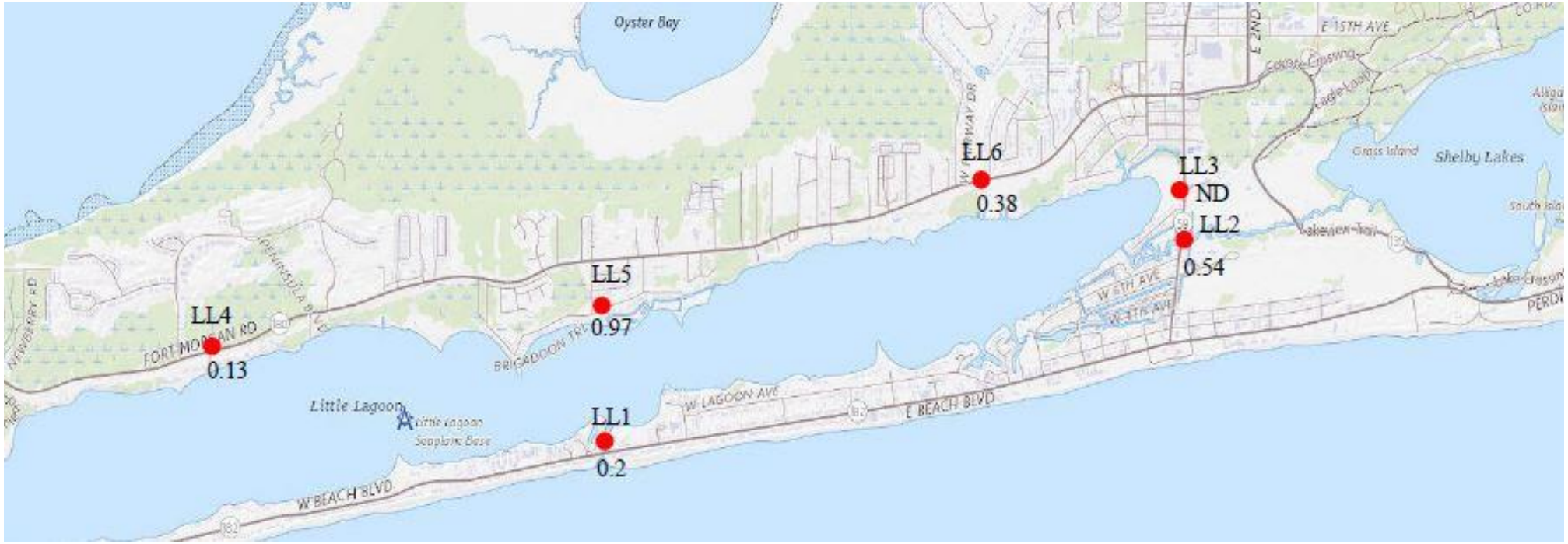


Figure 11.—Concentrations of total phosphorus in wet season surface-water samples collected at Little Lagoon sites.

Trail) (fig. 12, appendix A). Pesticides, herbicides, and PCBs were not detected in any groundwater samples (appendix A).

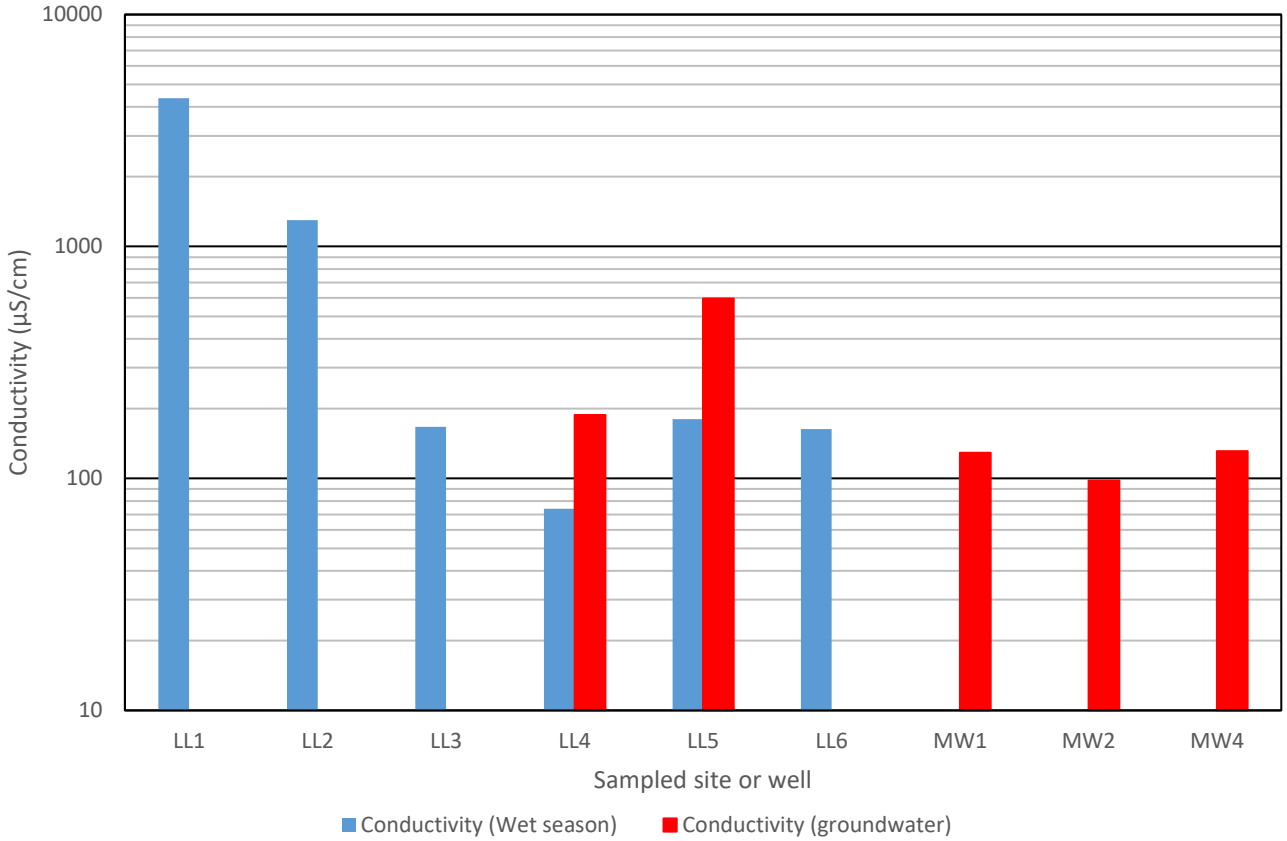


Figure 12.—Conductivity of surface groundwater and well samples in the Little Lagoon watershed.

NITROGEN

Analytical results for groundwater samples collected at Little Lagoon monitoring sites show that ammonia concentrations were below detection limit (0.1 mg/L) in wells MW1 and MW2 but concentrations at sites LL4, LL5, and well MW4 were 0.63, 1.1, and 0.14 mg/L, respectively, which were all above the ADEM reference guideline (fig. 13, appendix A).

The concentration of nitrate+nitrite nitrogen was below the detection limit of 0.05 mg/L at sites LL4, LL5, and well MW1 (fig. 14). Concentrations in samples from wells MW2 and MW4 were 1.5 and 1.7 mg/L, respectively (fig. 14, appendix A).

The concentration of total Kjeldahl nitrogen was below the detection limit in well MW1 (fig. 15). Concentrations of total Kjeldahl nitrogen were 0.76 mg/L at site LL4, 1.0 mg/L at site LL5, 0.26 mg/L in well MW2, and 0.78 mg/L in well MW4 (fig. 15, appendix A).

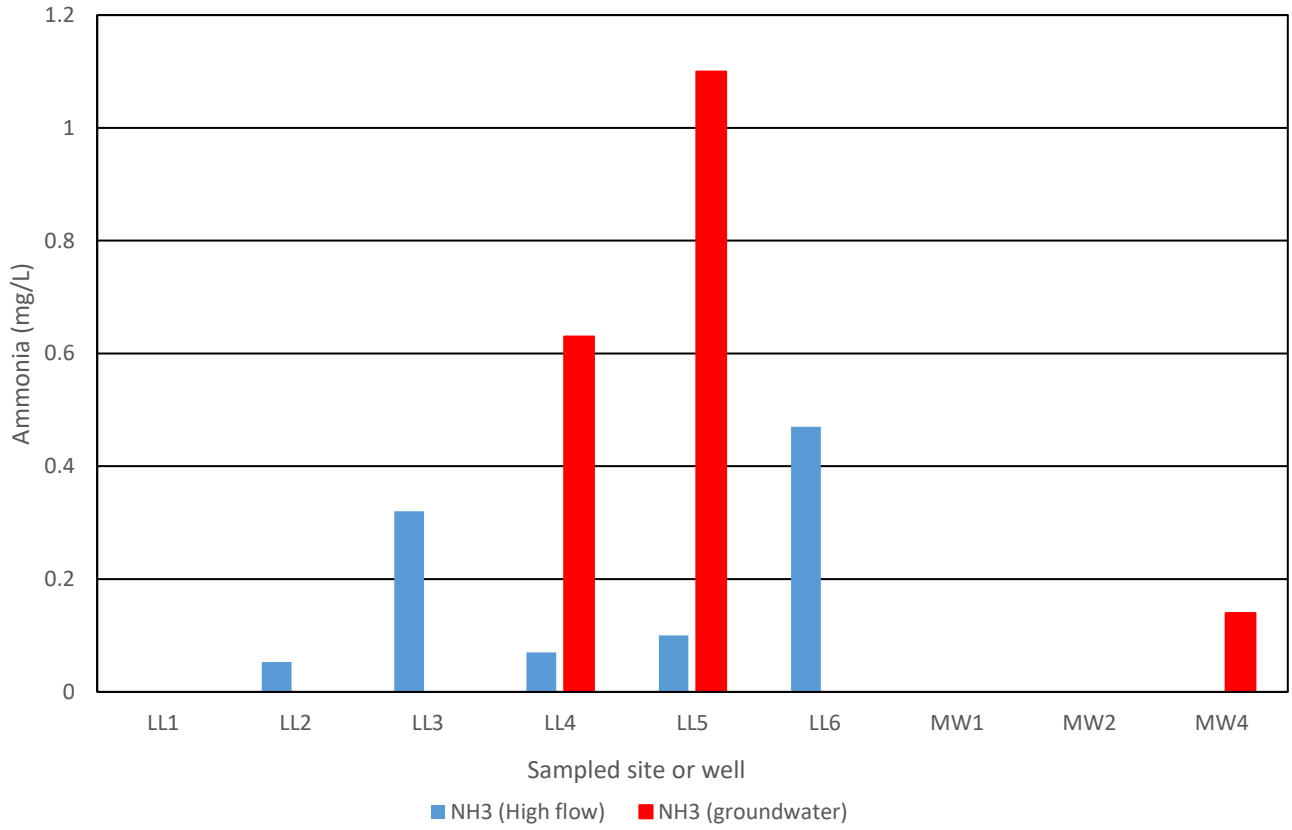


Figure 13.—Concentrations of ammonia in surface groundwater and well samples in the Little Lagoon watershed.

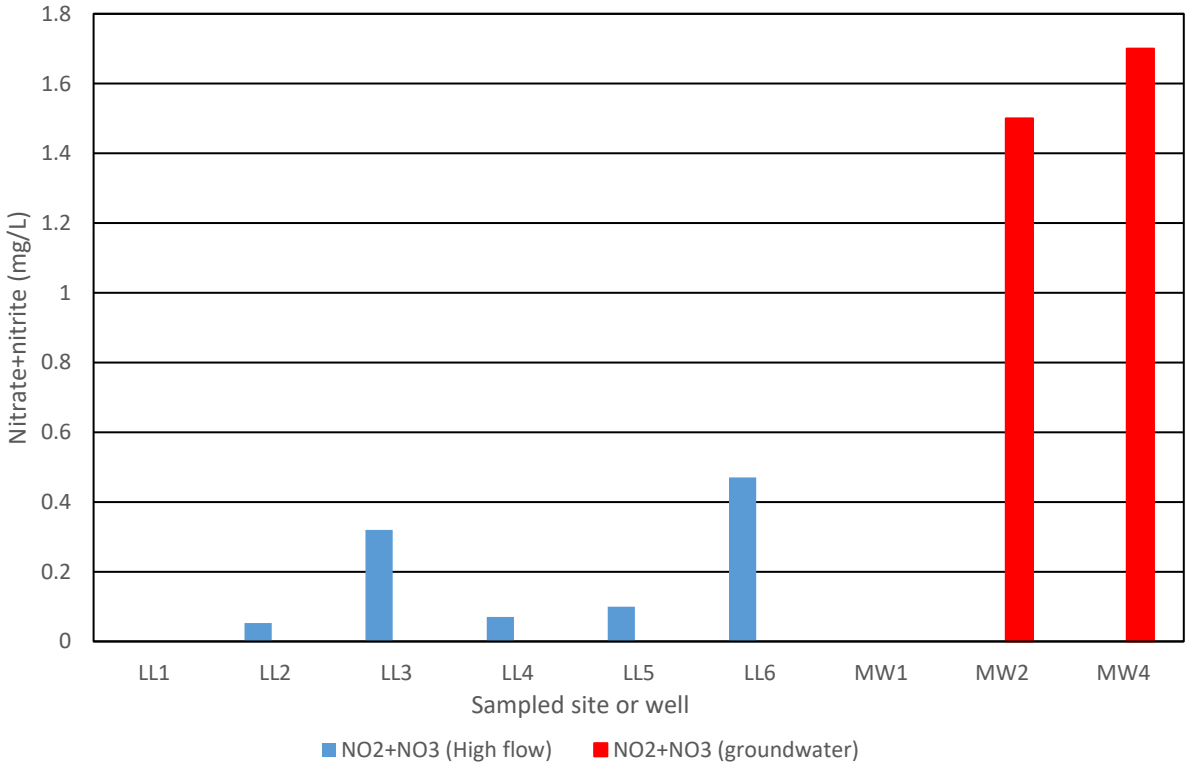


Figure 14.—Concentrations of nitrate+nitrite nitrogen in surface-water and well samples in the Little Lagoon watershed.

PHOSPHORUS

Analytical results for groundwater samples collected at Little Lagoon monitoring sites show that the total phosphorus concentration was below detection limit (0.1 mg/L) at site LL4 and in wells MW2 and MW4 (fig. 17). The total phosphorus concentration at site LL5 was 2.7 mg/L, and well MW1 was 0.13 mg/L (fig. 17, appendix A).

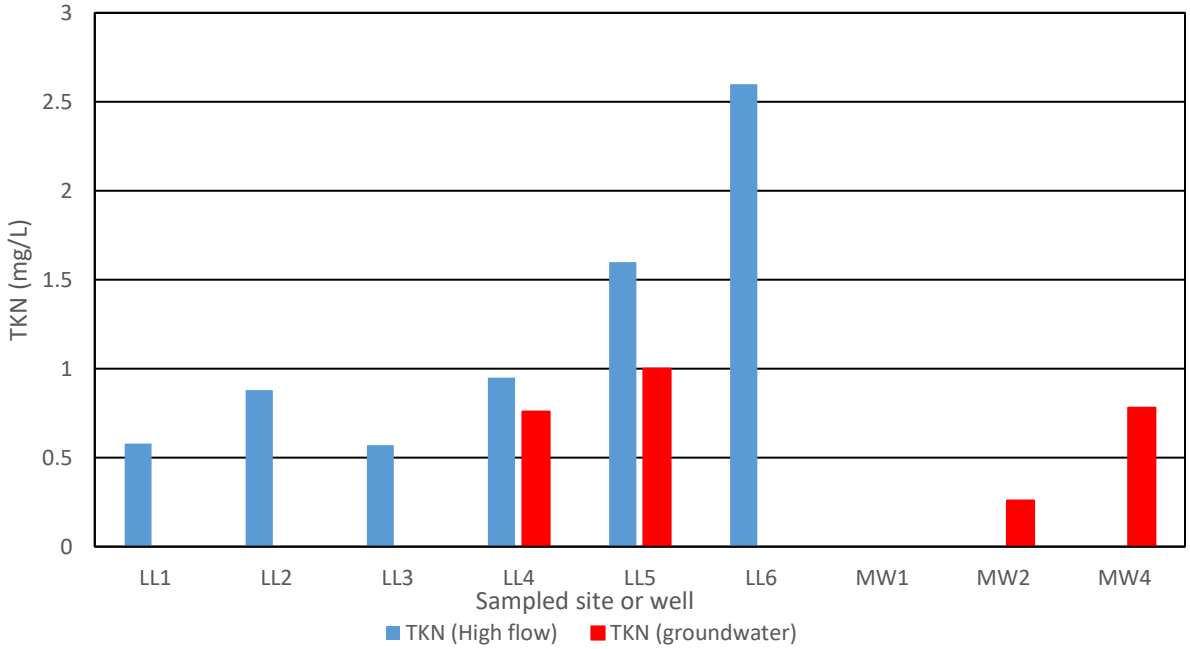


Figure 15.—Concentrations of total Kjeldahl nitrogen in surface-water and well samples in the Little Lagoon watershed.

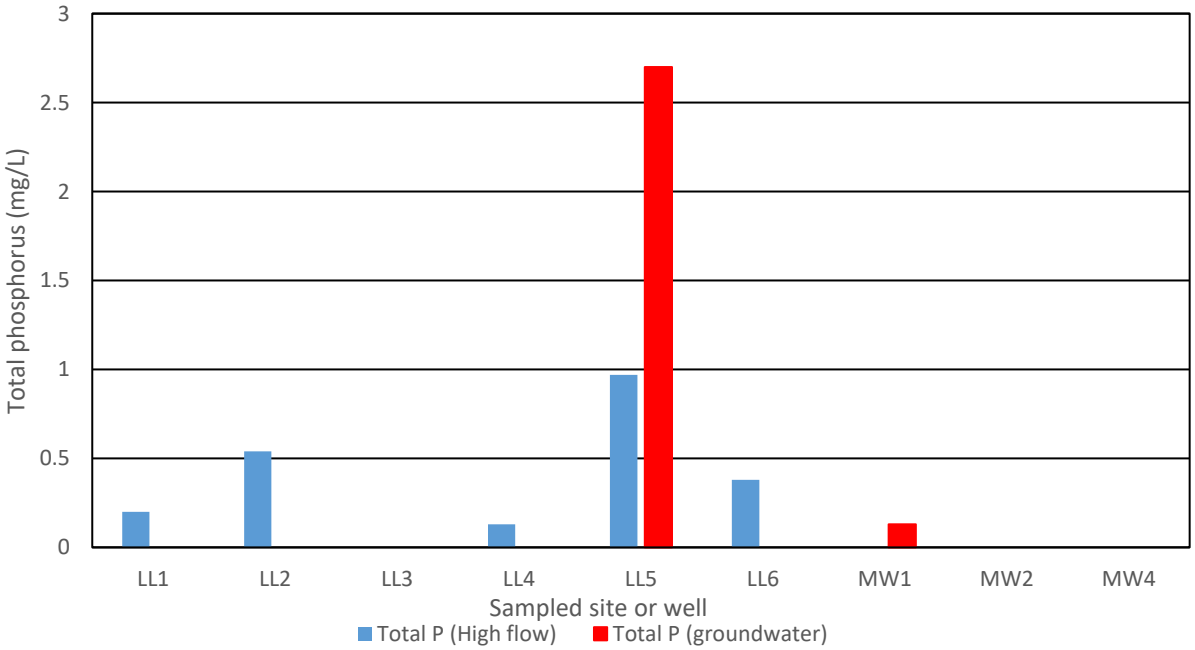


Figure 16.—Concentrations of total phosphorus in surface-water and well samples in the Little Lagoon watershed.

LAND USE/LAND COVER AND RELATED WATER-QUALITY IMPACTS

Land use is directly correlated with water quality, hydrologic function, ecosystem health, biodiversity, and the integrity of streams and wetlands. Land use in aquifer recharge areas may also impact groundwater quantity and quality. This is especially crucial in shallow aquifer systems, where recharge is local and residence times are short. Land-use classifications for the project area were calculated from the USDA National Agricultural Statistics Service 2013 Alabama Cropland Data Layer (NASS CDL) raster dataset. The CDL is produced using satellite imagery from the Landsat 5 TM sensor, Landsat 7 ETM+ sensor, the Spanish DEIMOS-1 sensor, the British UK-DMC 2 sensor, and the Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS) collected during recent growing seasons (USDA, 2013). Figure 18 shows land use subdivided into 17 classified types defined as developed, forested, grassland, wetlands, barren areas, open water, and agriculture, subdivided into eight specific crops (fig. 18). A comparison of 2013 land-use/cover data with 2020 Google Earth imagery shows that the overall land-use/cover trend has not significantly changed (fig. 19). An evaluation of Google Earth imagery since 1985 (Google Earth, 2022) shows that significant development of the northern shore watershed area occurred from 1997 to 2008. However, additional development has been relatively slow since 2008.

Land use/land cover for the northern shore Little Lagoon watershed can be divided into four areas. The northeastern part of the watershed is dominated by residential (single family and high density) and commercial development (fig. 17). The east-central part of the watershed is dominated by single family residential development, two recreational vehicle/trailer parks, a golf community (Gulf Shores Country Club), and a wastewater treatment facility. The west-central part of the watershed is dominated by single family residences along the northern shore and south of Alabama Highway 180 and a golf community (Peninsula Golf). The northwestern part of the watershed is undeveloped and is dominated by forested wetlands.

Wastewater, including sewage that is generated in the northern shore watershed is disposed of in two ways. Most of it is transported to the Baldwin County Sewer Service Fort Morgan Treatment Plant. However, on-site septic systems continue to be utilized in the watershed. A study by ADEM (2000) estimated that there were about 700 on-site

Figure 17.—Land-use/cover for the city of Gulf Shores and Little Lagoon watershed.

septic systems in operation in the watershed in the year 2000. A more recent estimate by Gulf Shores Utilities, based on water customers with no sewer charges, indicates that 187 on-site septic systems are active around the lagoon with 145 active systems in the north shore watershed. All wastewater receives some form of treatment and is disposed of by percolation into the groundwater system. The city of Gulf Shores enforces a city ordinance that permits on-site septic system owners to pump their tanks one time per year. If the system requires more frequent pumping or additional maintenance, the owner is required to access the public sewer system (personal communication with the city of Gulf Shores Planning and Zoning Department, July 29, 2022)

Water quality in Little Lagoon is impacted by inflow from Lake Shelby, runoff from high density residential and commercial development along the southern shore, and runoff and groundwater inflow from the watershed area on the north side of the lagoon.

Inflow from Lake Shelby was sampled on May 5, 2021 (site LL2) and is characterized as brackish with salinity of 7.5 parts per thousand (ppt), total dissolved solids of 8,000 mg/L, conductivity of 1,300 µS /cm, and pH of 7.0. Nitrogen concentrations were low, with nitrate + nitrite nitrogen at 0.053 mg/L and TKN at 0.88 mg/L. However, the total phosphorus concentration was relatively high at 0.54 mg/L.

The northeast quadrant of the lagoon watershed is dominated by urban development, which contributes nutrients and bacteria through runoff from impervious surfaces, including road surfaces, parking lots, driveways, sidewalks, and roofs. Runoff from this quadrant was sampled on May 5, 2021, at site LL3, and is characterized as freshwater with conductivity of 167 µS /cm and pH of 7.6. Toxic metals were detected with a chromium concentration of 1.7 µg/L and copper concentration of 5.1 µg/L. Nitrogen concentrations were moderate with nitrate + nitrite nitrogen at 0.32 mg/L, TKN at 0.57 mg/L. However, the total phosphorus concentration was below the detection limit of 0.1 mg/L.

East-central quadrant runoff was sampled on May 5, 2021, at site LL6, which includes Gulf Shores Country Club. Runoff was freshwater, with conductivity of 163 µS /cm and pH of 6.2. Chromium was detected at 1.7 µg/L and the aluminum concentration was relatively high at 797 µg/L. The ammonia concentration was high at 0.45 mg/L. Nitrogen concentrations were high, with nitrate + nitrite nitrogen at 0.47 mg/L and TKN at 2.6 mg/L. Total phosphorus concentration was relatively high at 0.38 mg/L.

East-central quadrant runoff was also sampled during wet season conditions on May 5, 2021, at site LL5, which includes residential development in the Brigadoon Trail Subdivision and the Baldwin County Sewer Service Fort Morgan Treatment Plant. Runoff was freshwater, with conductivity of 180 µS /cm and pH of 6.5. Chromium was detected at 1.7 µg/L and the aluminum concentration was high at 835 µg/L. Nitrogen concentrations were low to moderate, with nitrate + nitrite nitrogen at 0.1 mg/L and TKN at 1.6 mg/L. Total phosphorus concentration was relatively high at 0.97 mg/L.

Site LL5 was also sampled during dry, baseflow conditions on November 19, 2021. Water flow at the site consisted of groundwater with anomalously high conductivity at 596 µS /cm and pH of 6.9. Ammonia was high at 1.1 mg/L and TKN was 1.0 mg/L. Nitrate + nitrite was below the detection limit of 0.05 mg/L. Total phosphorus was anomalously high at 2.7 mg/L.

The west-central quadrant was sampled in Long Bayou (site LL4), a perennial stream that drains an area of 0.3 mi^2, including part of the Peninsula Golf community. The stream was sampled during wet conditions on May 5, 2021, with discharge of 24.6 cubic feet per second (cfs). The sample was freshwater with conductivity of 74 µS /cm and pH of 6.3. Water in the stream had a turbidity of 15 Nephelometric Turbidity Units (NTU) and total suspended solids of 4 mg/L. Nitrogen concentrations were low to moderate with nitrate + nitrite nitrogen at 0.07 mg/L, TKN at 0.95 mg/L. The total phosphorus concentration was moderate at 0.13 mg/L.

Site LL4 was also samples during dry, baseflow conditions on November 19, 2021. Water flow at the site consisted of groundwater, characterized by elevated conductivity at 188 µS /cm, relatively low pH of 5.7, and low dissolved oxygen (2.7 mg/L). Ammonia was high at 0.63 mg/L and TKN was 0.78 mg/L. Nitrate + nitrite was below the detection limit of 0.05 mg/L. Total phosphorus was also below the detection limit of 0.1 mg/L.

No samples were collected from the western quadrant, but water flowing into Little Lagoon from this area is expected to be good to excellent quality, due to land cover dominated by forested wetlands.

RECOMMENDATIONS

This assessment along with previous assessments of water quality in the Little Lagoon watershed show the importance of both surface-water and groundwater

monitoring in characterizing impacts of land use/cover on water quality in the lagoon. Due to low relief and highly porous sediments underlying the watershed, especially the northern shore watershed, the geochemical character of groundwater is a critical component in understanding water-quality conditions in the lagoon. Therefore, a groundwater monitoring system is recommended along the northern shore of Little Lagoon. A recommended groundwater monitoring system consists of eight sites at strategic locations along the northern shore (fig. 18). Each site will have two monitoring wells, one constructed to a depth of about 15 ft and one constructed to a depth of about 50 ft. Each well will be constructed of four-inch pvc casing with at least five ft of screen in a water-bearing sand at or near the bottom of the hole. Wells will be sealed above the screen with bentonite or grout. Wells will be sampled periodically (at least annually) according to US Environmental Protection Agency operating procedure SESDPROC-301-R4, effective April 26, 2017 (USEPA, 2017). Samples will be field evaluated for temperature, pH, conductivity, turbidity, and salinity and will undergo laboratory analyses at a minimum for, total dissolved solids (TDS), ammonia (NH_3), nitrate + nitrite nitrogen (NO_3+NO_2), total Kjeldahl nitrogen (TKN), total nitrogen, and total phosphorus (P). Construction of additional monitoring wells should be considered between site 6 and the Baldwin County Sewer Service Fort Morgan Treatment Plant, to evaluate effluent from the plant as it moves downgradient to Little Lagoon.

Water-quality trends can be used to determine specific sources of contaminants and can be used to aid the design and implementation of best management practices to improve the quality of surface-water and groundwater inflow to Little Lagoon.

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Figure 18.—Proposed monitoring well sites along the norther shore of Little Lagoon.

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APPENDIX A

FIELD AND ANALYTICAL DATA

Little Lagoon tidal channel.															
Lat 30.241287°N Long -087.737814°W															
Site	Date	Time	Velocity	Temp	Cond	Turb	pH	DO	TSS	Salinity	TDS	NO_3+NO_2	TKN	NH_3	Total P
			fps	°C	µS/cm	NTU		mg/L	mg/L	ppt	mg/L	mg/L	mg/L	mg/L	mg/L
LL1	5/5/21	900	to gulf 3.0	23.7	4360	8	6.3	5.7	6	28.1	26100	ND	0.58	ND	0.2
Lake Shelby inflow to Little Lagoon at AL Highway 59.															
Lat 30.254686°N Long -087.693729°W															
Site	Date	Time	Velocity	Temp	Cond	Turb	pH	DO	TSS	Salinity	TDS	NO3+NO2	TKN	NH3	Total P
			fps	°C	µS/cm	NTU		mg/L	mg/L	ppt	mg/L	mg/L	mg/L	mg/L	mg/L
LL2	5/5/21	940	to LL 1.0	23.7	1300	17	7.0	5.0	9.0	7.5	8000	0.053	0.88	ND	0.54
Surface-water and groundwater discharge from northeast side of Little Lagoon at AL Highway 59.															
Lat 30.259975°N Long -087.688637°W															
Site	Date	Time	Discharge	Temp	Cond	Turb	pH	DO	TSS	Salinity	TDS	NO3+NO2	TKN	NH3	Total P
			cfs	°C	µS/cm	NTU		mg/L	mg/L	ppt	mg/L	mg/L	mg/L	mg/L	mg/L
LL3	5/5/21	1040	N/A	22.9	167	40	7.6	5.8	5.0	0.1	100	0.32	0.57	ND	ND
Long Bayou. Peninsula Golf Resort drainage to Little Lagoon at AL Highway 180.															
Lat 30.248183°N Long -087.770853°W															
Site	Date	Time	Discharge	Temp	Cond	Turb	pH	DO	TSS	Salinity	TDS	NO3+NO2	TKN	NH3	Total P
			cfs	°C	µS/cm	NTU		mg/L	mg/L	ppt	mg/L	mg/L	mg/L	mg/L	mg/L
LL4	5/5/21	1225	24.6	22.3	74	15	6.3	5.2	4.0	0	50	0.07	0.95	ND	0.13
LL4	11/19/21	740	1.3	16.4	188	3	5.7	2.7	<4	0	N/A	ND	0.78	0.63	ND
Unnamed tributary 500 ft east of the intersection of Middle Brigadoon Trail and Brigadoon Trail.															
Lat 30.250881°N Long -087.737340°W															
Site	Date	Time	Discharge	Temp	Cond	Turb	pH	DO	TSS	Salinity	TDS	NO3+NO2	TKN	NH3	Total P
			cfs	°C	µS/cm	NTU		mg/L	mg/L	ppt	mg/L	mg/L	mg/L	mg/L	mg/L
LL5	5/5/21	1225	1.5	22.1	180	34	6.5	4.0	7.0	N/A	117	0.1	1.6	ND	0.97
LL5	11/19/21	1140	0.8	19.8	596	3	6.9	3.6	<4	N/A	N/A	ND	1.0	1.1	2.7
Surface-water runoff from Gulf Shores Country Club downstream from detention pond at AL Highway 180.															
Lat 30.258977°N Long -087.705147°W															
Site	Date	Time	Discharge	Temp	Cond	Turb	pH	DO	TSS	Salinity	TDS	NO3+NO2	TKN	NH3	Total P
			cfs	°C	µS/cm	NTU		mg/L	mg/L	ppt	mg/L	mg/L	mg/L	mg/L	mg/L
LL6	5/5/21	1250	0.5	22.3	163	33	6.2	4.5	10	0	67	0.47	2.6	0.45	0.38

Irrigation well at Island Retreat RV Park															
Lat 30.25811°N Long -087.71381°W															
Site	Date	Time	Water level	Temp	Cond	Turb	pH	DO	TSS	Salinity	TDS	NO3+NO2	TKN	NH3	Total P
			ft bls	°C	µS/cm	NTU		mg/L	mg/L	ppt	mg/L	mg/L	mg/L	mg/L	mg/L
MW1	5/5/21	935	11.6	23.5	129	31	6.1	N/A	N/A	0	84	ND	ND	ND	0.13
Langston well 2387 Ridge Road East															
Lat 30.258671°N Long -087.718536°W															
Site	Date	Time	Water level	Temp	Cond	Turb	pH	DO	TSS	Salinity	TDS	NO3+NO2	TKN	NH3	Total P
			ft bls	°C	µS/cm	NTU		mg/L	mg/L	ppt	mg/L	mg/L	mg/L	mg/L	mg/L
MW2	7/20/21	1900	N/A	24.5	98	3	5.6	N/A	N/A	0	N/A	1.5	0.26	ND	ND
Hatfield deep well															
Lat 30.255260°N Long -087.724568°W															
Site	Date	Time	Water level	Temp	Cond	Turb	pH	DO	TSS	Salinity	TDS	NO3+NO2	TKN	NH3	Total P
			ft bls	°C	µS/cm	NTU		mg/L	mg/L	ppt	mg/L	mg/L	mg/L	mg/L	mg/L
MW4	06/22/21	1540	0.82	24.1	131	15	5.3	N/A	N/A	0	85	1.7	0.78	0.14	ND